Western Washington and Oregon Community Tree Guide: Benefits, Costs and Strategic Planting

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The green infrastructure is a significant component of Western Washington and Oregon communities.

Introduction

Communities in Western Washington and Oregon include nearly 7.4 million people (State of Washington 2001, US Census Bureau 2001) comprising almost 80% of the states' total populations. The region's rapid growth, development, and increasing congestion belie the area's verdant repute. Forests continue to be a quintessential component of the Pacific Northwest's economic, physical, and social fabric. However, with reliance on traditional forest products waning, urban and community forests bring opportunity for economic renewal, combating development woes, and increasing the quality of life for community residents.

Compared with the Northwest's interior, Western Washington and Oregon's maritime climate is mild enough to grow a diverse array of trees. These guidelines are specific to this region, where mild rainy winters with relatively warm, dry summers predominate. This region extends from Western Whatcom County along the Canadian border in the north, and south throughout the Willamette Valley. It includes communities of the West Cascade foothills, Puget Sound, Olympic Peninsula Lowland, and the length of Oregon's coastal region (Figure 1). Boundaries correspond with Sunset Climate Zones 4, 5, and 6 (Brenzel 1997) and USDA Hardiness Zones 3-8.

1. The Western Washington and Oregon region (unshaded region) extends from the U.S.-Canada border, near Bellingham, to coastal southern Oregon.

As many Western Washington and Oregon communities continue to grow during the next decade, sustaining healthy community forests becomes integral to the quality of life residents experience. The role of urban forests to enhance the environment, increase community attractiveness and livability, and foster civic pride is taking 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 investment by local citizens, business, and government in the betterment of their communities (Figure 2).

Trees provide environmental benefits

Western Washington and Oregon communities can promote energy efficiency through tree planting and stewardship programs that strategically locate trees to save energy, mitigate urban heat islands, and minimize conflicts with powerlines and other aspects of the urban infrastructure. These same trees can provide additional benefits by reducing stormwater runoff, improving local air, soil, and water quality, reducing atmospheric carbon dioxide (CO_2), providing wildlife habitat, increasing property values, enhancing community attractiveness and investment, and promoting human health and well-being.

Scope defined

Remnant native forest parcels throughout the Pacific Northwest are one component of the community forests found in the region. Their importance to the people and ecology of regional communities has been the focus of recent regional analyses (American Forests 1998, 2001). As these studies show, the rapid decline and loss of the forest cover they provide is not trivial. However, of no less importance are the open-grown, urban tree resources. This guide provides information on benefits and costs of open-grown trees in yard, park, and street locations. It should not be used to estimate benefits and costs for trees growing in forest stands.

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

Present in all communities of Western Washington and Oregon, street, park, and shade trees are components of community forests that impact every resident. The benefits they afford communities are myriad. However, with municipal tree programs dependent on taxpayer-supported general funds (Thompson and Ahern 2000), 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 Western Washington and Oregon – providing a tool for community officials and tree managers to increase public awareness and support for tree programs (Dwyer and Miller 1999).

This tree guide addresses a number of questions about the environmental and aesthetic benefits community trees provide in Western Washington and Oregon:

- What is their potential to improve environmental quality, conserve energy, and add value to communities?
- Where should residential and public trees be placed to maximize their cost-effectiveness?
- Which tree species will minimize conflicts with powerlines, sidewalks, and buildings?

Answers to these questions should assist policy makers, urban forest managers, non-profit organizations, design and planning professionals, utility personnel, and concerned citizens who are planting and managing trees to improve their local environments and build better communities.

What's in the Tree Guide

This tree guide is organized as follows:

Chapter 1. Provides background information on the potential of trees in Western Washington and Oregon to provide benefits, as well as management costs that are typically incurred.

Chapter 2. Provides detailed assumptions, data sources, and calculations for tree benefits and costs.

Chapter 3. Illustrates how to estimate urban forest benefits and costs in your community and tips to increase cost-effectiveness.

Chapter 4. Presents guidelines for selecting and siting of trees in residential yards and public open spaces.

Chapter 5. Contains a tree selection list with information on tree species recommended for Western Washington and Oregon communities.

Chapter 6. Lists references cited in the guide.

Chapter 7. Provides definitions for technical terms used in the guide.

Appendix A. Contains tables that list annual benefits and costs of typical trees at 5-year intervals for 40 years after planting.

1. Identifying Benefits and Costs of Urban and Community Forests

This chapter provides an in-depth look at benefits and costs of public and privately managed trees. First, the functional benefits and associated economic value of community forests are described. Second, expenditures related to tree care and management are assessed–a procedure prerequisite to cost-effective programs (Hudson 1983).

Benefits

Saving Energy

Heat islands increase temperatures

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

Warmer temperatures increase CO_2

Warmer temperatures in cities, compared to surrounding rural areas, have other implications. Increases in CO_2 emissions from fossil fuel power plants, municipal water demand, unhealthy ozone levels, and human discomfort and disease are all symptoms associated with urban heat islands. These problems are accentuated by global climate change, which may double the rate of urban warming.

What can trees do?

In Western Washington and Oregon, there is ample opportunity to “retrofit” communities with more sustainable landscapes through strategic tree planting and stewardship of existing trees. Accelerating urbanization hastens the need for landscapes that reduce stormwater runoff, conserve energy and water, sequester CO_2, attract wildlife, and provide other aesthetic, social, and economic benefits in new development.

How trees work

Trees of the urban forest modify climate and conserve building-energy use in three principal ways:

- Shading–reduces the amount of radiant energy absorbed and stored by built surfaces.
- Transpiration–converts moisture to water vapor and thus cools by using solar energy that would otherwise result in heating of the air.
- Wind speed reduction–reduces the infiltration of outside air into interior spaces and conductive heat loss where thermal conductivity is relatively high (e.g., glass windows) (Simpson 1998).

Trees lower temperatures

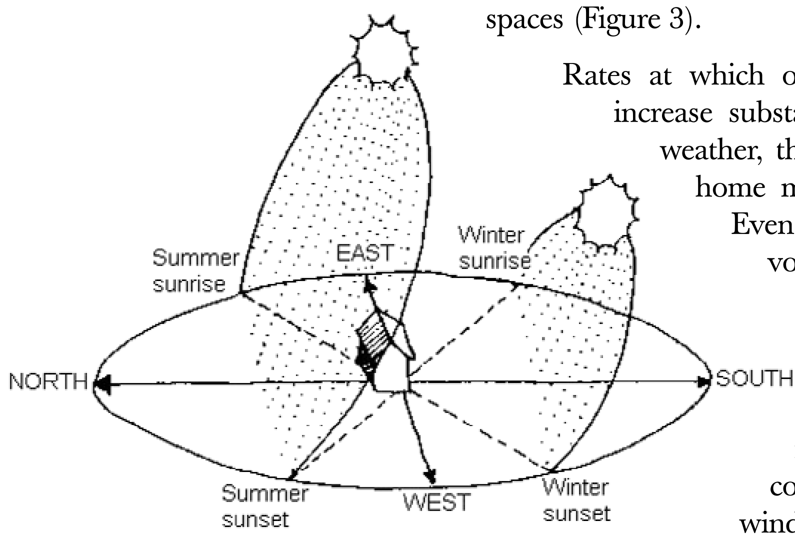
Trees and other greenspace within individual building sites may lower air temperatures 5°F (3°C) compared to outside the greenspace. At the larger scale of urban climate (6 miles or 10 km square), temperature differences of more than 9°F (5°C) have been observed between city centers and more vegetated suburban areas (Akbari et al. 1992).

Urban forests cool

The relative importance of these effects depends on the size and configuration of trees and other landscape elements (McPherson 1993). Generally, large greenspaces (300-1,500 ft [100-500 m] distance) have a greater sphere of influence on the climate than do smaller greenspaces. Tree spacing, crown spread and vertical distribution of leaf area influence the transport of cool air and pollutants along streets and out of urban canyons.

Trees increase home energy efficiency

For individual buildings, strategically placed trees can increase energy efficiency in the summer and winter. Solar angles are important when the summer sun is low in the east and west for several hours each day. Tree shade to protect east–and especially west–walls help keep buildings cool. In the winter, solar access on the southern side of buildings can warm interior spaces (Figure 3).



3. Paths of the sun at winter and summer solstices (from Sand 1991).

Rates at which outside air infiltrates into a building can increase substantially with wind speed. In cold windy weather, the entire volume of air in a poorly sealed home may change two to three times per hour. Even in newer or tightly sealed homes, the entire volume of air may change every two to three hours. Windbreaks reduce wind speed and resulting air infiltration by up to 50%, translating into potential annual heating savings of 25% (Heisler 1986). Reductions in wind speed reduce heat transfer through conductive materials as well. Cool winter winds, blowing against single-pane windows, can contribute significantly to the heating load of homes and buildings by increasing the temperature gradient between inside and outside temperatures. Windbreaks reduce air infiltration and conductive heat loss from buildings.

Shade saves $

Compared with the Northwest interior, the maritime influence on Western Washington and Oregon moderates the potential energy savings from trees during the heating/cooling seasons. A computer simulation of annual cooling savings for an energy efficient home in Portland, OR indicated that the typical household with air conditioning spent about $50 each year for cooling and $600 for heating. Two 25-ft tall (7.5 m) trees–on the west side of the house–were estimated to save $18 each year for cooling, a 36% reduction (365 kWh) (McPherson et al. 1993). The same two trees reduced annual heating costs by about $7 (1%). The total $25 savings represented a 4% reduction in annual heating and cooling costs.

Reducing Atmospheric Carbon Dioxide

Trees reduce CO_2

Urban forests can reduce atmospheric CO_2 in two ways:

- Trees directly sequester CO_2 as woody and foliar biomass while they grow, and
- Trees near buildings can reduce the demand for heating and air conditioning, thereby reducing emissions associated with electric power production.

Releases of 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 woody biomass is released into the atmosphere through decomposition.

Avoided CO_2 emissions

Regional variations in climate and the mix of fuels that produce energy to heat and cool buildings influence potential CO_2 emission reductions. Average emission rates for three main Western Washington and Oregon operator-based Power Control Areas–Puget Sound Power & Light Co., Portland General Electric Co., and Seattle City Light–are approximately 0.67 lbs (0.30 kg) CO_2/kWh (US EPA 2001). Due to the mix of fuels used to generate the power, this emission rate was higher than the two-state average (0.27 lbs [0.12 kg] CO_2/kWh), where hydroelectric power predominates. Trees' role in reducing energy demand is vital to reducing these emissions.

What is the complete CO_2 picture?

To provide a complete picture of atmospheric CO_2 reductions from tree planting it is important to consider CO_2 released into the atmosphere through tree planting and care activities, as well as decomposition of wood from pruned or dead trees. The combustion of gasoline and diesel fuels by vehicle fleets, and equipment such as chainsaws, chippers, stump removers, and leaf blowers is a relatively minor source of CO_2. Typically, CO_2 released due to tree planting, maintenance, and other program-related activities is about 2-8% of annual CO_2 reductions obtained through sequestration and avoided power plant emissions (McPherson and Simpson 1999).

Financial value of CO_2 reduction

One of the most comprehensive studies of atmospheric CO_2 reductions by an urban forest found that Sacramento California's six million trees removed approximately 335,100 tons (304,000 metric tonnes) of atmospheric CO_2 annually, with an implied value of $3.3 million (McPherson 1998). Avoided power plant emissions (83,300 tons [75,600 tonnes]) accounted for 32% of the amount reduced (262,300 tons [238,000 tonnes]). The amount of CO_2 reduction by Sacramento's urban forest offset 1.8% of total CO_2 emitted annually as a byproduct of human consumption. This savings could be substantially increased through strategic planting and long-term stewardship that maximizes future energy savings from new tree plantings, as with the Cities for Climate Protection Campaign (McPherson 1994).

CO_2 reduction in Portland

Portland's nonprofit tree planting organization, Friends of Trees, estimated that planting 144,250 trees and seedlings over five years would sequester more than 74,679 tons (73,000 tonnes) of CO_2 at a cost of about $34/ton

($31/tonne) (Friends of Trees 1995). The average annual sequestration rate at maturity was 223 lb (101 kg) per tree planted. This calculation assumed loss rates of 20% and 60% for trees planted in urban areas (yards and streets) and those in natural areas, respectively. After the study was completed, Portland General Electric funded a tree planting and education plan aimed at reducing atmospheric CO_2.

Improving Air Quality

Trees improve air quality

Urban trees provide air quality benefits in four main ways:

- Absorbing gaseous pollutants (e.g., ozone, nitrogen oxides, and sulfur dioxide) through leaf surfaces,
- Intercepting particulate matter (e.g., dust, ash, pollen, smoke),
- Releasing oxygen through photosynthesis, and
- Transpiring water and shading surfaces, which lowers local air temperatures, thereby reducing ozone levels.

Trees and ozone relationship

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

Although many communities in Western Washington and Oregon do not experience poor air quality, several areas have exceeded U.S. Environmental Protection Agency (EPA) standards. Recently, there have been few cases of noncompliance, but several areas in the region continue to experience periods of poor air quality. Continued progress is needed to meet and sustain mandated air quality standards.

The extent to which urban trees reduce air pollutants in Western Washington and Oregon communities has begun to be documented. As a result, potentially cost-effective approaches to improving air quality, such as urban tree planting, are being examined.

Community trees in the Pacific Northwest

American Forest's (1998) study of the Puget Sound area found that tree canopy cover in 1996 removed 38,990 tons (35,380 metric tonnes) of air pollutants valued at $166.5 million. A similar analysis for the Willamette/Lower Columbia Region reported that existing tree cover in 2000 (24%) removed 89,000 tons (80,740 tonnes) of pollutants annually with a value of $419 million (American Forests 2001). Trees were most effective in removing ozone (O_3), nitrogen dioxide (NO_2), and particulate matter (PM_{10}).

Trees "eat" pollutants and save money

Other West Coast studies highlight recent research aimed at quantifying air quality benefits of urban trees. The annual value of pollutant uptake by a typical medium-sized tree in coastal southern California was estimated at approximately $20, and $12 in the San Joaquin Valley (McPherson et al. 1999a, 2000).

What about hydrocarbons?

Trees in a Davis, CA parking lot were found to benefit air quality by reducing air temperatures 1-3°F (0.5-1.5°C) (Scott et al. 1999). By shading asphalt surfaces and parked vehicles, the trees reduced hydrocarbon emissions from gasoline that evaporates out of leaky fuel tanks and worn hoses. These evaporative emissions are a principal component of smog, and parked vehicles are a primary source. In Chicago, the EPA adapted this research to the local climate and developed a method for easily estimating evaporative emission reductions from parking lot tree plantings. Grant applicants can use this approach to quantify pollutant reductions from parking lot tree planting projects.

Reducing Stormwater Runoff and Hydrology

Trees protect water and soil resources

Urban stormwater runoff is a major source of pollution entering riparian areas of the Pacific Northwest. With several salmon species now listed as threatened and endangered, stormwater management requirements have become increasingly stringent and costly. A healthy urban forest can reduce the amount of runoff and pollutant loading in receiving waters in three primary ways:

- Leaves and branch surfaces intercept and store rainfall, thereby reducing runoff volumes and delaying the onset of peak flows,
- Root growth and decomposition increase the capacity and rate of soil infiltration by rainfall and reduce overland flow,
- Tree canopies reduce soil erosion by diminishing the impact of raindrops on barren surfaces.

Trees reduce runoff

Studies that have simulated urban forest effects on stormwater report annual runoff reductions of 2-7%. Annual interception of rainfall by Sacramento's urban forest for the urbanized area was only about 2% due to the winter rainfall pattern and predominance of non-evergreen species (Xiao et al. 1998). However, average interception on land with tree canopy cover ranged from 6-13% (150 gal [20 m^3] per tree on average), close to values reported for rural forests. In Modesto, CA, each street and park tree was estimated to reduce stormwater runoff by 845 gal (3.2 m^3) annually, with a benefit valued at $7 per tree (McPherson et al. 1999b). A typical medium-sized tree in coastal southern California was estimated to intercept 2,380 gal (9 m^3) ($5) annually (McPherson et al. 2000). These studies showed that broadleaf evergreens and conifers intercept more rainfall than deciduous species where winter rainfall patterns prevail.

In Puget Sound, the existing canopy was estimated to reduce runoff by 2.9 billion ft^3 (82.1 million m^3) valued at $5.9 billion (American Forests 1998).

In the Willamette/Lower Columbia region, existing canopy (24%) reduced runoff by 8.5 billion ft^3 (240.7 million m^3) (American Forests 2001). The one-time construction cost for detention basins large enough to handle this amount of runoff was $20.2 billion, with an annualized value of $140 million.

Urban forests can dispose of waste water

Urban forests can provide other hydrologic benefits. For example, irrigated tree plantations or nurseries can be a safe and productive means of wastewater treatment and disposal (Dwyer et al. 1992). Reused wastewater 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.

Shade yields less water use at power plants

Power plants consume water in the process of producing electricity. For example, coal-fired plants use about 0.6 gal/kWh (0.002 m^3/kWh) of electricity provided. Trees that reduce the demand for electricity can also reduce water consumed at the power plant (McPherson et al. 1993). Precious surface water resources are preserved and thermal pollution of rivers reduced.

Aesthetics and Other Benefits

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

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 indicated that they shop more often and longer in well-landscaped business districts, and were willing to pay more for goods and services (Wolf 1999).

Public safety

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 values

Well-maintained trees increase the “curb appeal” of properties. Research comparing sales prices of residential properties with different tree resources suggests that people are willing to pay 3-7% more for properties with ample tree resources versus few or no trees. One of the most comprehensive studies of the influence of trees on residential property values was based on actual sales prices and found that each large front-yard tree was associated with about a 1% increase in sales price (Anderson and Cordell 1988). A much greater value of 9% ($15,000) was determined in a U.S. Tax Court case for the loss of a large black oak on a property valued at $164,500 (Neely 1988). Depending on average home sales prices, the value of this benefit can contribute significantly to cities' property tax revenues.

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). Following natural disasters people often report a sense of loss if the urban forest in their community has been damaged (Hull, 1992). Views of trees and nature from homes and offices provide restorative experiences that ease mental fatigue and help people to concentrate (Kaplan & Kaplan 1989). Desk-workers with a view of nature report lower rates of sickness and greater satisfaction with their jobs compared to those having no visual connection to nature (Kaplan 1992). Trees provide important settings for recreation and relaxation in and near cities. The act of planting trees can have social value, for community bonds between people and local groups often result.

Human health benefits

The presence of trees in cities provides public health benefits and improves well-being of those who live, work and recreate in cities. Physical and emotional stress has both short term and long-term effects. Prolonged stress can compromise the human immune system. A series of studies on human stress caused by general urban conditions and city driving show that views of nature reduce stress response of both body and mind (Parsons et al. 1998). City nature also appears to have an "immunization effect," in that people show less stress response if they've had a recent view of trees and vegetation. Hospitalized patients with views of nature and time spent outdoors need less medication, sleep better, and have a better outlook than patients without connections to nature (Ulrich 1985). Trees reduce exposure to ultraviolet light, thereby lowering the risk of harmful effects from skin cancer and cataracts (Tretheway and Manthe 1999).

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 6-15 decibels. Plants absorb more high frequency noise than low frequency, which is advantageous to humans since higher frequencies are most distressing to people (Miller 1997).

Wildlife

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

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

Costs

Planting and Maintaining Trees

PNW cities spend about $3.25 per tree

The environmental, social, and economic benefits of urban and community forests come with a price. A 1994 survey reported that communities in the Pacific Northwest spent an average of $3.25 per tree, annually, for street and park tree management (Tschantz and Sacamano 1994). Generally, the single largest expenditure was for tree pruning, followed by tree removal/disposal, and tree planting.

Most trees in new residential subdivisions are planted by developers, while cities/counties and volunteer groups plant most trees on existing streets and parklands. In many cities, tree planting has not kept pace with removals. Moreover, limited growing space in cities is responsible for increased planting of smaller, shorter-lived trees that provide fewer benefits compared to larger trees.

Residents spend about $5-$10 per tree

Annual expenditures for tree management on private property have not been well-documented. Costs vary considerably, ranging from some commercial/residential properties that receive regular professional landscape service to others that are virtually “wild” and without maintenance. An initial analysis of data for Sacramento and other cities suggested that households typically spent about $5-$10 annually per tree for pruning and pest and disease control (McPherson et al. 1993, Summit and McPherson 1988).

Irrigation costs

Despite the temperate climate in Western Washington and Oregon, newly planted trees require irrigation for about three years. Installation of drip or bubbler irrigation can increase planting costs by $100 or more per tree. Once planted, 15-gal trees typically require 100-200 gal (0.4-0.8 m^3) per year during the establishment period. Assuming a water price of $1.76/Ccf, annual irrigation water costs are initially less than $1 per tree. However, as trees mature their water use can increase with an associated increase in annual costs. Trees planted in areas with existing irrigation may require supplemental irrigation. Other trees grown in the region, however, require little or no supplemental irrigation after an establishment period.

Conflicts with Urban Infrastructure

Tree roots and sidewalks can conflict

Like other cities across the U.S., communities of Western Washington and Oregon are spending millions of dollars each year to manage conflicts between trees and powerlines, sidewalks, sewers, and other elements of the urban infrastructure. In California, for example, a 1998 survey showed that cities spent an average of $2.36 per capita on sidewalk, curb and gutter repair, tree removal and replacement, prevention methods, and legal/liability costs (McPherson 2000). Some cities spent as little as $0.75 per capita while others spent $6.98 per resident. These figures were for street trees only and did not include repair costs for damaged sewer lines, building foundations, parking lots, and various other hardscape elements. When these additional expenditures were included, the total cost of root-sidewalk conflicts was well over $100 million per year in California alone.

In Washington and Oregon, dwindling budgets are forcing an increasing number of cities to shift the costs of sidewalk repair to residents. This shift especially impacts residents in older areas, where large trees have outgrown small sites and infrastructure has deteriorated.

Cost of conflicts

The consequences of efforts to control these costs are having alarming effects on urban forests (Bernhardt and Swiecki 1993, Thompson and Ahern 2000):

- Cities are continuing to "downsize" their urban forests by planting smaller-stature trees. Although small trees are appropriate under powerlines 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. We lose thousands of healthy urban trees and forgo their benefits each year because of this problem.
- 25% of cities surveyed were removing more trees than they were planting. Residents forced to pay for sidewalk repairs may not want replacement trees.

Use the right tree to fix conflicts

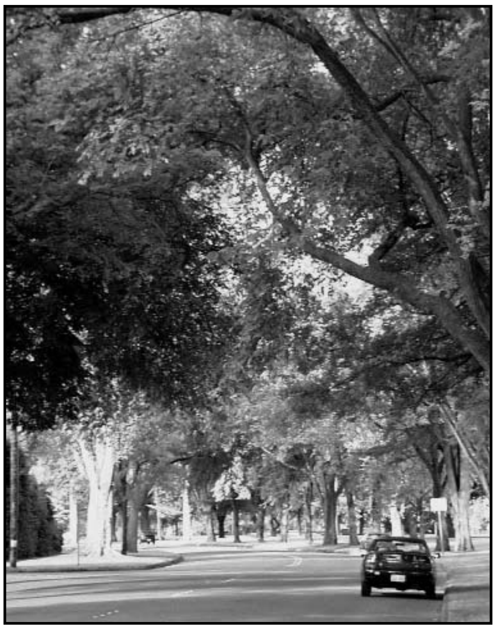
Collectively, this is a lose-lose situation. Cost-effective strategies to retain benefits from large street trees while reducing costs associated with infrastructure conflicts are described in *Strategies to Reduce Infrastructure Damage by Tree Roots* (Costello et al. 2000). Matching the growth characteristics of trees to conditions at the planting site is one strategy. The recommended tree selection list in Chapter 5 contains information on planting suitability by location and size.

Roots can damage sewer lines

Tree roots can damage old sewer lines that are cracked or otherwise susceptible to invasion. 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 later 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 rodding to $1,000 or more for 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, leaf litter from trees 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. Clean-up costs also occur after windstorms. Although these natural crises are infrequent, they can result in large expenditures.



4. Although large trees can increase clean-up costs and repair costs to sidewalks compared to small trees, their shade can extend the life of street surfaces and defer costs for re-paving.

Conflicts between trees and powerlines are reflected in electric rates. In Portland, the local electric utility, Portland General Electric, prunes approximately 50,000 trees annually at a total cost of $2.5 million ($50/tree) (Johnson 2002). Large trees under powerlines require more frequent pruning than better-suited trees. Frequent crown reduction reduces the benefits these trees could otherwise provide.

Tree shade on streets can help offset some of these costs by protecting the paving from weathering. The asphalt paving on streets contains stone aggregate in an oil binder. Tree shade lowers the street surface temperature and reduces the heating and volatilization of the oil. As a result, the aggregate remains protected for a longer period by the oil binder. When unprotected, vehicles loosen the aggregate and much like sandpaper, the loose aggregate grinds down the pavement (Brusca 1998). Because most weathering of asphalt concrete pavement occurs during the first 5-10 years, when new street tree plantings provide little shade, this benefit mainly applies when older streets are resurfaced (Figure 4).

Wood Salvage, Recycling and Disposal

In our survey, Western Washington and Oregon cities are recycling most if not all of their green waste from urban trees as mulch, compost, and firewood. In many cases, the net costs of waste wood disposal are less than 1% of total tree care costs as cities and contractors strive to break-even (hauling and recycling costs are nearly offset by revenues from purchases of mulch, milled lumber, and firewood). Hauling waste wood and recycling is the primary cost.

Greenwaste recycling saves $

The city of Longview, WA salvages 85% of its wood waste at a break-even point, and recycles the remaining 15% at a cost of $12/ton ($13/tonne), a substantial savings over the typical landfilling fee of $28/ton ($31/tonne). Sixty-five percent of the salvaged wood is turned into mulch, 30% into firewood, and 5% into milled lumber.

2. Quantifying Benefits and Costs of Community Forests in Western Washington and Oregon Communities

In this chapter, we present estimated benefits and costs for trees planted in typical residential and public sites. Because benefits and costs vary with tree size, we report results for typical large-, medium-, and small-stature trees. Tree growth rates and dimensions are based on street and park tree data obtained in Longview, WA during the summer of 2001.

Estimates are initial approximations

Estimates of benefits and costs are initial approximations—as some benefits and costs are intangible or difficult to quantify (e.g., impacts on psychological health, crime, and violence). Also, limited knowledge about the physical processes at work and their interactions 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 and benefits and costs depend on the specific conditions at a site (e.g., tree species, growing conditions, maintenance practices). Therefore, this method of quantification was not intended to account for each penny. Rather, this approach was meant to be a general accounting of the benefits produced by urban trees; an accounting with an accepted degree of uncertainty that can, nonetheless, provide a platform on which decisions can be made (Maco 2001).

Procedures and Assumptions

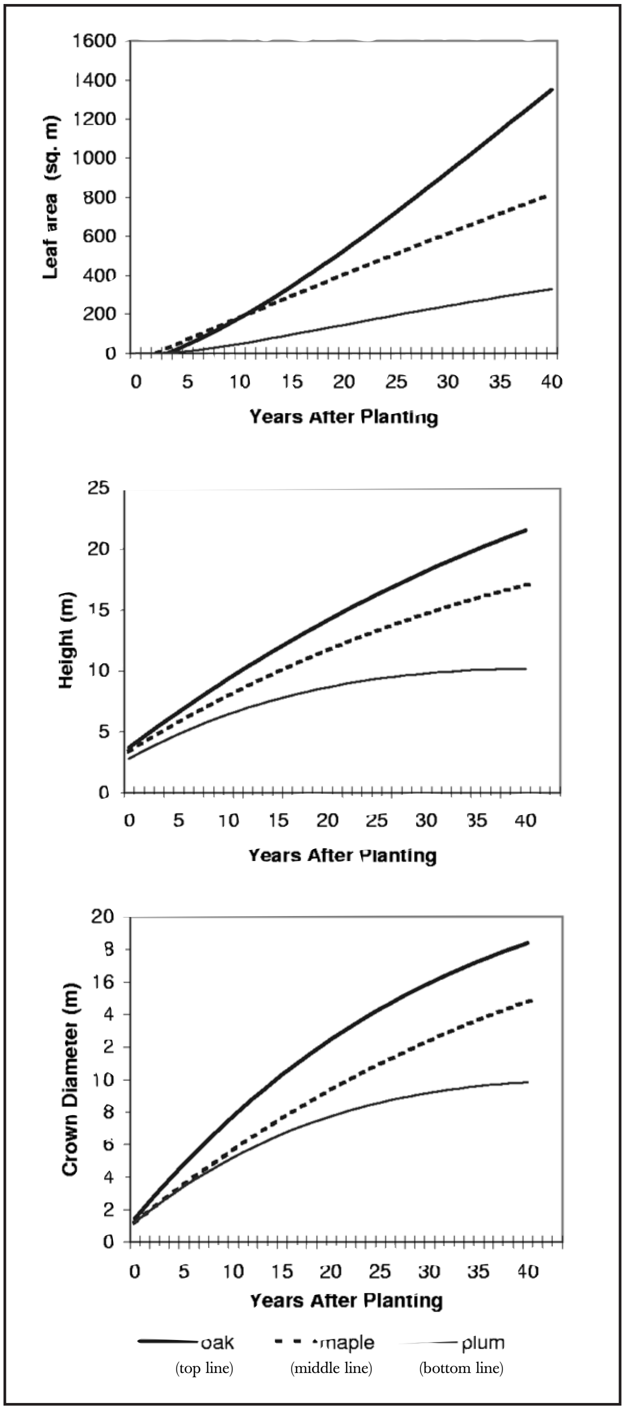
Approach

Pricing benefits and costs

In this study, annual benefits and costs were estimated for newly planted trees in three residential yard locations (east, south, and west of the dwelling unit) and a public streetside/park location for a 40-year planning horizon. 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 absorption, 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 and with "typical" tree species. To account for differences in the mature size and growth rates of different tree species, we report results for large (*Quercus rubrum*, red oak), medium, (*Acer platanoides*, Norway maple), and small (*Prunus cerasifera*, purple-leaf plum) trees. Results are reported at 5-year intervals for 40 years.

Leaf surface area and crown volume are useful indicators

Mature tree height is frequently used to distinguish between large, medium, and small species because matching tree height to available overhead space is an important design consideration. However, in this analysis, leaf surface area (LSA) and crown volume were also used to differentiate mature tree size. These additional measurements are useful indicators for many functional



5. Tree dimensions are based on data from street and park trees in Longview. Data for typical" large, medium, and small trees are from the red oak, Norway maple, and purple-leaf plum, respectively. Differences in leaf surface area among species are most important for this analysis because functional benefits such as rainfall interception, pollutant uptake, and shading are related to leaf surface area.

benefits of trees in relation to leaf-atmosphere processes (e.g., interception, transpiration, photosynthesis). Tree growth rates, dimensions, and LSA estimates are based on measurements taken for 30-60 street and park trees of each species in Longview, WA (Figure 5).

Reporting Results

Tree mortality included. Results are reported in terms of annual values per tree planted. However, to make these calculations realistic, mortality rates must be included. Therefore, based on our survey of regional municipal foresters, average mortality rates (23.4%) for public and residential trees are assumed over the 40-year period. Annual mortality rates of trees are 1% for the first five years and 0.53% for the remaining 35 years. Hence, this accounting approach "grows" trees in different locations and uses computer simulation to directly calculates the annual flow of benefits and costs as trees mature and die (McPherson 1992).

Benefits and costs are connected with tree size. Benefits and costs are directly connected with tree size variables such as trunk diameter at breast height (DBH), tree canopy cover, and LSA. For instance, pruning and removal costs usually increase with tree size expressed as diameter at breast height (DBH). 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.

Annual vs. periodic costs. 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). Most costs and benefits are reported for the year that 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

Municipal foresters and private arborists were source of costs estimates

Frequency and costs of tree management were directly estimated based on surveys with municipal foresters in Washington (Longview, Olympia, and Seattle) and Oregon (Portland, Tigard, and Albany) cities. Private arborists throughout the region were also contacted as a source for tree management costs and frequency of contracted activities on residential properties.

Pruning benefits

Regional electricity and natural gas prices were used in this study to quantify energy savings (McPherson and Simpson 1999). Control costs were used to estimate society's willingness to pay for air quality and stormwater runoff improvements. For example, the price of stormwater benefits was estimated using marginal control costs, which represent the opportunity cost that can be avoided by implementing alternative control measures (e.g., trees) other than measures traditionally used to meet standards–that is, if other control measures are implemented, the most costly control measure can be avoided (Wang and Santini 1995). If a developer is willing to pay an average of 2.7¢ per gallon of stormwater–treated and controlled–to meet minimum standards, then the stormwater mitigation value of a tree that intercepts one gallon of stormwater, eliminating the need for treatment and control, should be 2.7¢.

Calculating Benefits

Air Conditioning and Heating Energy Savings

Using a typical single-family residence for energy simulations

The prototype building used as a basis for the simulations was typical of post-1980 construction practices, and represented 10-20% of the total single-family residential housing stock in Western Washington and Oregon. This house was a two-story, wood frame building with crawl space and a conditioned floor area of 2,070 ft^2 (192 m^2), window area (double-glazing) of 383 ft^2 (36 m^2), and wall, ceiling and floor insulation of R11, R19, and R32, 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%. Building footprints were square, reflective of average impacts for a large building population (McPherson and Simpson 1999). Buildings were simulated with 1.5-ft (0.45-m) overhangs. Blinds had a visual density of 37%, and were assumed closed when the air conditioner was operating. Summer thermostat settings were 78° F (25° C); winter settings were 68° F (20° C) during the day and 60° F (16° C) at night. Because the prototype building was more energy efficient than most other construction types, our projected energy savings are relatively conservative. The energy simulations relied on typical year meteorological data from Seattle (Marion and Urban 1995).

Calculating energy savings

The dollar value of energy savings was based on average residential electricity and natural gas prices of $0.06 per kWh (Puget Sound Energy 2001a; Seattle City Light 2001; Tacoma Public Utilities 2001; Portland General Electric 2001) and $0.92 per therm (NW Natural 2001; Puget Sound Energy 2001b), respectively. Electricity rates were 2001, baseline rates of both public-and investor-owned utilities serving Western Washington and Oregon. Gas prices were year 2000 baseline averages for all communities served by the region's two largest providers–NW Natural and Puget Sound Energy. Homes were assumed to have central air conditioning and natural gas heating.

Calculating shade effects

Residential yard trees were within 60 ft (18 m) of homes so as to directly shade walls and windows. Shading effects of these trees on building energy use were simulated for large, medium, and small trees at three tree-building distances, following methods outlined by McPherson and Simpson (1999). The large tree (red oak) has a visual density of 80% during summer and 23% during winter. The medium tree (Norway maple) has a leaf-off visual density of 31% and leaf-on density of 88%. The small tree (purple-leaf plum) has a leaf-off visual density of 40% and a summer density of 80%. All three trees are leafless November 15–March 31. Results for each tree were averaged over distance and weighted by occurrence of trees within each of three distance classes: 28% 10-20 ft (3-6 m), 68% 20-40 ft (6-12 m), and 4% 40-60 ft (12-18 m) (McPherson and Simpson 1999). Results are reported for trees shading east-, south-, and west-facing surfaces. Our results for public trees are conservative in that we assumed that they do not provide shading benefits. In Modesto, 15% of total annual dollar energy savings from street trees were due to shade and 85% due to climate effects (McPherson et al. 1999a). In Longview, over 60% of street trees sampled were within 60 ft (18 m) of conditioned structures.

6. Although park trees seldom provide energy benefits from direct shading of buildings, they provide settings for recreation and relaxation as well as modify climate, sequester carbon dioxide, reduce stormwater runoff, and improve air quality.

In addition to localized shade effects, which were assumed to accrue only to residential yard trees, lowered air temperatures and wind speeds from increased neighborhood tree cover (referred to as climate effects) produce a significant net decrease in demand for winter heating and summer cooling (reduced wind speeds by themselves may increase or decrease cooling demand, depending on the circumstances). Climate effects on energy use, air temperature and wind speed reductions, as a function of neighborhood canopy cover, were estimated from published values (McPherson and Simpson 1999). Existing canopy cover (trees + buildings) was estimated to be 25% (American Forests 1998, 2001; Mead 2001). Canopy cover was calculated to increase by 7%, 19% and 23% for mature small, medium, and large trees at maturity, respectively, based on an effective lot size (actual lot size plus a portion of adjacent streets and other rights-of-way) of 8,000 ft^2 (743 m^2), and assumed one tree per lot on average. Climate effects were estimated as described previously for shading by simulating effects of wind and air temperature reductions on energy use. Climate effects accrue for both public (Figure 6) and private trees.

Atmospheric Carbon Dioxide Reduction

Calculating the value of reduced CO_2 emissions

Conserving energy in buildings results in reduced CO_2 emissions from power plants. These avoided emissions were calculated as the product of energy savings for heating and cooling based on the respective CO_2 emission factors for cooling and heating (Table 1). Pollutant emission factors were based on data for the region's three largest power control areas–Seattle City

Light, Puget Sound Power and Light, and Portland General Electric Company–and were weighted based on average fuel mixes: 49% hydro, 30% natural gas, 16% coal, and 5% other (US EPA 2001) (Table 1). The value of CO_2 reductions (Table 1) was based on social costs (e.g., loss of arable land) associated with increased global warming (California Energy Commission 1994).

Table 1. Emissions factors and prices for air pollutants.

	– Emission Factor[1] –		
	Electricity lbs/MWh	Natural gas lbs/MBtu	Price[2] $/lb
CO_2	1,460	116	0.015
NO_2	3.223	0.2248	2.40
SO_2	2.102	0.0013	1.00
PM_{10}	0.232	0.0164	2.72
VOCs	0.216	0.0119	6.65

1 U.S. Environmental Protection Agency 2001.
2 $30/ton for CO_2 (California Energy Commission 1994) and values for all other pollutants are based on emission control costs in Western Oregon (Oregon Public Utilities Commission 1993; Wang and Santini 1995).

Calculating Carbon Storage. Sequestration, the net rate of CO_2 storage in above- and below-ground biomass over the course of one growing season, was calculated using tree height and DBH data with biomass equations (Pillsbury et al. 1998). Lacking equations for red oak, Norway maple and purple plum, formulas for London plane (*Platanus acerifolia*), sawleaf zelkova (*Zelkova serrata*) and Chinese pistache (*Pistacia chinensis*) were substituted, respectively. Volume estimates were converted to green and dry weight estimates (Markwardt 1930) and divided by 78% to incorporate root biomass. Dry weight biomass was converted to carbon (50%) 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 trees add biomass each year.

Power equipment releases CO_2. A national survey of 13 municipal forestry programs determined that the use of vehicles, chain saws, chippers, and other equipment powered by gasoline or diesel results in the average annual release of 0.78 lb of CO_2/inch DBH (0.14 kg CO_2/cm DBH) (McPherson and Simpson 1999). This value was utilized for private and public trees, recognizing that it may overestimate CO_2 release associated with less intensively maintained residential yard trees.

Decomposition releases CO_2

To calculate CO_2 released through decomposition of dead woody biomass, we conservatively estimated that dead trees are removed and mulched in the year that death occurs, and that 80% of their stored carbon is released to the atmosphere as CO_2 in the same year.

Air Quality Improvement

Value of emission reductions

Reductions in building-energy use also result in reduced emissions of air pollutants from power plants and space heating equipment. Volatile organic hydrocarbons (VOCs) and nitrogen dioxide (NO_2)–both precursors of ozone 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 offset values were calculated in the same way as for CO_2, using utility-specific emission factors for electricity and heating fuels (Ottinger et al. 1990; US EPA 1998), with the price of emissions savings (Table 1) based on cost of control studies to meet air pollution standards in Oregon, west of the Cascade mountains (Oregon Public Utilities Commission 1993; Wang and Santini 1995).

Calculating pollutant uptake by trees

Trees also remove pollutants from the atmosphere. The hourly pollutant dry deposition per tree is expressed as the product of a deposition velocity ($V_d = 1/[R_a+R_b+R_c]$), a pollutant concentration (C), a canopy projection area (CP), and a time step. Hourly deposition velocities for each pollutant were calculated during the growing season using estimates for the resistances (Ra, Rb, and Rc) estimated for each hour throughout the year using formulations described by Scott et al. (1998). Hourly concentrations for NO_2, and O_3 (ppm), daily total PM_{10} (μg^{-3}, approximately every sixth day) and hourly meteorological data (e.g., air temperature, wind speed, solar radiation) for 1998 were obtained from the Oregon Department of Environmental Quality (Barnack 2001) (atmospheric concentrations of SO_2 were not available and therefore not included in air pollutant uptake calculations). See Scott et al. (1998) for details of the methods employed. We used implied values from Table 1 to price emissions reductions; the implied value of NO_2 was used for ozone.

Estimating BVOC emissions from trees

Annual emissions of biogenic volatile organic compounds (BVOCs) were estimated for the three tree species (red oak, Norway maple, and purple-leaf plum) 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 a base emission rate adjusted for sunlight and temperature (μg-C g^{-1} dry foliar biomass hr^{-1}) and the amount of dry, foliar biomass present in the tree. Monoterpene emissions were estimated using a base emission rate adjusted for temperature. The base emission rates for the three species were based upon values reported in the literature (Benjamin and Winer 1998). Hourly emissions were summed to get monthly and annual emissions.

Annual dry foliar biomass values for red oak and purple plum were taken from the literature (Winer et al. 1998). The value for sweetgum (*Liquidambar styraciflua*) foliar biomass was substituted for Norway maple. Annual dry foliar biomass was derived from field data collected in Longview, WA during the summer of 2000. The amount of foliar biomass present for each year of the simulated tree's life was unique for each species. Year 1998 hourly air temperature and solar radiation data from Portland were used as model input. This year was chosen because data were available and it closely approximated long-term, regional climate records.

Calculating net air quality benefits

Net air quality benefits were calculated by subtracting the costs associated with BVOC emissions from benefits due to pollutant uptake and avoided power plant emissions. These calculations do not take into account the ozone reduction benefit from lowering summertime air temperatures, thereby reducing hydrocarbon emissions from anthropogenic and biogenic sources. Simulation results from Los Angeles indicate that ozone reduction benefits of tree planting with "low-emitting" species exceed costs associated with their BVOC emissions (Taha 1996).

Stormwater Runoff Reduction

Estimating rainfall interception by tree canopies

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

The volume of water stored in the tree crown was calculated from crown projection area (area under tree dripline), leaf area indices (LAI, the ratio of leaf surface area to crown projection area), and water depth on the canopy surface. Species-specific shade coefficients and tree surface saturation (0.04 in for all three trees) values influence the amount of projected throughfall. Hourly meteorological and rainfall data for 1999 from the Pacific Northwest Cooperative Agricultural Network–at Aurora, Oregon–were used for this simulation. Annual precipitation during 1999 was 41.7 inches (1059 mm), somewhat greater than the 30-year average annual precipitation of 39.4 inches (1001 mm), as reported at Portland International Airport (Hydrosphere Data Products 2001). A more complete description of the interception model can be found in Xiao et al. (1998).

Calculating the water treatment and flow control benefit of intercepted rainfall

To estimate the value of rainfall intercepted by urban trees, stormwater management control costs were used based on minimum requirements for stormwater management in Western Washington (Herrera Environmental Consultants 2001). For a 10-acre, single-family residential development on permeable soils (e.g., glacial outwash or alluvial soil) it costs approximately $20.79/Ccf ($0.02779/gal [$.00011/m^3]) to treat and control flows stemming from a 6-month, 24-hr storm event. Runoff control for very large events (100-year, 24-hr storm) was omitted, as trees effective interception diminishes once surfaces have been saturated.

To calculate water quality benefits, the management cost was multiplied by gallons of rainfall intercepted after the first 0.078 in (2mm) had fallen for each event (24-hr without rain) during the year. Based on surface detention calculations for Olympia, WA, this initial abstraction (~0.1 in) of rainfall seldom results in runoff (City of Olympia 1995; NRCS 1986). Thus, interception is not a benefit until precipitation exceeds this amount (4% of total rainfall in 1999).

Aesthetics 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 products that are difficult to price. However, the value of some of these benefits may be captured in the property values for the land on which trees stand. To estimate the value of these "other" benefits we applied results of research that compared differences in sales prices of houses to statistically quantify the amount of difference associated with trees.

The amount of difference in sales price reflects the willingness of buyers to pay for the benefits and costs associated with the trees. This approach has the virtue of capturing what buyers perceive to be as both the benefits and costs of trees in the sales price. Limitations to using this approach include the difficulty associated with 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 Washington and Oregon, and the need to extrapolate results from front yard trees on residential properties to trees in other locations (e.g., back yards, streets, parks, and non-residential land uses).

A large tree adds $1,978 to sale price of 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% increase in the average home sales price. This percentage of sales price was utilized as an indicator of the additional value a resident in Western Washington and Oregon would gain from selling a home with a large tree.

The sales price of residential properties varied widely by location within the region. For example, year 2000 average home prices ranged from less than $100,000 in Grays Harbor, WA to over $325,000 in Lake Oswego, OR (RMS Multiple Listing Service 2000; NW MLS 2001). For the year 2000, the average home price for Western Washington and Oregon communities was $224,261. Therefore, the value of a large tree that added 0.88% to the sales price of such a home was $1,978. Based on growth data for a 40-year-old red oak, such a tree is 71 ft tall (21.5 m), has a 60-ft (18 m) crown diameter, and has a 28-inch DBH (71 cm); leaf surface area totals 15,897 ft^2 (1,477 m^2).

Calculating aesthetic value of residential yard trees

To calculate the base value for a large tree on private residential property we assumed that a 40-year old red oak in the front yard would increase the property's sales price by $1,978. Approximately 75% of all yard trees, however, are in backyards (Richards et al. 1984). Lacking specific research findings, it was assumed that backyard trees have 75% 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, therefore, $0.10/$ft^2$ ($0.01/$m^2$) LSA. To estimate annual benefits, this value was multiplied by the amount of leaf surface area added to the tree during one year of growth.

Calculating the base value of a street tree

Street trees were treated similar to front yard trees in calculating their base value. However, because street trees may be adjacent to land with little value or resale potential, an adjusted value was calculated. An analysis of street trees in Modesto, CA, sampled (8% of population) from aerial photographs, found that 15% were located adjacent to non-residential or commercial land uses (McPherson et al. 1999b). We assumed that 33% of these trees–or 5% of the entire street tree population–produced no benefits associated with property value increases.

Although the impact of parks on real estate values has been reported (Hammer et al. 1974; Schroeder 1982; Tyrvainen 1999), to our knowledge the on-site and external benefits of park trees alone have not been isolated (More et al. 1988). After reviewing the literature and recognizing an absence of data, we assumed that park trees had the same impact on property sales prices as street trees. Given these assumptions, the typical large street and park trees were estimated to increase property values by \$0.118 and \$0.124/ft^2 (\$0.01 and \$0.012/m^2) LSA, respectively. Assuming that 85% of all municipal trees are on streets and 15% are in parks, a weighted average benefit of \$0.119/ft^2 (\$0.011/m^2) LSA was calculated for each tree, dependent on annual change in leaf area.

Calculating Costs

Planting Costs

Planting costs are two-fold, the cost for purchasing the tree and the cost for planting, staking, and mulching the tree. Based on our survey of Western Washington and Oregon municipal and commercial arborists, the total cost for purchasing, planting, staking, and mulching a 15-gal (1-1/4" cal.) container public tree was \$122. The total cost was \$125 for a residential yard tree.

Pruning Costs

Calucating pruning costs

After studying data from municipal forestry programs and their contractors we assumed that during the first three years after planting, young public trees were pruned once a year at a cost of \$10.67/tree. Thereafter, pruning occurred on a 9-year average cycle. Pruning of small public trees cost \$38.67/tree until their height exceeded 18 ft (6 m) and more expensive equipment was required. Medium-sized trees (taller than 18 ft [6 m] and less than 46 ft [14 m]) were pruned at a cost of \$112/tree. The cost increased to \$201/tree for large trees (taller than 46 ft [14 m]). After factoring in pruning frequency, annualized costs were \$7.47, \$3.01, \$8.71, and \$15.66 for public young, small, medium, and large trees, respectively.

Pruning residential trees

Based on findings from our survey of Western Washington and Oregon commercial arborists, only 30% of residential trees were assumed to be professionally pruned. Using this contract rate, along with average pruning prices (\$15, \$48, \$165, and \$377 for young, small, medium, and large trees, respectively), the average annual cost for pruning a residential yard tree was \$4.50, \$1.61, \$5.50, and \$12.56 for young, small, medium, and large trees. These prices include pruning frequencies and mortality rates identical to public trees, as well as costs for waste wood recycling.

Tree and Stump Removal and Disposal

The costs for removing public and private trees were \$18 and \$12 per inch (\$46 and \$30/cm) DBH, respectively. Stump removal and wood waste disposal costs were \$7/in (\$18/cm) DBH for public and private trees. The total cost for public and private trees was \$26 and \$19/in (\$66 and \$48/cm) DBH.

Pest and Disease Control

Public trees receive treatments to control pests and disease on an as needed basis. In Western Washington and Oregon communities this expenditure was small, averaging about $0.11 per tree per year, or approximately $0.01 per inch ($0.03/cm) DBH.

A mature red oak, used in this tree guide as representative of a large tree.

Though results of our survey suggest that commercial arborists cared for 30% of residential trees, only 15% of these trees were treated for pests or disease. Of the trees that were treated, regional arborists report that control measures were contracted about every nine years. Based on these figures–and average treatment prices charged by arborists ($85)–the average annual cost for pest and disease control was calculated at $0.43 per residential yard tree per year; this averages $0.03 per inch ($0.08/cm) DBH.

Irrigation Costs

Trees in most Western Washington and Oregon landscape situations require relatively little supplemental irrigation after establishment because they are planted in irrigated areas or can use existing soil moisture. The cost for irrigating a public street or park tree was $9 per year for the first three years after planting. This price was the average price of labor and equipment to irrigate young trees with a municipal water truck during the arid summer weeks.

Based on evapotranspiration (ET) calculations, irrigation costs for residential yard trees assume that supplemental water was applied at a maximum rate of 0.2 gallons/ft^2 LSA over a 6-week period in midsummer. For the first three years after planting, all trees were watered. Thereafter, however, it was assumed that only 30% of trees were irrigated regularly for the remainder of their life. Assuming that water was purchased at a price of $1.76 Ccf (Portland Water District 2001), and the mature tree had 15,897 ft^2 (1,477 m^2) of LSA, the annual price was approximately $0.0005/ft^2 LSA. Hence, annual irrigation water cost was assumed to increase with tree leaf area.

Other Costs for Public and Private Trees

Infrastructure conflicts

Other costs associated with the management of trees include expenditures for infrastructure repair/root pruning, leaf litter clean-up, litigation/liability, and inspection/administration.

Tree roots can cause damage to sidewalks, curbs, paving, and sewer lines. Though sidewalk repair is typically the single largest expense for public trees (McPherson and Peper 1995), many Western Washington and Oregon municipalities reported that these costs were the responsibility of abutting property owners. As a result, infrastructure related expenditures for public trees were less here than in comparable cities nationwide (McPherson 2000;

McPherson and Peper 1995), averaging approximately $1.59/tree ($0.12/in [$0.30/cm] DBH) on an annual basis.

Liability costs

Urban trees can, and do, incur costly legal fees due to trip and fall claims. A survey of Western U.S. cities showed that an average of 8.8% of total tree-related expenditures were spent on tree-related liability (McPherson 2000). This percentage, coupled with the average total expenditure reported for Pacific Northwest cities (Tschantz and Sacamano 1994) adjusted to 2001 dollars, suggests the annual cost of this expenditure was $0.35/tree ($0.03/in [$0.08/cm] DBH). Because street trees are in closer proximity to sidewalks and sewer lines than most trees on private property, we assumed that repair and legal costs were 25% of those for public trees (McPherson et al. 1993).

Litter and storm clean-up

The average annual per tree cost for litter clean-up (i.e., street sweeping) was $1.57 ($0.12/in [$0.30/cm] DBH). This value was based on costs in Longview, WA, where litter removal was approximately 5.8% of tree related expenditures. Because most residential yard trees are not littering the street with leaves, it was assumed that clean-up costs for private trees were 25% of those for public trees.

Inspection and administration costs

Municipal tree programs have administrative costs for salaries of supervisors and clerical staff, operating costs, and overhead. Surveys show that average annual costs for inspection and administration associated with street and park tree management is approximately 10% of the total budget. This number was used to calculate associated costs for publicly managed trees only–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 off-site. Benefits are realized at four different scales: parcel, neighborhood, community, and global. For example, property owners with on-site 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, as with 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 on-site trees depending on their location and condition. For example, judiciously located on-site trees can provide air conditioning savings by shading windows and walls and cooling building microclimates. This benefit can extend to the neighborhood because trees provide off-site benefits. Adjacent neighbors can 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. On 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 CO2 concentrations due to trees are an example of benefits that are realized at the global scale.

The sum of all benefits

The sum of all benefits was used to capture the value of all annual benefits (B):

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

where

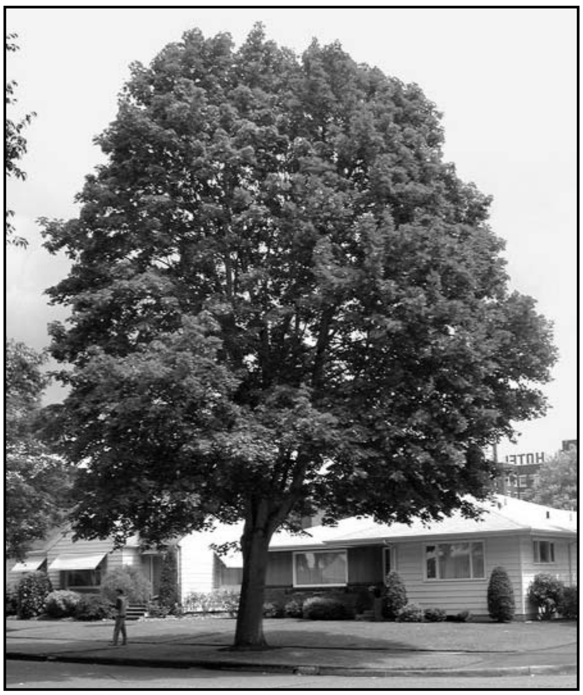
E = value of net annual energy savings (cooling and heating)

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

CO_2 = value of annual carbon dioxide reductions (sequestration, avoided emissions, release due to tree care and decomposition)

H = value of annual stormwater runoff reductions (water quality and flood control)

A = value of annual aesthetics and other benefits



A mature Norway maple, representative of medium trees in this tree guide.

The sum of all costs. 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 for residential yard trees (C_Y) and public trees (C_P) were summed:

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

$$C_P = P + T + R + D + I + S + C + L + A$$

where

P = cost of tree and planting

T = average annual tree trimming cost

R = annual 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

C = annual litter and storm clean-up cost

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

A = annual program administration, inspection, and other costs.

Net benefits. Net benefits are calculated as the difference between total benefits and costs (B – C).

Limitations of this Study

This analysis does not account for the wide variety of trees planted in Western Washington and Oregon communities or their diverse placement. It does not incorporate the full range of climatic differences within the region that influence potential energy, air quality, and hydrology benefits. There is much uncertainty associated with estimates of aesthetics and other benefits as well as the true value of hydrology benefits because science in these areas is not well developed. We considered only residential and municipal tree cost scenarios, but realize that the costs associated with planting and managing trees can vary widely depending on program characteristics. For example, our analysis does not incorporate costs incurred by utility companies and passed on to ratepayers for maintenance of trees under powerlines. However, as described by example in Chapter 3, local cost data can be substituted for the data in this report to evaluate the benefits and costs of alternative programs.

A mature purple-leaf plum, representative of small trees in this tree guide.

Future benefits are not discounted to present value. In this analysis, results are presented in terms of future values of benefits and costs, not present values. Thus, findings do not incorporate the time value of money or inflation. We assume that the user intends to invest in community forests and our objective is to identify the relative magnitudes of future costs and benefits. If the user is interested in comparing an investment in urban forestry with other investment opportunities, it is important to discount all future benefits and costs to the beginning of the investment period. For example, trees with a future value of $100,000 in 10 years, have a present value of $55,840, assuming a 6% annual interest rate.

Findings of this Study

Average Annual Net Benefits

Average annual net benefits increase with size of tree

Average annual net benefits (40-year total/40 years) increase with mature tree size (see Appendix A for detailed results):

- $1 to $8 for a small tree
- $19 to $25 for a medium tree
- $48 to $53 for a large tree

Large trees provide the most benefits

This finding suggests that average annual net benefits from large-growing trees, like the red oak, can be substantially greater than those from small trees like purple-leaf plum. Average annual net benefits for the small, medium, and large street/park trees are $1, $19, and $48, respectively. The largest average annual net benefits, however, stem from residential yard trees opposite a west-facing wall: $8, $25, and $53 for the small, medium, and large trees, respectively. Residential yard trees produce net benefits that are greater than public trees primarily because of lower maintenance costs.

Net annual benefits at year 40

The large residential tree opposite a west wall produces a net annual benefit of $81 at year 40 and $2,120 total over a 40-year span. Planting the red oak in a public site produces a slightly reduced annual net benefit–$74 at year 40. Over the entire 40-year period, it produces a stream of net benefits that total $1,880.

Forty-year benefits for medium and small trees follow a similar pattern. Forty years after planting, they produce annual net benefits of $37 and $15 for west-side residential trees, netting $1,480 and $600 of the full 40 years, respectively. The small plum in a typical public space nets $7 at year 40, while a medium maple in the same location produces $28 in annual net benefits. Over 40 years, net benefits total $280 for the plum and $1,120 for the maple tree in street/park locations.

Net annual benefits at year 20

Twenty years after planting, annual net benefits for a residential yard tree located west of a home are estimated to be approximately $51 for a large tree, $29 for a medium tree, and $12 for a small tree (Table 2). For a large red oak at 20 years after planting, the total value of environmental benefits ($28), alone, is two times greater than annual costs ($14). Similarly, environmental

Table 2. Estimated annual benefits for a small-, medium- and large-sized residential yard tree opposite a west-facing wall 20 years after planting.

BENEFIT CATEGORY	SMALL TREE 28 ft tall, 25 ft spread LSA = 1,891 sq. ft.		MEDIUM TREE 38 ft tall, 31 ft spread LSA = 4,770 sq. ft.		LARGE TREE 46 ft tall, 41 ft spread LSA = 6,911 sq. ft.	
Electricity savings ($0.06/kWh)	62 kWh	$3.89	93 kWh	$5.87	125 kWh	$7.85
Natural gas ($0.92/therm)	-150 kBtu	-$1.38	-80 kBtu	-$0.73	133 kBtu	$1.22
Carbon dioxide ($0.015/lb)	28 lb	$0.42	76 lb	$1.14	263 lb	$3.95
Ozone ($2.40/lb)	0.13 lb	$0.32	0.21 lb	$0.51	0.35 lb	$0.84
NO_2 ($2.40/lb)	0.07 lb	$0.18	0.14 lb	$0.34	0.24 lb	$0.58
SO_2 ($1.00/lb)	0.04 lb	$0.04	0.07 lb	$0.07	0.10 lb	$0.10
PM_{10} ($2.72/lb)	0.15 lb	$0.41	0.24 lb	$0.66	0.40 lb	$1.09
VOCs ($6.65/lb)	0.001 lb	$0.018	0.002 lb	$0.063	0.005 lb	$0.030
BVOCs ($6.65/lb)	-0.004 lb	-$0.024	-0.012 lb	-$0.081	-0.034 lb	-$0.224
Rainfall Interception ($0.028/gal)	169 gal	$4.70	288 gal	$8.01	449 gal	$12.47
ENVIRONMENTAL SUBTOTAL		**$8.58**		**$15.85**		**$27.91**
Other Benefits		$9.38		$20.19		$37.27
Total Benefits		$17.96		$36.04		$65.18
Total Costs		$6.23		$6.87		$13.72
NET BENEFITS		**$11.73**		**$29.16**		**$51.46**

LSA=leaf surface area

Table 3. Tree numbers by age class and estimated annual net benefits for three street tree species in Longview, WA.

	< 10 yrs	10-19 yrs	20-29 yrs	30-39 yrs	40+ yrs	Total
red oak (#)	29	76	50	37	67	259
$/tree	-7	41	52	63	66	–
Total $	-217	3,082	2,611	2,349	4,424	12,249
Norway maple (#)	138	28	126	149	312	753
$/tree	-13	19	25	23	25	–
Total $	-1,806	537	3,120	3,447	7,834	13,132
cherry plum (#)	367	650	501	160	15	1,693
$/tree	-24	4	6	7	7	–
Total $	-8,802	2,394	3,146	1,124	101	-2,037
Grand Total $	**-10,825**	**6,013**	**8,877**	**6,920**	**12,359**	**23,344**
$/tree	**-20**	**8**	**13**	**20**	**31**	**9**

benefits total $16 for the Norway maple, with tree care costs totaling less than half ($7). Annual environmental benefits are nearly $9 for a 20-year-old small yard tree, while management costs are about $6.

What is the net benefit for an urban forest?

The average annual net benefit for a population of trees can be estimated using data presented here and in Appendix A. For example, the city of Longview's street and park tree inventory indicates that there are about 12,000 trees: 259 are red oak (2%), 753 are Norway maple (6%), and 1,693 are purple-leaf plums (14%). Table 3 shows the distribution of these trees among age classes and the estimated annual net benefits assuming costs and benefits described in this report. The total annual net benefits produced by the oaks, maples, and plums are $12,249 ($47/tree), $13,132 ($17/tree), -$2,037 (-$1.20/tree), respectively. Together, trees belonging to these three species account for 22% of Longview's tree population and their benefits exceed costs by approximately $23,300 ($8.63/tree). Chapter 3 shows how to adjust benefit and cost data to account for impacts of a proposed change in a street tree planting program.

Average Annual Costs

Costs increase with size of tree

Average annual costs for tree planting and care increase with mature tree size (see Appendix A for detailed results):

- $9 to $17 for a small tree
- $12 to $20 for a medium tree
- $14 to $23 for a large tree

Table 4. Estimated annual costs for a small-, medium- and large-sized public and private, residential yard tree located opposite a west-facing wall 20 years after planting.

COSTS ($/yr/tree)	SMALL TREE 28 ft tall, 25 ft spread LSA = 1,891 sq. ft. Private: West	 Public Tree	MEDIUM TREE 38 ft tall, 31 ft spread LSA = 4,770 sq. ft. Private: West	 Public Tree	LARGE TREE 46 ft tall, 41 ft spread LSA = 6,911 sq. ft. Private: West	 Public Tree
Tree and Planting	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Pruning	$4.79	$7.59	$4.79	$7.59	$11.00	$13.73
Remove and Dispose	$0.28	$1.45	$0.34	$1.79	$0.42	$2.22
Pest and Disease	$0.31	$0.08	$0.38	$0.10	$0.47	$0.12
Infrastructure	$0.28	$1.13	$0.35	$1.39	$0.43	$1.73
Irrigation	$0.24	$0.00	$0.60	$0.00	$0.86	$0.00
Clean-Up	$0.28	$1.11	$0.34	$1.37	$0.43	$1.71
Liability and Legal	$0.06	$0.25	$0.08	$0.31	$0.10	$0.38
Administration and Other	$0.00	$1.29	$0.00	$1.39	$0.00	$2.21
Total Costs	**$6.23**	**$12.90**	**$6.87**	**$13.94**	**$13.72**	**$22.10**
Total Benefits	$17.96	$18.12	$36.04	$37.24	$65.18	$68.92
Total Net Benefits	**$11.73**	**$5.22**	**$29.16**	**$23.30**	**$51.46**	**$46.82**

Larger trees are more expensive to maintain

Given our assumptions and the dimensions of these trees, it is 35-55% more expensive to maintain a large tree than a small tree (Table 4). Average annual maintenance costs for private trees are $9-$14 per tree, considerably less than estimated costs for a public tree ($17-$23). Tree pruning is the single greatest cost for private and public trees, averaging approximately $4-$11/year/tree. Annualized expenditures for tree planting are the second most important cost whether planted on private or public lands.

For public trees in Western Washington and Oregon, significant additional costs include annual expenditures for program administration (about $2/tree), tree removal ($1-$2/tree), infrastructure repair ($1-$2/tree) and leaf/debris clean-up ($1-$2/tree). Strategies are needed to reduce these costs so that municipalities can use their limited funds to plant and care for more trees rather than abate challenges posed by trees.

Average Annual Benefits

Average annual net benefits increase with size of tree

Average annual benefits (40-year total / 40 years) also increase with mature tree size (see Appendix A for detailed results):

- $13 to $17 for a small tree
- $33 to $39 for a medium tree
- $60 to $71 for a large tree

Aesthetic and Other

Benefits greatest for property values

Benefits associated with property value account for the largest proportion of total benefits. Average annual values range from \$8-\$10, \$20-\$23, and \$35-\$41 for the small, medium, and large tree, respectively. These values reflect the region's relatively high residential real estate sales prices and the potential beneficial impact of urban forests on property values and the municipal tax base.

Public vs. private trees and property values

Aesthetic and other benefits are slightly greater for the public street/park tree than the residential yard tree because of the assumption that most of these trees have backyard placements, where they have less impact on home value than front yard trees. This assumption has not been tested so there is a high level of uncertainty associated with this result.

Stormwater Runoff

Stormwater runoff benefits are crucial to environmental integrity

After aesthetics, values are largest for benefits associated with rainfall interception. Annual averages are substantial for all three trees. The red oak intercepts 549 gal/yr (2.1 m^3/yr) on average with an implied value of \$15. Bark and foliage of a Norway maple intercepts 346 gal/yr (1.3 m^3/yr) on average, with a value of \$9.72. By intercepting 182 gallons (0.7 m^3) of rainfall annually, a typical purple-leaf plum provides over \$5 in stormwater management savings.

Though a large, red oak at 40 years after planting has an interception rate of over 1,100 gal/yr (4.2 m^3/yr)—valued at \$31—total rainfall intercepted is lower than trees planted in similar locations, but warmer, drier climates (Xiao et al. 2000). The deciduous nature of the "typical" trees coupled with cool, rainy winters reduces the rainfall storage capacity as well as surface evaporation rate.

Carbon Dioxide

CO_2 reduction is substantial for large and medium trees

Benefits associated with atmospheric CO_2 reduction were significant for the large tree and marginally positive for the medium tree. Average annual net reductions range from 206-279 lbs (94-127 kg) (\$3-\$4) for the large tree and 22-78 lbs (10-35 kg) (\$0.35-\$1.15) for the medium tree. Trees opposite west-facing walls produce the greatest CO_2 reduction due to avoided power plant emissions associated with energy savings. Releases of CO_2 associated with tree care activities offsets CO_2 sequestration by the small trees when averaged over the four locations (opposite west-, south-, and east-facing residential buildings and street/park); avoided power plant emissions are small because energy savings are small.

Energy

Larger trees produce more energy savings

Mature tree size matters when considering energy benefits. A large tree produces approximately four to six times more energy savings than a small tree due to the greater effects on wind, building shade, and increased transpirative cooling. However, as trees mature and their leaf surface area increases, energy savings increase regardless of their mature size (Figures 7 and 8).

West is the best

Average annual net energy benefits for residential trees are estimated to be greatest for a tree located west of a building because the detrimental effects on heating costs associated with winter shade is minimized. A yard tree located south of a building typically produces the least net energy benefit, while trees located east of a building provide intermediate net benefits. Winter shade, however, is a function of size, branch pattern and density, and foliar period, resulting in a slightly better performance of a south-side Norway maple over that of an east-side placement. The small plum–opposite both south- and east facing walls–increases heating costs more than shading and climate benefits reduce cooling and heating costs. Thus, this small tree is a net energy cost at these locations.

The medium-sized maple and large oak provide net energy benefits at all locations. Their annual average cooling savings during the summer months ($1-$7) more than offset heating costs associated with winter shade ($1-$3). These results indicate that energy savings are significant even in Western Washington and Oregon's temperate climate. Annual savings can be doubled through strategic placement of solar friendly tree species to maximize summer shade and winter sunlight.

Air Quality

Large trees remove more air pollutants

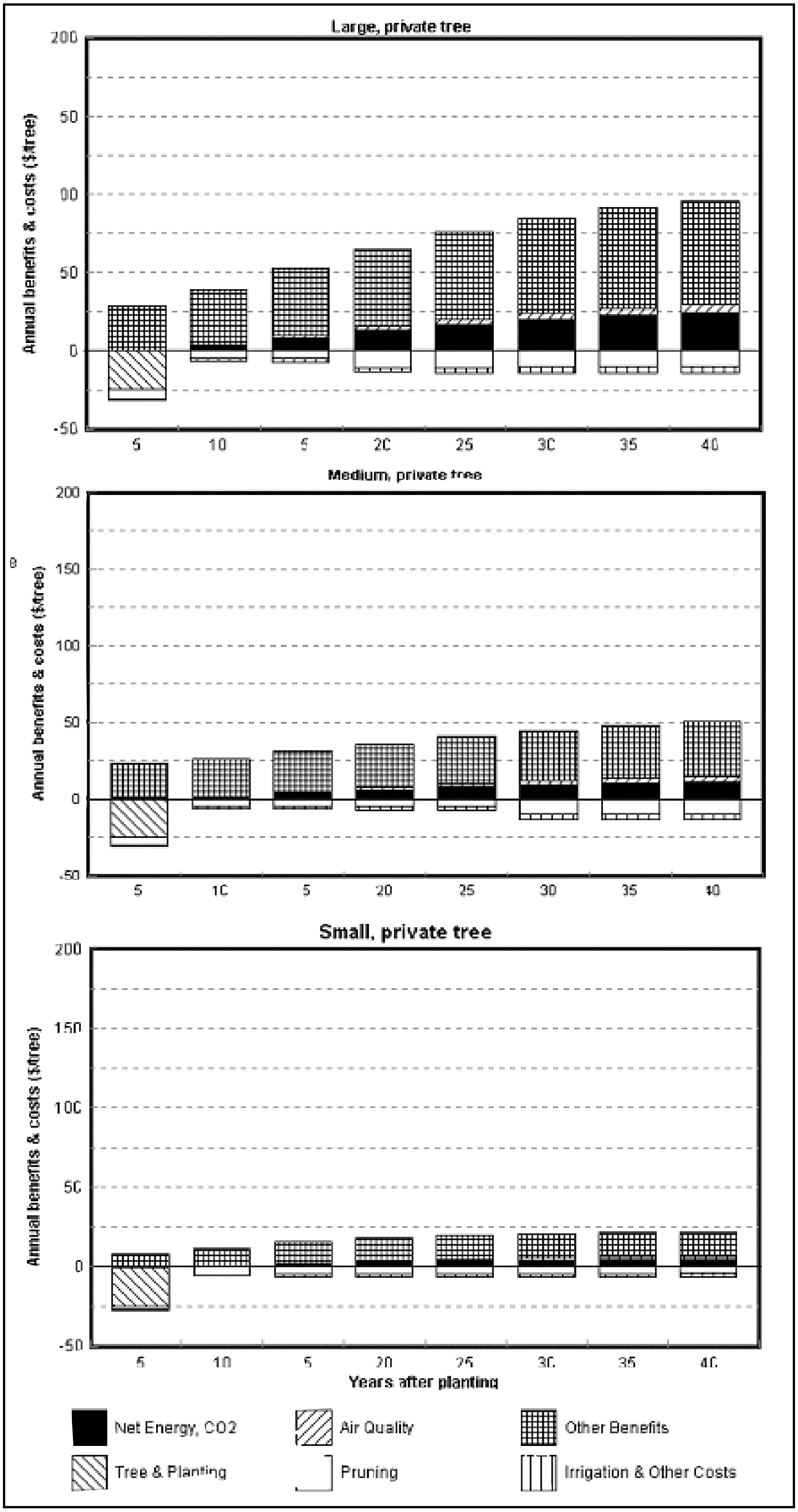
Air quality benefits were defined as the sum of pollutant uptake by trees and avoided power plant emissions due to energy savings, minus BVOCs released by trees. Contributions to the air quality of Western Washington and Oregon provided 4%-7% of the total average annual benefits for the small ($1), medium ($2) and large tree ($3). Benefit values are greatest for PM_{10} and O_3, followed by NO_2. Though positive, trees had minimal effect on SO_2 and VOCs.

The cost of BVOCs released by the low-emitting plum and maple was negligible and similar to the benefit from avoided VOC emissions from power plants due to energy savings. Pollutant uptake benefits far exceed the benefits of avoided pollutant emissions. A single, large red oak at 40 years can remove approximately 2.4 lbs (1.1 kg) of pollutants each year valued at $6. However, because this tree emits about 1 oz (28 grams) more BVOCs than VOCs avoided, the net economic benefit is slightly lower, $5.50/year.

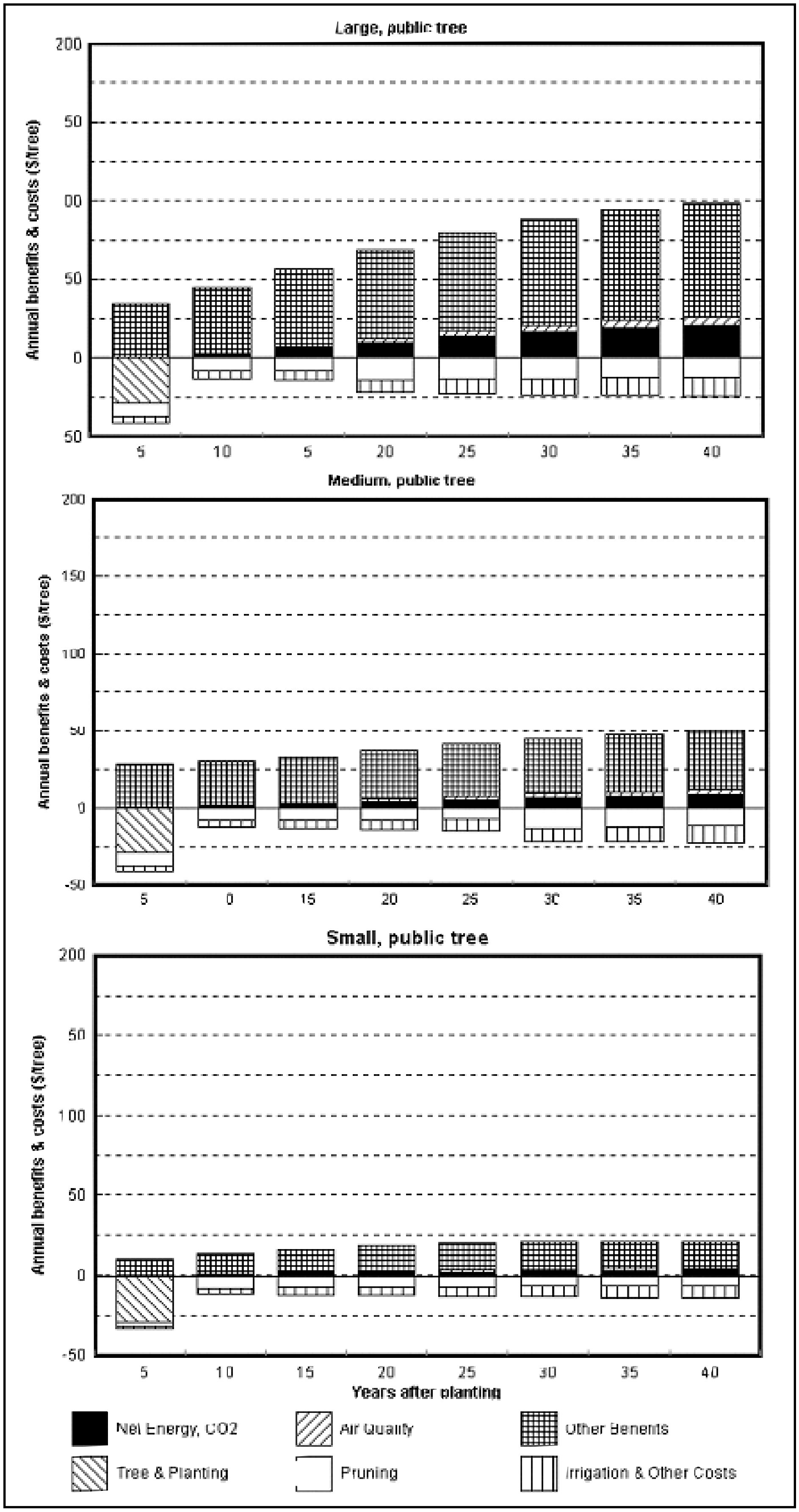
Benefit Summary

Environmental benefits alone can exceed costs for many trees

When totaled and averaged over the 40-year period, summed benefits for all trees, in all locations, exceed costs of tree planting and management. Surprisingly, in many situations, annual environmental benefits, alone, exceed total costs. Trees that meet this standard include all large trees (public or private), all medium trees on residential property, and small trees planted opposite a west-facing wall. Adding the value of aesthetics and other benefits to these environmental benefits results in substantial net benefits.



7. Residential trees. Estimated annual benefits and costs for a large (red oak), medium (Norway maple), and small (purple-leaf plum) residential yard tree located west of the building. Costs are greatest during the initial establishment period while benefits increase with tree size.



8. Public street/park trees. Estimated annual benefits and costs for a large (red oak), medium (Norway maple), and small (purple-leaf plum) public street/park tree.

3. How to Estimate Benefits and Costs for Trees in Your Community

In this chapter, we describe how benefit-cost information can be used for a specific project. A hypothetical problem serves as an example. The following section provides a discussion of actions communities can employ to aid in maintaining a cost-effective tree program.

Applying Benefit-Cost Data: An Example

As a municipal cost-cutting measure, the city of Evergreen is planning to no longer require street tree planting with new development. Instead, developers will be required to plant yard trees. These yard trees will not receive care from municipal arborists, thereby reducing costs to the city. The community forester and local non-profit believe that, although this policy will result in lower costs for tree care, the benefits "forgone" will exceed cost savings. The absence of street trees in new developments will mean that benefits will not be received by residents and the community since there will be fewer trees to enhance neighborhood aesthetics, property values, air quality, water quality, and other aspects of the environment. What can the community forester and concerned citizens do to convince the city that it should continue to plant and maintain street trees?

The first step: calculate benefits and costs over 40 years

As a first step, the city forester and local non-profit group staff decide to quantify the total cumulative benefits and costs over 40 years for a typical street tree planting of 100 trees in Evergreen. Based on planting records, this would include 50 large trees, 30 medium trees, and 20 small trees. Data in Appendix A are obtained for the calculations. However, three aspects of Evergreen's urban and community forestry program are different than assumed in this tree guide:

- ➢ The price of electricity is \$0.09/kWh, not the \$0.06/kWh assumed in Appendix A,
- ➢ No funds are spent on pest and disease control,
- ➢ Planting costs are \$180/tree for city trees instead of the \$122/tree municipal average presented in this tree guide.

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 A (40 Year Average) is multiplied by 40 years. Since this value is for one tree it must be multiplied by the total number of trees planted in the respective large, medium, or small tree size classes. To adjust for higher electricity prices we multiply electricity saved for a large public tree in the resource unit column by the Evergreen price (47 kWh x \$0.09 = \$4.23). This value is multiplied by 40 years and 50 trees (\$4.23 x 40 x 50 = \$8,460) to obtain cumulative air conditioning savings for the project (Table 5). The same steps are followed for medium and small trees.

Table 5. Estimated 40-year total benefits and costs for Evergreen's street tree planting (100 trees).

	50 Large Trees		30 Medium Trees		20 Small Trees		100 Tree Total	
Benefits	Res units	$	Res units	$	Res units	$	Res units	$
Electricity (kWh)	94,000	8,460	26,400	2,376	7,200	648	127,600	11,484
Natural Gas (kBtu)	954,000	8,740	267,600	2,448	68,800	632	1,290,400	11,820
Net Energy (kBtu)	1,898,000	14,680	531,600	4,116	136,800	1,064	2,566,400	19,860
Net CO_2 (lb)	514,000	7,720	73,200	1,092	12,000	184	599,200	8,996
Air Pollution (lb)	2,000	5,620	1,200	2,268	0	776	3,200	8,664
Hydrology (gal)	1,098,000	30,500	415,200	11,544	145,600	4,040	1,658,800	46,084
Aesthetics and Other Benefits		82,680		27,888		7,920		118,488
Total Benefits		**$158,400**		**$51,732**		**$15,264**		**$225,396**
Costs		Public		Public		Public		Public
Tree and Planting		13,768		4,356		2,904		21,028
Pruning		21,040		11,160		5,552		37,752
Remove and Dispose		4,420		2,172		1,136		7,728
Infrastructure		220		108		56		384
Irrigation		3,300		1,620		864		5,784
Clean-Up		1,340		804		536		2,680
Liability and Legal		3,240		1,596		848		5,684
Administration and Other		720		360		192		1,272
Total Costs		**$48,048**		**$22,176**		**$12,088**		**$82,312**
Total Net Benefits		**$110,352**		**$29,556**		**$3,176**		**$143,084**

Res units = Resource Unit

Adjust for local costs

To adjust the cost figures, we eliminate a row for pest and disease control costs in Table 5. We multiply 50 large trees by the unit planting cost ($180) to obtain the adjusted cost for Evergreen (50 x $180 = $9,000). The average annual 40-year costs for other items are multiplied by 40 years and the appropriate number of trees to compute total costs. These 40-year cost values are entered into Table 5.

Calculate cost savings and benefits forgone

Net benefits are calculated by subtracting total costs from total benefits for the large ($110,352), medium ($29,556), and small ($3,176) trees. The total net benefit for the 40-year period is $143,084 (total benefits – total costs), or $1,431/tree ($143,084/100 trees) on average (Table 5). By not investing in street tree planting and maintenance, the city saves $82,312 in total costs, but forgoes $225,396 in total benefits, for a net loss of potential benefits in the amount of $143,084 or $1,431/tree.

Following the results of our survey, this analysis assumes 23.4% of the planted trees die. It does not account for the time value of money from a municipal capital investment perspective, but this could be done using the municipal discount rate. For a more complete analysis it is important to consider the extent to which benefits from increased yard tree plantings may offset the loss of street tree benefits.

Increasing Program Cost-Effectiveness

What if the costs are too high?

What if the program you have designed is promising in terms of stormwater runoff reduction, energy savings, volunteer participation, and ancillary 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.

Increase 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 increased energy savings and reduced tree removal costs.

Target tree plantings with highest pay back

Conifers and broadleaf evergreens intercept rainfall and particulates year-round. Also, they tend to have relatively more leaf surface area than similar sized deciduous trees. Locating these types of trees in yards, parks, school grounds, and other open space areas can increase benefits.

Customize planting locations

You can further increase energy benefits by targeting a higher percentage of trees for locations that produce the greatest energy savings, such as opposite west-facing walls and close to buildings. By customizing tree locations to increase numbers in high-yield sites, cooling savings can be boosted.

Reduce Program Costs

Reduce up-front and establishment costs

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

Cost-effectiveness = Total Net Benefit / Total Program Cost

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

- Plant bare root or smaller tree stock
- Use trained volunteers
- Provide follow-up care to increase tree survival and reduce replacement costs
- Select and locate trees to avoid conflicts

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 that reduce planting costs. However, in highly urbanized settings and sites subject to vandalism, large stock may survive the initial establishment period better than small stock.

Train volunteers to monitor tree health

Investing in the resources needed to promote tree establishment during the first three 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.

Prune early

A cadre of trained volunteers can easily maintain trees until they reach a height of about 20 ft (6 m) and limbs are too high to prune from the ground with pole pruners. By the time trees reach this size they are well-established. Pruning during this establishment period should result in a safer tree that will require less care in the long-term. Training young trees will provide a strong branching structure that requires less frequent thinning and shaping. Although organizing and training these volunteers requires labor and resources, it is usually less costly than contracting the work. As trees grow larger, contracted pruning costs may increase on a per-tree basis. The frequency of pruning will influence these costs, since it takes longer to prune a tree that has not been pruned in 10 years than one that was pruned a few years ago. Although pruning frequency varies by species and location, a return frequency of about five years is usually sufficient (Miller 1997).

Match tree to site

Carefully select and locate trees to avoid conflicts with overhead powerlines, 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

When evaluating the bottom line–whether trees pay–do not forget to consider benefits other than the stormwater runoff reductions, energy savings, atmospheric CO_2 reductions, and other tangible benefits described in this report. The magnitude of benefits related to employment opportunities, job training, community building, and enhanced human health and well-being can be substantial. Moreover, these benefits extend beyond the site where trees are planted, furthering collaborative efforts to build better communities.

Additional information

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

- *An Introductory Guide to Community and Urban Forestry in Washington, Oregon, and California.* World Forestry Center, Portland, OR.
- *A Technical Guide to Urban and Community Forestry.* World Forestry Center, Portland, OR. 1993.

Copies are available from your state urban and community forestry coordinator in Washington (Department of Natural Resources) and Oregon (Department of Forestry).

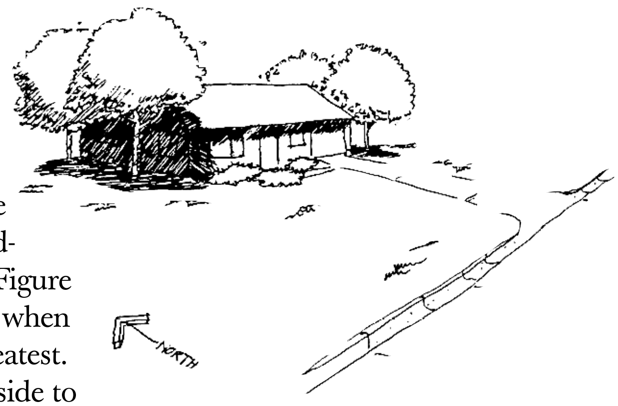
4. General Guidelines for Selecting and Siting Trees

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

Residential Yard Trees

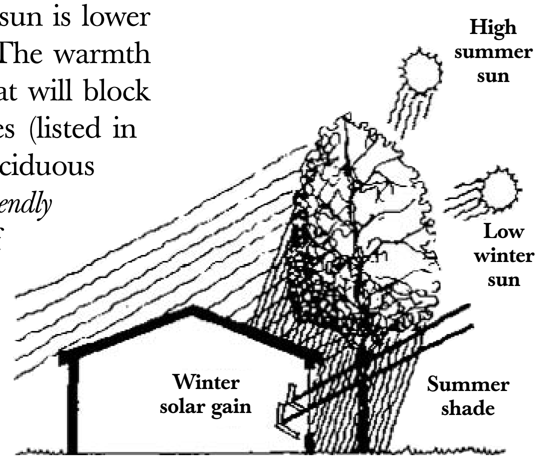
Maximizing Energy Savings from Shading

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 (Figure 3 on page 6). Electricity use is highest during the afternoon when temperatures are warmest and incoming sunshine is greatest. Therefore, the west side of a home is the most important side to shade. Depending on building orientation and window placement, sun shining through windows can heat a home quickly during the morning hours. The east side is the second most important side to shade when considering the net impact of tree shade on cooling and heating costs (Figure 9).



9. Locate trees to shade west and east windows (from Sand 1993).

Use solar friendly trees. Trees located to shade south walls can block winter sunshine and increase heating costs, because during winter the sun is lower in the sky and shines on the south side of homes (Figure 10). The warmth the sun provides is an asset, so do not plant evergreen trees that will block southern exposures and solar collectors. Use solar friendly trees (listed in Chapter 5) to the south because 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%). Examples of solar friendly trees include most species and cultivars of maple (*Acer spp.*) and ash (*Fraxinus spp.*).



10. Select solar friendly trees for south exposures and locate close enough to provide winter solar access and summer shade (from Sand 1991).

To maximize summer shade and minimize winter shade, locate trees about 10-20 ft (3-6 m) 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 (Figure 11).

Roots, branches and buildings don't mix. Although the closer a tree is to the home the more shade it provides, the 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. Keep trees at least 5-10 ft (1.5-3 m) from the home to avoid these conflicts, but within 30-50 ft (9-15 m) to effectively shade windows and walls.

BEFORE

AFTER

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

Patios, driveways and air conditioners need shade. Paved patios and driveways can become heat sinks that warm the home during the day. 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.

Avoid power, sewer, and water lines. Plant only suitable trees under overhead powerlines and do not plant directly above underground water and sewer lines. Contact your local utility company before planting to determine where underground lines are located and which tree species should not be planted under powerlines.

Planting Windbreaks for Heating Savings

With the relatively long winter heating season in Western Washington and Oregon, additional energy savings can be obtained in situations where lot sizes are large enough to plant windbreaks. A tree's size and porosity can make it an ideal wind filter, reducing the impacts of cold winter weather.

Locating windbreaks. Locate rows of trees perpendicular to the primary wind (Figure 12). Design the windbreak row to be longer than the building being sheltered because the wind speed increases at the edge of the windbreak. Ideally, the windbreak is planted upwind about 25-50 ft (7-15 m) from the building and consists of dense evergreens that will grow to twice the height of the building they shelter (Heisler 1986; Sand 1991).

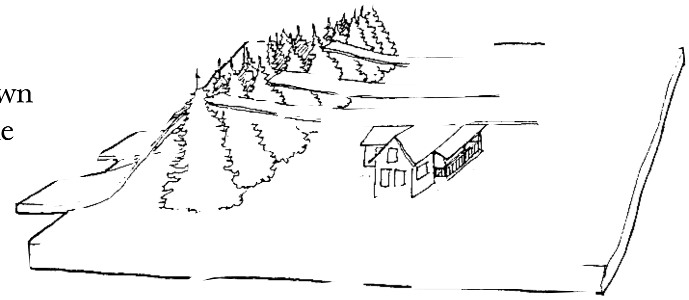
Avoid locating windbreaks that will block sunlight to south and east walls (Figure 13). Trees should be spaced close enough to form a dense screen, but not so close that they will block sunlight to each other, causing lower branches to self-prune. Most conifers can be spaced about 6 ft (2 m) on center. If there is room for two or more rows, then space rows 10-12 ft (3-4 m) apart.

Plant dense evergreens. Evergreens 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 do not self-prune. Large windbreak trees for Western Washington and Oregon communities include western hemlock, (*Tsuga heterophylla*), incense-cedar (*Calocedrus decurrens*), and western redcedar (*Thuja pli-*

cata). Good windbreak species for smaller sites include American arborvitae (*Thuja occidentalis*), English laurel (*Prunus laurocerasus*), and Fraser photinia (*Photinia* x *fraseri*).

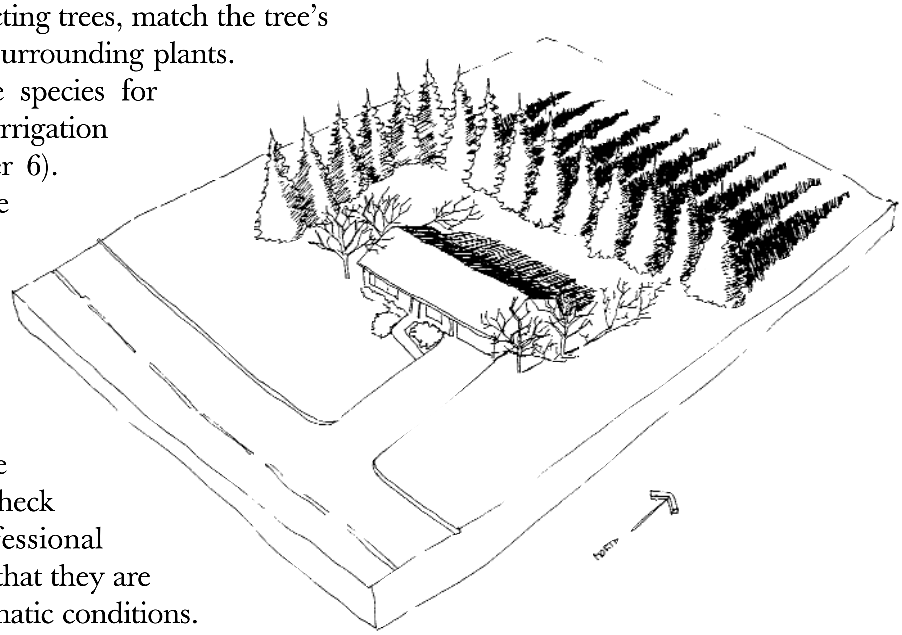
Selecting Yard Trees to Maximize Benefits

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 building shade than a small tree. Deciduous trees allow sun to shine through leafless branches in winter. Plant small trees where nearby buildings or powerlines limit aboveground space. Columnar or upright 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, resisting storm damage, disease, and pests (Sand 1994). Examples of trees not to select for placement near buildings include cottonwoods (*Populus spp.*) because of their invasive roots, weak wood, and large size, and ginkgos (*Ginkgo biloba*) because of their sparse shade and slow growth.



12. Evergreens guide wind over the building (from Sand, 1993).

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 (see Tree Selection List in Chapter 6). 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. 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.



13. Mid-winter shadows from a well-located windbreak and shade trees do not block solar radiation on the south-facing wall (from Sand 1993).

Trees in Public Places

Locating and Selecting Trees to Maximize Climate Benefits

Large trees mean more shade. Locate trees in common areas, along streets, in parking lots, and commercial areas 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, they reduce emissions of evaporative hydrocarbons from parked cars that are involved in smog formation (Scott et al. 1998). Large trees can shade more area than smaller trees, but should be used only where space permits. Remember that a tree needs space for both branches and roots.

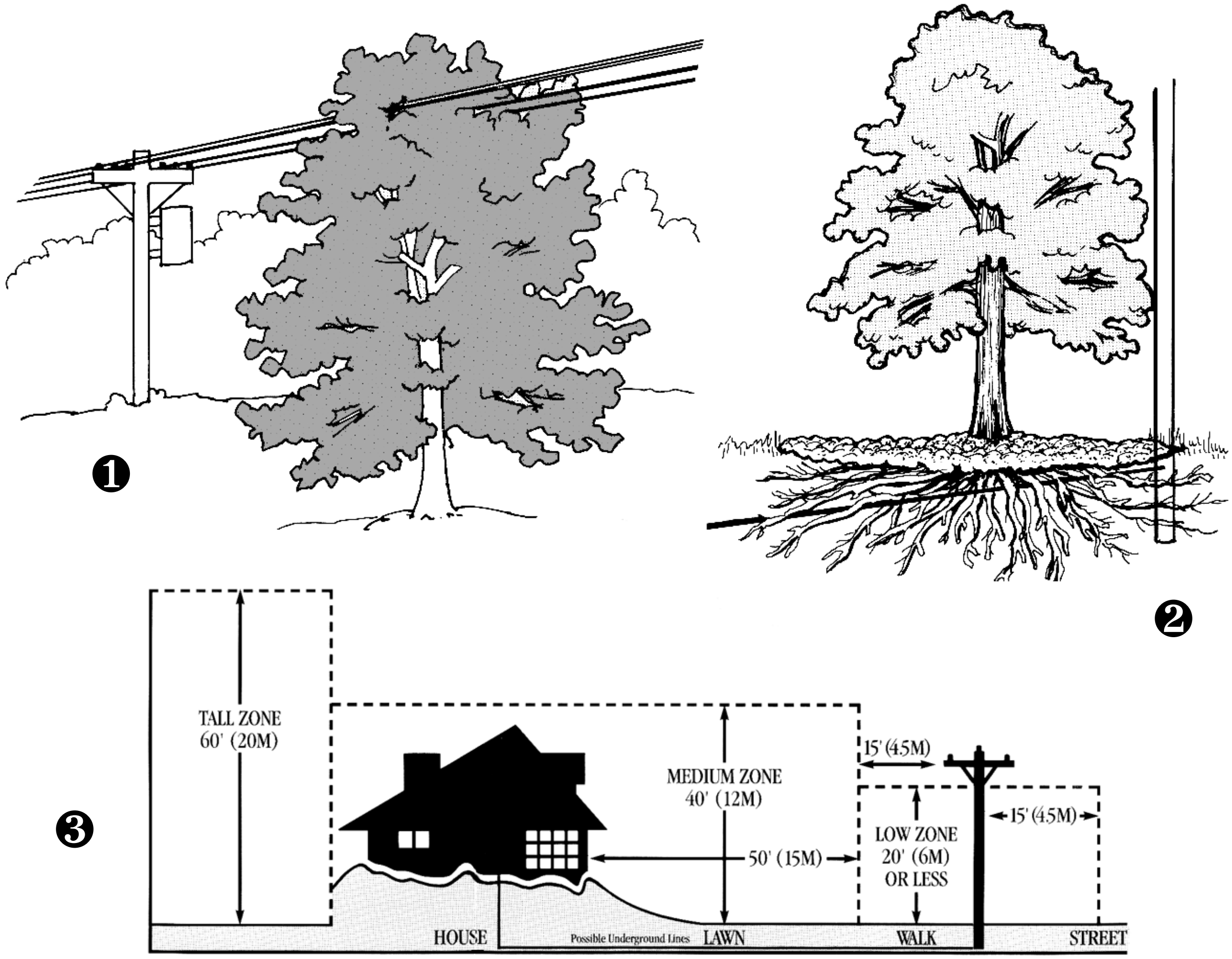
For CO_2 reduction, select trees well-suited to the site.

Because trees in common areas and other public places may not shelter buildings from sun and wind, CO_2 reductions 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 growing trees have the capacity to store more CO_2 than smaller growing trees. To maximize CO_2 sequestration, select tree species that are well-suited to the site where they will be planted. Use information in the Tree Selection List (see Chapter 5), and consult with your local landscape professional or arborist 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.

How to maximize trees as CO_2 sinks

Parks and other public landscapes serve multiple purposes. Some of the following guidelines may help you maximize their ability to serve as CO_2 sinks:

- Provide as much pervious surface as possible so that trees grow vigorously and store more CO_2.
- Maximize use of woody plants, especially trees, since they store more CO_2 than do herbaceous plants and grass.
- Increase tree-stocking levels where feasible, and immediately replace dead trees to compensate for CO_2 lost through tree and stump removal.
- Create a diversity of habitats, with trees of different ages and species, to promote a continuous canopy cover.
- Select species that are adapted to local climate, soils, and other growing conditions. Adapted plants should thrive in the long run and will avoid CO_2 emissions stemming from high maintenance needs.
- Group species with similar landscape maintenance requirements together and consider how irrigation, pruning, fertilization, weed, pest, and disease control can be done most efficiently.
- Compost litter and apply it as mulch to reduce CO_2 release associated with irrigation and fertilization.
- Where feasible, reduce CO_2 released through landscape management by using push mowers (not gas or electric), hand saws (not chain saws), pruners (not gas/electric shears), rakes (not leaf blowers), and employing local landscape professionals who do not have to travel far to work sites.
- Consider the project's life-span when making species selection. Fast-growing species will sequester more CO_2 initially than slow-growing species, but may not live as long.



14. (❶, ❷) Know where power lines and other utility lines are before planting. ❸ 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)

➢ Provide a suitable soil environment for the trees in plazas, parking lots, and other difficult sites to maximize initial CO_2 sequestration and longevity.

Pay attention to infrastructure. Contact your local utility company before planting to locate underground water, sewer, gas, and telecommunication lines. Note the location of powerlines, streetlights, and traffic signs, and select tree species that will not conflict with these aspects of the city's infrastructure. Keep trees at least 30 ft (10 m) 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 (1 m) of pavement, and remember that trunk flare at the base of large trees can displace soil and paving for a considerable distance. Select only small-growing trees (<25 ft tall [8 m]) for locations under overhead powerlines, and do not plant directly above underground water and sewer lines (Figure 14). Avoid locating trees where they will block illumination from streetlights or views of street signs in parking lots, commercial areas, and along streets.

Match tree to site on case-by-case basis

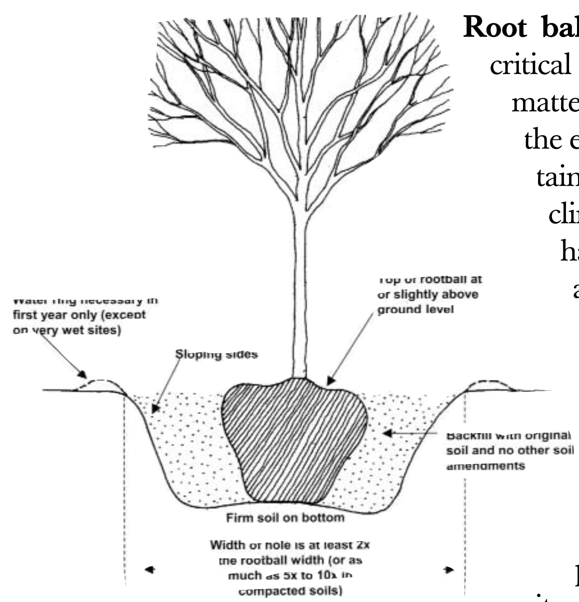
Maintenance requirements and public safety issues influence the type of trees selected for public places. The ideal public tree is not susceptible to wind damage and branch drop, does not require frequent pruning, produces little litter, is deep-rooted, has few serious pest and disease problems, and 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. Plant only small or medium sized trees under powerlines. Consult the Tree Selection List in Chapter 5 and your local landscape professional for horticultural information on tree traits.

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.

Root ball critical to survival. 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. If the tree has many roots circling around the outside of the root ball or the root ball is very hard it is said to be pot-bound. The mass of circling roots can act as a physical barrier to root penetration into the surrounding soil after planting. Dense surface roots that circle the trunk may girdle the tree. Do not purchase pot-bound trees.

A good tree is well-anchored. Another way to evaluate the quality of the tree before planting is to gently move the trunk back and forth. A good tree trunk bends and does not move in the soil, while a poor quality trunk bends little and pivots at or below the soil line. If it pivots and the soil loosens, it may not be very well anchored to the soil.



15. Prepare a broad planting area, plant tree with rootball at ground level, and provide a watering ring to retain water (from Head et al. 2001).

Plant the tree in a quality hole. Dig the planting hole one inch shallower than the depth of the root ball to allow for some settling after it is watered in. The crown of the root ball should be slightly above ground level. Make the hole two to three times as wide as the root ball and roughen the sides of the hole to make it easier for roots to penetrate. Backfill with the native soil unless it is very sandy, in which case you may want to add composted organic matter such as peat moss or shredded bark (Figure 15).

Use the extra backfill to build a berm outside the root ball that is 6 inches (15 cm) high and 3 ft (1 m) in diameter. Soak the tree, and gently rock it to set-

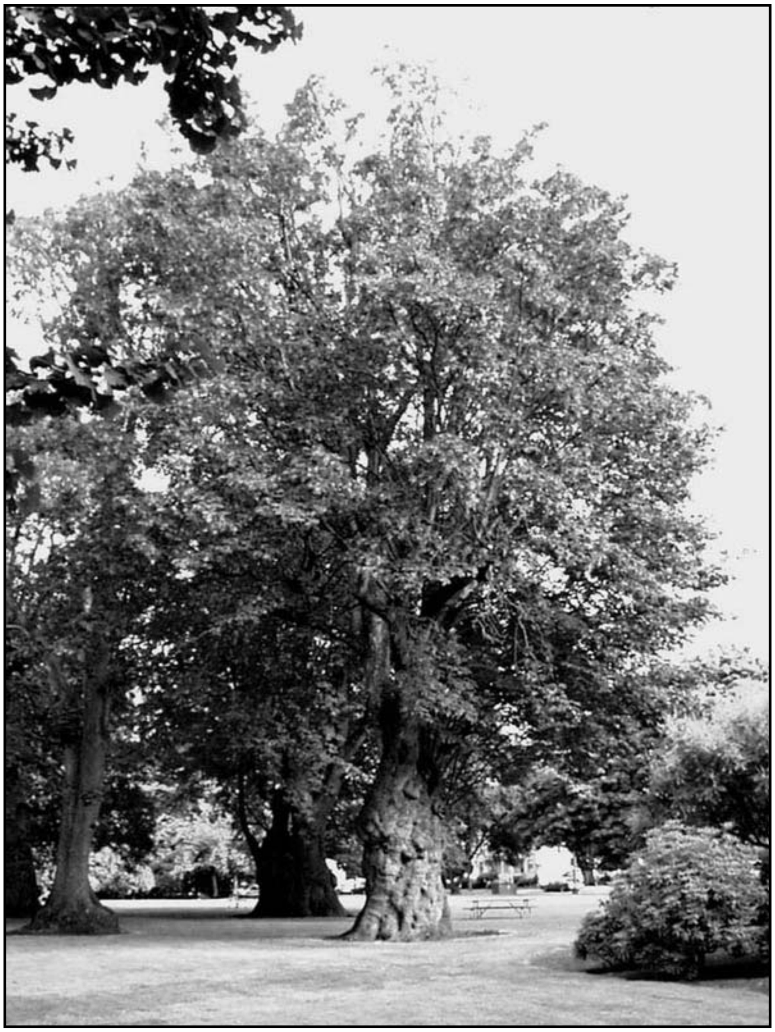
Mulch and water

tle it in. Cover the basin with a 4-inch (10 cm) thick layer of mulch, but avoid placing mulch against the tree trunk. Water the new tree twice a week for the first month and weekly thereafter for the following two growing seasons.

Don't forget about the tree

Inspect your tree several times a year, and contact a local tree or landscape professional if problems develop. If your tree needed staking to keep it upright, remove the stake and ties as soon as the tree can hold itself up. Reapply mulch and irrigate the tree as needed. Prune the young tree to maintain a central leader and equally spaced scaffold branches. As the tree matures, have it pruned on a regular basis by a certified arborist or experienced professional. By keeping your tree healthy, you maximize its ability to intercept rainfall, reduce atmospheric CO_2, and provide other benefits.

For additional information on tree planting, establishment and care, see *Principles and Practice of Planting Trees and Shrubs* (Watson and Himelick 1997), *Arboriculture* (Harris et al. 1999), and the video *Training Young Trees for Structure and Form* (Costello 2000).



5. Recommended Trees for Western Washington and Oregon Communities

In this chapter, recommended trees and their attributes are presented to help select the right tree for specific planting situations throughout Western Washington and Oregon.

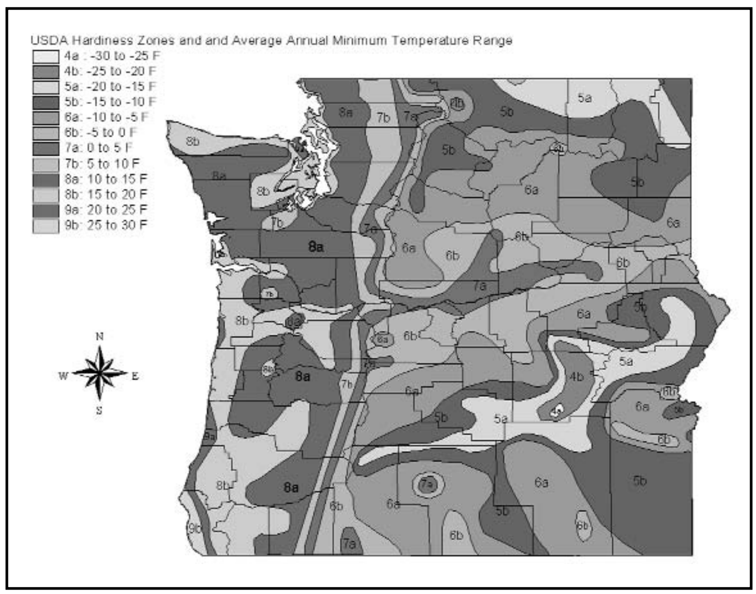
What is the geographic scope?

Because of their natural adaptability, many of the trees listed in Table 6 (starting on p. 50) are suitable for growing in the cold, drier areas east of the Cascade mountain range in Oregon and Washington, as well as the typically rainy areas west of the Cascades (Figure 1 on page 1). However, many of the species listed grow more vigorously in the growing conditions west of the Cascades. Cost-benefit data and other information in this tree guide pertain to trees growing in areas west of the Cascades only.

What are the selection criteria?

Species listed in Table 6 were selected for several reasons:

- ➢ Have been documented to grow well in USDA Hardiness Zones 3-8 and are acceptable or recommended for use by a number of municipalities in the region (Figure 16).
- ➢ Typically have no serious pest or excessive maintenance problems.
- ➢ Provide energy conservation benefits by creating significant amounts of summer shade when planted individually.
- ➢ Are readily available in the regional nursery industry based on the most recent production data available (Note: some of the 'newer' cultivars may not be available in large quantities).



16. Recommended trees for Western Washington and Oregon grow well in USDA Hardiness Zones 3-8 and are acceptable for use by a number of municipalities in the Pacific Northwest region.

This list includes a number of species that have traditionally made up the urban forest in the Pacific Northwest as well as a number of 'newer' species and cultivars that warrant increased planting by municipalities and homeowners. Readers are encouraged to use the reference materials cited in this chapter to identify additional species and cultivars to plant in their communities. It is important to select species and cultivars that are not currently overplanted in your community to maintain a stable tree population. A species-diverse urban forest can help minimize potential disease or insect epidemics, as well as increase community attractiveness and expand the availability of well-adapted species.

One recommendation is that no single genera should constitute more than 12% of the total tree population, and no single species should constitute more than 5%. While valuable as a guideline, it's important to remember that communities differ in growing conditions and management needs. Planting decisions should consider the need for well-adapted species, some experimental species, as well as overall diversity (Richards 1983).

What information is included?

Tree species are listed alphabetically by botanical name, and includes information regarding their mature size, leaf retention habit, growth rate, powerline compatibility, and best uses within the urban landscape. Trees are also classified as Solar Friendly–or not–based on data reported by the City of Portland and the Oregon Energy Office (1987). Solar friendly trees are deciduous and have relatively open crowns. When leafless, they permit transmission of winter sunlight. Also, they tend to be early to drop leaves and late to leaf-out. When planted south of buildings, solar friendly trees maximize winter solar heat gain. A "Comments" column highlights specific features for some of the trees.

It is important to note that a tree's size, lifespan, growth, and rooting pattern are highly variable depending on how it was planted, its growing conditions, and the care it receives. Therefore, the tree's actual performance can be very different from that described here. Use this information as a general guide and obtain more specific information from the references cited below and from local landscape professionals. In preparing this information, the following important assumptions were made:

- ➢ Trees will be planted as 15-gallon container sized plants.
- ➢ Conventional planting practices will be followed, such as appropriate site/soil preparation, root ball management, and mulching.
- ➢ Trees will be maintained and irrigated as needed until established (2-3 years) and then receive about 60% to 80% of reference evapotranspiration.

How to Match the Tree to the Site

Finding the best tree for a specific site takes time and study. Collecting information on conditions at the site is the first step. Consider the amount of below- and above-ground space, soil type and irrigation, microclimate, and the type of activities occurring around the tree that will influence its growth and management (e.g., mowing, parking, social events). In most cases, it is too expensive to alter site conditions by making them more suitable for a specific tree species. Instead, it is more practical to identify trees with characteristics that best match the existing site conditions, particularly those conditions that will be most limiting to growth. For example, microclimate can effect disease susceptibility of some genera (e.g., *Prunus* and *Malus*) and should be carefully considered when matching a tree to a site. Information in this chapter, such as disease susceptibility, will assist in finding the best match possible.

Tree List References

References used to develop the tree list include:

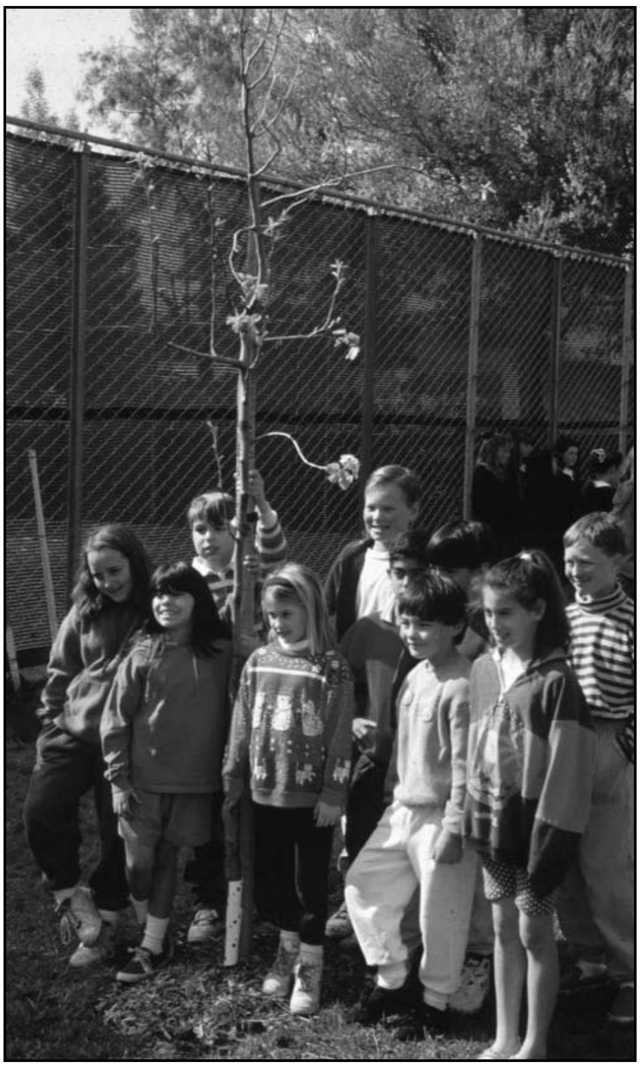
For more information

Ames, M.J. 1987. **Solar friendly trees report**. City of Portland, Oregon, Energy Office. Portland Oregon.

Dirr, M. A. 1998. **Manual of woody landscape plants**. 5th ed. Stipes Publishing, L.L.C., Champaign, Illinois.

Lofton, J. 2001. **Willamette Valley community street tree inventory**. Engineering Department, City of Dallas, OR.

McNeilan, R.A. and A.M. VanDerZanden. 1999. **Plant materials for landscaping: a list of plants for the Pacific Northwest**. PNW 500. Pacific Northwest Extension Publication, Oregon State University, Corvallis, OR.



TREE SELECTION LIST

Table 6. Recommended Trees for Western Washington and Oregon Communities

Common Name	Botanical Name	Height (feet)	Spread (feet)	Evergreen Deciduous	Growth Rate	USDA Zone	Suitable Under Powerline	Planting Location	Solar Friendly	Comments
Trident Maple	*Acer buergeranum*	30	30	D	S	5-8	Y	P/C; LR/C; SR/C	Y	Good bark effect on mature specimens, yellow-orange-red fall color.
Queen Elizabeth™ Hedge Maple	*Acer campestre* 'Evelyn'	35	30	D	S	6-8	N	P/C; LR/C; SR/C	Y	Oval-round crown, flat top, dense growth, leaves are dark green, yellowish fall color.
Vine Maple	*Acer circinatum*	15-30	10-20	D	S	5-8	Y	P/C; LR/C; SR/C; P	Y	Tolerates considerable shade, often found as multi-stemmed tree.
David Maple	*Acer davidii*	30-50	20-35	D	M	5-8	N	P/C; LR/C	Y	Grown for the spectacular bark which is green with white stripes.
Paperbark Maple	*Acer griseum*	25	25	D	S	5-8	Y	P/C; LR/C; SR/C	Y	Bark is spectacular, cinnamon colored and peeling, excellent red fall color, tolerates some shade.
Fernleaf Fullmoon Maple	*Acer japonicum* 'Aconitifolium'	25	25	D	M	5-8	Y	P/C; LR/C; SR/C;	Y	A multi-stemmed selection of spreading habit with superb yellow-red fall color.
Pacific Sunset™ Maple	*Acer* 'Warrenred'	30	25	D	M	5-8	Y	P/C; LR/C; SR/C; P	Y	Very glossy dark green leaves, yellow-orange-red fall color.
Japanese Maple	*Acer palmatum*	6-40	5-25	D	S	5-8	Y	P/C; LR/C; SR/C; P	Y	Huge number of cultivars, much variation in plant size, color, habit.
Parkway® Norway Maple	*Acer platanoides* 'Columnarbroad'	45	35	D	M	4-8	N	P/C; LR/C	Y	Surface-rooted, adapted to poor soil, heat and drought-tolerant, yellow fall color, one of the best cultivars for urban sites, tolerant of verticillium wilt.
Columnar Norway Maple	*Acer platanoides* 'Columnare'	60	20	D	M	4-8	N	P/C; LR/C	Y	Surface-rooted, adapted to poor soil, heat and drought-tolerant, may seed itself.
Crimson King Norway Maple	*Acer platanoides* 'Crimson King'	45	40	D	M	4-8	N	P/C; LR/C	Y	Surface-rooted, adapted to poor soil, heat and drought-tolerant, maroon leaf color, may seed itself.

Height: average ultimate height in feet for mature tree growing in these areas.
Spread: average ultimate spread in feet for mature tree growing in theses areas.
Type: E = evergreen; D = deciduous.
Growth Rate: years to mature size when planted from a 15-gal. container; S = slow, >20 years; M = moderate, 10-20 years; F = fast, <10 years.
Use categories:

Suitable under powerlines: Tree has a mature height of 30 ft. or less and is suitable for planting under powerlines.

Suitable planting locations:

P/C = park/commercial: ±8,000 sq.ft. of planting area; ultimate ht. >50 ft.
LR/C = large residential/commercial: 4,000 – 8,000 sq.ft. of planting area; ultimate ht. 30 = 50 ft.
SR/C = small residential/commercial: <4,000 sq.ft. of planting area; ultimate ht. 30 ft. or less.
P = patio: very clean; ultimate ht. of 20-30 ft.

Solar friendly: Y=yes (promotes winter solar gain), N=No, NDA= No Data Available.

Table 6. Recommended Trees for Western Washington and Oregon Communities

Common Name	Botanical Name	Height (feet)	Spread (feet)	Evergreen Deciduous	Growth Rate	USDA Zone	Suitable Under Powerline	Planting Location	Solar Friendly	Comments
Deborah Norway Maple	*Acer platanoides* 'Deborah'	50	45	D	M	4-8	N	P/C; LR/C	Y	Surface-rooted, adapted to poor soil, heat and drought-tolerant, brilliant red new growth, orange-yellow fall color, may seed itself.
Emerald Queen Norway Maple	*Acer platanoides* 'Emerald Queen'	50	40	D	M-F	4-8	N	P/C; LR/C	Y	Surface-rooted, adapted to poor soil, heat and drought-tolerant, ascending branches, rapid grower, commonly used cultivar, may seed itself.
Autumn Flame Red Maple	*Acer rubrum* 'Autumn Flame'	50	40	D	M-F	3-8	N	P/C; LR/C	Y	Rounded crown on mature trees, red fall color.
Bowhall Red Maple	*Acer rubrum* 'Bowhall'	50	15	D	M-F	3-8	N	P/C; LR/C	Y	Upright form with yellowish-red fall color.
Karpick Red Maple	*Acer rubrum* 'Karpick'	45	20	D	M-F	3-8	N	P/C; LR/C	Y	Twigs are distinctly red, yellow-red fall color.
October Glory® Red Maple	*Acer rubrum* 'October Glory'	45	30	D	M-F	3-8	N	P/C; LR/C	Y	Oval-rounded form, orange-red fall color.
Red Sunset® Red Maple	*Acer rubrum* 'Franksred'	45	35	D	M-F	3-8	N	P/C; LR/C	Y	Rounded outline, orange to red fall color.
Commemoration Sugar Maple	*Acer saccharum* 'Commemora-tion'	50	35	D	F	4-8	N	P/C; LR/C	Y	Fast-growing oval-rounded tree, glossy dark green leaves, yellow-orange-red fall color.
Green Mountain® Sugar Maple	*Acer saccharum* 'Green Mountain'	70	45	D	M	4-8	N	P/C; LR/C	Y	Dark green leathery leaves, yellow-red fall color. May be more tolerant than other cultivars of drought.
Legacy Sugar Maple	*Acer saccharum* 'Legacy'	50	35	D	M	4-8	N	P/C; LR/C	Y	Glossy dark green leaves, very dense crown, yellow-orange fall color.
Pattern Perfect Tatarian Maple	*Acer tataricum* 'Pattern Perfect'	15-20	15-20	D	M	3-8	Y	P/C; LR/C; SR/C	NDA	Attractive small specimen tree, good substitution for *A. ginnala*, red samaras in summer.
Armstrong Maple	*Acer x freemanii* 'Armstrong'	50	15	D	F	4-8	N	P/C; LR/C	NDA	Fast-growing, silvery underside to leaf, yellow-orange fall color.
Autumn Blaze® Maple	*Acer x freemanii* 'Autumn Blaze'	50	40	D	F	4-8	N	P/C; LR/C	N	Fast-growing, orange-red fall color.
Briotii Red Horsechestnut	*Aesculus x carnea* 'Briotii'	50	45	D	M	5-8	N	P/C; LR/C	N	Rounded head, resistant to blotch and mildew, red flowers in 10" panicles.
Fort McNair Red Horsechestnut	*Aesculus x carnea* 'Fort McNair'	40-50	40-50	D	M	5-8	N	P/C; LR/C	N	Flowers 6-8" long, reddish-pink with yellow throats.

TREE SELECTION LIST

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Table 6. Recommended Trees for Western Washington and Oregon Communities

Common Name	Botanical Name	Height (feet)	Spread (feet)	Evergreen Deciduous	Growth Rate	USDA Zone	Suitable Under Powerline	Planting Location	Solar Friendly	Comments
Heritage® River Birch	*Betula nigra* 'Cully'	50	35	D	M	3-8	N	P/C; LR/C	N	Glossy dark green leaves, yellow fall color, excellent peeling white/cream bark. Quite drought-tolerant.
Whitebark Himalayan Birch	*Betula utilis* var. *jacquemontii*	40	30	D	M	5-8	N	P/C; LR/C	Y	Dark green leaves, exceptional white bark.
Pyramidal Hornbeam	*Carpinus betulus* 'Fastigiata'	30-40	20-30	D	S	4-7	N	P/C; LR/C; SR/C	N	Upright, oval shape; densely branched.
Pyramidal European Hornbeam	*Carpinus betulus* 'Franz Fontaine'	30-35	15-18	D	M	4-7	N	P/C; LR/C; SR/C	NDA	Excellent small landscape tree; strongly fastigiate.
Katsura tree	*Cercidiphyllum japonicum*	60-80	30-50	D	M	4-8	N	P/C; LR/C	Y	Single-stemmed or multi-stemmed forms; heart shaped leaves. Well suited for park sites. Protect from sun scald and does best in an irrigated site.
Eastern Redbud	*Cercis canadensis*	20-30	25-35	D	M	5-8	Y	P/C; LR/C; SR/C	Y	Nice small specimen tree. Rosy pink flowers with legume type fruit in fall. Yellow fall color.
White Redbud	*Cercis canadensis* 'Alba'	20-30	25-35	D	M	5-8	Y	P/C; LR/C; SR/C	Y	White flowers.
Forest Pansy Redbud	*Cercis canadensis* 'Forest Pansy'	20	25	D	M	5-8	Y	P/C; LR/C; SR/C	Y	Purple foliage, rose-purple flowers.
Oklahoma Redbud	*Cercis canadensis* ssp. *texensis* 'Oklahoma'	20	20	D	M	6-8	Y	P/C; LR/C; SR/C	Y	Leaves are shiny, leathery green, rosy magenta flowers.
Yellowwood	*Cladrastis kentukea*	30-50	40-50	D	M	3-8	N	P/C; LR/C	Y	Excellent flowers & leaves; nice shade tree.
June Snow Giant Dogwood	*Cornus controversa* 'June Snow'	30	40	D	M	5-8	Y	P/C; LR/C	Y	Horizontally-branched, wide-spreading tree, flowers in May-June.
Flowering Dogwood	*Cornus florida*	20-30	20-30	D	M	5-8	Y	P/C; LR/C; SR/C	Y	Large number of cultivars, exceptionally showy in flower. May be susceptible to anthracnose.
Kousa Dogwood	*Cornus kousa* 'National' or 'Satomi'	20-30	20-30	D	S	5-8	Y	P/C; LR/C; SR/C	Y	Listed cultivars are most commonly available tree forms, flowers much later than *C. florida*. Has been used as street tree but large, soft red fruit may limit use.

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Cornelian Cherry	*Cornus mas*	25	20	D	M	4-8	Y	P/C; LR/C; SR/C	NDA	Yellow flowers in March, followed by edible red fruit. Fruit may limit use as street tree.
Lavalle Hawthorn	*Crataegus x lavallei*	20-30	20	D	M	4-7	Y	P/C; LR/C; SR/C	N	Small dense oval to rounded canopy, white flowers in late May, orange-red fruit persist into winter.
Washington Hawthorn	*Crataegus phaenopyrum*	30	30	D	M	4-8	Y	P/C; LR/C; SR/C	N	White flowers and very showy red fruit, thorny so avoid high-traffic areas.
Dove Tree	*Davidia involucrata*	40	30	D	M	6-8	N	P/C; LR/C	Y	Exceptionally showy and unusual flower display, best with summer irrigation.
Hardy Rubber Tree	*Eucommia ulmoides*	40	40	D	M	5-8	N	P/C; LR/C	NDA	Excellent foliage effect.
Dawyck Beech	*Fagus sylvatica* 'Dawyck'	50-60	10-20	D	S	4-8	N	P/C; LR/C	NDA	Very columnar to slightly cone shaped.
Purple Fountain Beech	*Fagus sylvatica* 'Purple Fountain'	25	12	D	S	4-8	Y	P/C; LR/C; SR/C	NDA	Narrow upright growth with cascading branches, purple foliage.
Riversii Beech	*Fagus sylvatica* 'Riversii'	50	40	D	S	4-8	N	P/C; LR/C	NDA	Very deep purple leaves.
Autumn Applause White Ash	*Fraxinus americana* 'Autumn Applause'	40	25	D	M	4-8	N	P/C; LR/C	Y	Densely-branched oval form, purple fall color.
Autumn Purple® White Ash	*Fraxinus americana* 'Junginger'	45	60	D	M	4-8	N	P/C; LR/C	Y	Pyramidal-rounded outline, deep green leaves, purple fall color.
Golden Desert™ Ash	*Fraxinus excelsior 'Jaspidea'*	30	20	D	M	4-8	N	P/C; LR/C	Y	Rounded shape, new growth is gold, golden bark with black buds makes interesting winter contrast.
Summit Green Ash	*Fraxinus pennsylvanica* 'Summit'	45	20	D	M	3-8	N	P/C; LR/C	Y	Upright habit, pyramidal in shape, glossy summer foliage, yellow fall color.
Magyar Maidenhair tree	*Ginkgo biloba* 'Magyar'	50	30	D	S-M	4-8	N	P/C; LR/C	Y	True, sterile male clone, excellent yellow fall color.
Fairmount Maidenhair tree	*Ginkgo biloba* 'Fairmount'	70	30	D	S-M	4-8	N	P/C; LR/C	Y	Male tree, strongly upright-growing, yellow fall color.

TREE SELECTION LIST

TREE SELECTION LIST

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Princeton Sentry® Maidenhair tree	*Ginkgo biloba* 'PNI 2720'	60	25	D	S-M	4-8	N	P/C; LR/C	Y	Male tree, upright habit, yellow fall color.
Kentucky Coffeetree	*Gymnocladus dioicus*	60	40	D	S-M	3-8	N	P/C; LR/C	Y	Unusual tree with white flowers, good furrowed bark effect, root suckers easily.
Carolina Silverbell	*Halesia tetraptera*	35	25	D	M	4-8	N	P/C; LR/C; SR/C	Y	White flowers dangle from the branches, good in shady sites.
Goldenrain tree	*Koelreuteria paniculata*	35	35	D	M-F	5-8	N	P/C; LR/C; SR/C	Y	Yellow flowers in summer, followed by interesting brown, papery fruits.
Crape Myrtle	*Lagerstroemia indica x L. fauriei*	25	20	D	M	6-8	Y	P/C; LR/C; SR/C; P	Y	Excellent trees for late summer flowers, bark and foliage effect. Usually multi-stemmed, best with some summer water. 'Natchez', 'Tuskarora' and 'Tuskegee' are good growers in PNW.
Yulan Magnolia	*Magnolia denudata*	30	30	D	M	5-8	Y	P/C; LR/C; SR/C	N	Flowers in early spring, flowers are 5-6" across, white, fragrant.
Galaxy Magnolia	*Magnolia* 'Galaxy'	25	25	D	S	5-8	Y	P/C; LR/C; SR/C	NDA	Flowers are red-purple to pink, later than earliest Magnolias to avoid frost.
Edith Bogue Southern Magnolia	*Magnolia grandiflora* 'Edith Bogue'	30	15	E	S-M	6-8	Y	P/C; LR/C; SR/C	NDA	Dark green, narrow leaves, white, very fragrant flowers in summer. Best with supplemental water.
Victoria Southern Magnolia	*Magnolia grandiflora* 'Victoria'	30	30	E	S-M	6-8	Y	P/C; LR/C; SR/C	NDA	Glossy green leaves with brown undersides, fragrant white flowers in summer. PNW selection and good performer locally.
Royal Star Magnolia	*Magnolia stellata* 'Royal Star'	15	20	D	S	4-8	Y	P/C; LR/C; SR/C	Y	Pure white fragrant flowers in early spring.
Leonard Messel Magnolia	*Magnolia x loebneri* 'Leonard Messel'	20	20	D	M	4-8	Y	P/C; LR/C; SR/C	NDA	Fragrant flowers in early spring, flowers are white on inside, pink on the outside.
Merrill Magnolia	*Magnolia x loebneri* 'Merrill'	25	25	D	M	4-8	Y	P/C; LR/C; SR/C	NDA	Fragrant white flowers, heavy flowering.
Alexandrina Saucer Magnolia	*Magnolia x soulangiana* 'Alexandrina'	20	15	D	M	4-8	Y	P/C; LR/C; SR/C	Y	Often multi-stemmed, flowers in early spring, flowers are purple outside, white inside.
Rustica Rubra Saucer Magnolia	*Magnolia x soulangiana* 'Rustica Rubra'	20	20	D	M	4-8	Y	P/C; LR/C; SR/C	Y	Often multi-stemmed, flowers in early spring, flowers are rose-red outside, white inside.

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Common Name	Botanical Name	Height (feet)	Spread (feet)	Evergreen Deciduous	Growth Rate	USDA Zone	Suitable Under Powerline	Planting Location	Solar Friendly	Comments
Prairifire Crabapple	*Malus* 'Prairifire'	20	20	D	M	4-8	Y	P/C; LR/C; SR/C	Y	Rounded habit, new growth is reddish-green, flowers and fruit are dark purplish-red.
Red Baron Crabapple	*Malus* 'Red Baron'	18	8	D	M	4-8	Y	P/C; LR/C; SR/C	Y	Narrow, columnar shape, purple-bronze foliage, red to pink flowers, good disease resistance.
Red Jewel™ Crabapple	*Malus* 'Jewelcole'	15	12	D	M	4-8	Y	P/C; LR/C; SR/C	N	Upright, pyramidal form, flowers are white, fruit are red, fruit persists very late.
Sentinel Crabapple	*Malus* 'Sentinel'	20	12	D	M	4-8	Y	P/C; LR/C; SR/C	NDA	Narrow, upright shape, dark green glossy leaves, pale pink flowers, red fruit, good to excellent disease resistance.
Spring Snow Crabapple	*Malus* 'Spring Snow'	20-25	15-20	D	M	4-8	Y	P/C; LR/C; SR/C;P	NDA	Upright, oval tree, white flowers, considered fruitless or nearly fruitless. May be susceptible to scab.
Sentinel Crabapple	*Malus* 'Sentinel'	20	12	D	M	4-8	Y	P/C; LR/C; SR/C	NDA	Narrow, upright shape, dark green glossy leaves, pale pink flowers, red fruit, good to excellent disease resistance.
Black Gum	*Nyssa sylvatica*	30-50	20-30	D	S	3-9	N	P/C; LR/C	Y	Specimen tree, superb red fall color, abundant fruit production, street tree when adequate space.
Sourwood	*Oxydendrum arboreum*	30-40	20	D	S	5-9	N	P/C; LR/C; SR/C	Y	A narrow, graceful tree with pendulous lily-of-the-valley-like midsummer flowers and brilliant red fall color. Best with supplemental summer water.
Persian parrotia	*Parrotia persica*	20-40	15-30	D	M	5-8	Y	P/C; LR/C; SR/C	N	Oval crown, sometimes multi-branched tree has beautiful exfoliating bark and excellent fall color. Hardy and pest resistant, but requires good drainage.
Amur Corktree	*Phellodendron amurense*	30-45	30-45	D	M	3-8	N	P/C	Y	Suitable in parks & large areas, resistant to pests.
Ornamental Cherry	*Prunus serrulata*	15-40	15-40	D	M	4-8	---	---	---	Numerous cultivars available. Select carefully for disease and insect resistance.
Chanticleer Flowering Pear	*Pyrus calleryana* 'Chanticleer'	30-50	20-35	D	M	4-8	N	P/C; LR/C	N	Similar to 'Bradford' but more narrow; good for narrow spaces.
Redspire Pear	*Pyrus calleryana* 'Redspire'	30-50	20-35	D	M	4-8	N	P/C; LR/C	N	Small to medium sized tree of upright form; brilliant white flowers and attractive fall color. Superior branching habit to the storm-breakage prone Bradford pear.
Scarlet Oak	*Quercus coccinea*	75	50	D	S	4-8	N	P/C	Y	Glossy dark green foliage, reddish fall color, tan-colored leaves persist on tree in winter.

TREE SELECTION LIST

TREE SELECTION LIST

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Bur Oak	*Quercus macrocarpa*	70-80	70-80	D	S	3-8	N	P/C	N	Excellent tree for large areas, dark green leaves, yellowish fall color, interesting, fringed acorns.
Pin oak	*Quercus palustris*	60-70	30-40	D	M	4-7	N	P/C	N	Distinctive leaves and pyramidal habit, fall color is variable, very intolerant of high pH soil.
Fastigiate English Oak	*Quercus robur* 'Fastigiata'	50-60	10-15	D	S	4-8	N	P/C	N	Upright & columnar form, dark green leaves, no fall color.
Skymaster™ English Oak	*Quercus robur* 'Pyramich'	50	25	D	S	4-8	N	P/C	N	Narrow habit when young, becomes pyramidal with age, dark green leaves, no fall color.
Red Oak	*Quercus rubra*	60-75	40-50	D	F	4-8	N	P/C	N	Excellent fast growing oak for large spaces. Excellent fall color.
Purple Robe Black Locust	*Robinia pseudoacacia* 'Purple Robe'	30-40	30-40	D	M	5-8	Y	P/C; LR/C; SR/C; P	NDA	Compact round form; new foliage is bronze, dark rose-pink flowers.
Korean Mountainash	*Sorbus alnifolia*	40-50	20-30	D	M	4	N	P/C; LR/C	Y	Fruit can be messy; suited for parks, commercial sites.
Japanese Stewartia	*Stewartia pseudocamellia*	20-40	20-30	D	S	5-7	Y	P/C; LR/C; SR/C; P	Y	Outstanding small specimen tree, excellent bark effect, pretty white flowers, best in an irrigated site.
Japanese Snowbell	*Styrax japonicus*	20-30	20-30	D	M	5-8	Y	P/C; LR/C; SR/C; P	Y	Small, graceful tree, rounded crown, white spring flowers.
Ivory Silk Japanese Tree Lilac	*Syringa reticulata* 'Ivory Silk'	20-30	15-20	D	M	3-7	Y	P/C; LR/C; SR/C; P	Y	Trouble-free plant, deep green leaves, very showy white flowers, excellent specimen or street tree, looks good when massed.
Littleleaf Linden	*Tilia cordata*	40-50	25-40	D	F	3-7	N	P/C	Y	Select from cultivars: 'Chancellor', 'DeGroot', 'Glenleven' and 'Greenspire'. Each has slightly different characteristics, growth habit.
Crimean Linden	*Tilia x euchlora*	40-60	20-30	D	M	3-7	N	P/C	Y	Graceful tree with glossy dark green leaves, tolerant of urban conditions and dry soil. May sucker if grafted.
Sterling Silver® Linden	*Tilia tomentosa* 'PP6511'	45	20-25	D	M	4-7	N	P/C	N	Impressive pyramidal specimen. Dark green leaves above, silver underside, and grayish bark.
Lacebark elm; Chinese elm	*Ulmus parvifolia*	40-50	40	D	MF	5-9	N	P/C	N	Suitable to tough sites, and is resistant to Dutch elm disease and elm leaf beetle; attractive bark and form.

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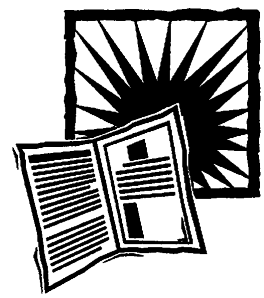
Allee® Elm	*Ulmus parvifolia* 'Emer II'	70	60	D	M	5-9	N	P/C	N	Upright, spreading tree, attractive exfoliating bark, glossy green leaves, yellowish fall color. Drought tolerant; resistant to Dutch elm disease.
Athena® Elm	*Ulmus parvifolia* 'Emer I'	40	55	D	M	5-9	N	P/C	N	Broad spreading tree, attractive exfoliating bark, dark green, leathery leaves, drought-tolerant and resistant to Dutch elm disease.
Green Vase Zelkova	*Zelkova serrata* 'Green Vase'	50-80	50-80	D	MF	5-8	N	P/C	Y	Vase-shaped with upright branches, very vigorous, dark green leaves, bronzy-red fall color.
Village Green Zelkova	*Zelkova serrata* 'Village Green'	50-80	50-80	D	MF	5-8	N	P/C	Y	Large tree with smooth straight trunk, dark green leaves turn rusty-red in fall, resistant to Dutch elm disease.

TREE SELECTION LIST

6. References



American Forests. 1998. **Regional Ecosystem Analysis Puget Sound Metropolitan Area.** Washington, D.C.: American Forests.

American Forests. 2001. **Regional Ecosystem Analysis for the Willamette/Lower Columbia Region of Northwestern Oregon and Southwestern Washington State.** Washington, D.C.: American Forests.

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

Ames, M.J. 1987. **Solar Friendly Trees Report.** Portland, Oregon: City of Portland Energy Office.

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

Barnack, A. 2001. **Personal communication on December 10.** Oregon Dept. of Environmental Quality, OR.

Benjamin, M.T.; Sudol, M.; Bloch, L.; Winer, A.M. 1996. **Low-emitting urban forests: a taxonomic methodology for assigning isoprene and monoterpene emission rates.** Atmos. Environ. 30:1437-1452.

Bernhardt, E.; Swiecki, T.J. 1993. **The State of Urban Forestry in California: Results of the 1992 California Urban Forest Survey.** Sacramento: California Department of Forestry and Fire Protection. 51 p.

Brenzel, K.N., (Ed.). 1997. **Sunset Western Garden Book.** Fifth Edition. Menlo Park, CA: Sunset Books Inc.

Brusca, J. 1998. **Personal communication on November 17.** Streets Superintendent, City of Modesto, CA.

California Air Resources Board. 1999. Compact disk TSD-98-010-CD.

California Energy Commission. 1994. **Electricity Report**, State of California, Energy Commission, Sacramento, CA.

City of Olympia. 1995. **Impervious Surface Reduction Study, Final Report.** City of Olympia, WA, Public Works Department, Water Resources Department. 207 pp.

Costello, L.R. 2000. **Training Young Trees for Structure and Form.** Videotape Number: V99-A. University of California, Agriculture and Natural Resources, Communication Services Cooperative Extension Service, Oakland, CA. (Telephone: 800-994-8849).

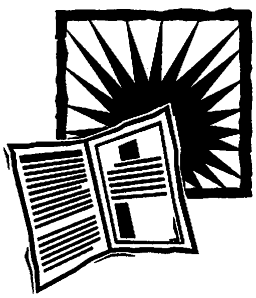
Costello, L.R.; McPherson, E.G.; Burger, D.W.; Dodge, L.L. (Eds.). 2000. **Strategies to Reduce Infrastructure Damage by Tree Roots: Proceedings of a Symposium for Researchers and Practitioners.** International Society of Arboriculture, Western Chapter, Cohasset, CA.

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

Dwyer, M.C.; Miller, R.W. 1999. **Using GIS to assess urban tree canopy benefits and surrounding greenspace distributions.** J. Arboric. 25(2):102-107.

Friends of Trees. 1995. **Tree Planting Potential Study and Five Year Planting and Education Plan.** Portland, OR: Friends of Trees.

Guenther, A. B.; Monson, R.K.; Fall, R. 1991. **Isoprene and monoterpene emission rate variability: observations with eucalyptus and emission rate algorithm development.** Journal of Geophysical Research. 96: 10799-10808.



Guenther, A. B.; Zimmermann, P.R.; Harley, P.C.; Monson, R.K.; Fall, R. 1993. **Isoprene and monoterpene emission rate variability: model evaluations and sensitivity analyses.** Journal of Geophysical Research. 98:12609-12617.

Hammer, T.T.; Coughlin, R.; Horn, E. 1974. **The effect of a large urban park on real estate value.** Journal of the American Institute of Planning. July:274-275.

Harris, R.W.; Clark, J.R.; Matheny, N.P. 1999. **Arboriculture.** 3rd ed. Englewood Cliffs, NJ: Regents/Prentice Hall.

Head, C.P.; Fisher, R.; O'Brien, M. 2001. **Best Management Practices for Community Trees: A Technical Guide to Tree Conservation in Athens-Clarke County, Georgia.** Landscape Management Division Office, Athens, GA.

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

Herrera Environmental Consultants, Inc. 2001. **Cost Analysis: Washington Department of Ecology Year 2001 Minimum Requirements for Stormwater Management 2001.** Seattle, WA.

Hildebrandt, E.W.; Kallett, R.; Sarkovich, M.; Sequest, R. 1996. **Maximizing the energy benefits of urban forestation.** In Proceedings of the ACEEE 1996 summer study on energy efficiency in buildings, volume 9; Washington DC: American Council for an Energy Efficient Economy. 121-131.

Hudson, B. 1983. **Private sector business analogies applied in urban forestry.** J. Arboric. 9(10):253-258.

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

Hydrosphere Data Products. 2001. **Hydrosphere Environmental Database: NCDC Summary of daily values.** Hydrosphere Data Products Inc., Boulder, CO.

ISA. 1992. **Avoiding tree and utility conflicts.** Savoy, IL: International Society of Arboriculture. 4 p.

Johnson, D. 2002. **Personal communication on January 7.** Portland General Electric Comany. Portland, OR.

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

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

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

Maco, S.E. 2001. **A practical approach to assessing structure, function, and value of street tree populations in small communities.** MS Thesis, University of California, Davis.

Marion, W.; Urban, K. 1995. **User's manual for TMY2s – typical meteorological years.** National Renewable Energy Laboratory, Golden, CO.

Markwardt, L.J. 1930. **Comparative Strength Properties of Woods Grown in the United States.** Tech. Bull. No. 158. Washington, D.C.; United States Department of Agriculture.

McPherson, E.G. 1992. **Accounting for benefits and costs of urban greenspace.** Landscape and Urban Planning. 22: 41-51.

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

McPherson, E.G.; Sacamano, P.L.; Wensman, S. 1993. **Modeling Benefits and Costs of Community Tree Plantings.** Davis, CA: USDA Forest Service, Pacific Southwest Research Station. 170 p.

McPherson, E.G. 1994. **Using urban forests for energy efficiency and carbon storage.** Journal of Forestry 92(10): 36-41.

McPherson, E.G. 1995. **Net benefits of healthy and productive forests**, pp. 180-194. In Bradley, G.A. (Ed.). 1995. Urban forest landscapes: Integrating multidisciplinary perspectives. University of Washington press, Seattle, WA.

McPherson, E.G.; Peper; P.J. 1995. **Infrastructure repair costs associated with street trees in 15 cities**, pp. 49-63. in Watson, G.W. and D. Neely (Eds.). Trees and Building Sites. International Society of Arboriculture, Champaign, Ill.

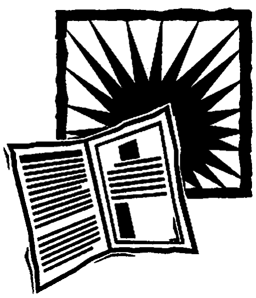
McPherson, E.G. 1996. **Urban forest landscapes, how greenery saves greenbacks.** In Wagner, C., ed. 1996 Annual Meeting Proceedings, American Society of Landscape Architects. Washington, DC: ASLA; 27-29.

McPherson, E.G. 1998. **Atmospheric carbon dioxide reduction by Sacramento's urban forest.** Journal of Arboriculture. 24(4): 215-223.

McPherson, E.G. 2000. **Expenditures associated with conflicts between street tree root growth and hardscape in California.** Journal of Arboriculture. 26(6): 289-297.

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

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



McPherson, E.G.; Simpson, J.R.; Peper, P.J.; Xiao, Q. 1999a. **Tree Guidelines for San Joaquin Valley Communities.** Local Government Commission: Sacramento, CA. 63 p.

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

McPherson, E.G.; Simpson, J.R.; Peper, P.J.; Scott, K.; Xiao, Q. 2000. **Tree Guidelines for Coastal Southern California Communities.** Local Government Commission: Sacramento, CA. 97 p.

Mead, M. 2001. **Personal communication on October 23.** Department of Parks and Recreation, City of Seattle, WA.

Miller, R.W. 1997. **Urban Forestry: Planning and Managing Urban Greenspaces.** Second Edition. Upper Saddle River: Prentice-Hall. 502 p.

More, T.A.; Stevens, T; Allen, P.G. 1988. **Valuation of urban parks.** Landscape and Urban Planning. 15:139-52.

Natural Resources Conservation Service (NRCS). 1986. **Urban Hydrology for Small Watersheds, Technical Release 55, 2nd Ed.** United States Department of Agriculture.

Neely, D. (Ed.) 1988. **Valuation of Landscape Trees, Shrubs, and Other Plants.** Seventh Edition. Urbana, IL: International Society of Arboriculture. 50 p.

Northwest MLS (Alliance Communications). 2001. **Year 2000 Summary Data.** Contact: C. Brennan.

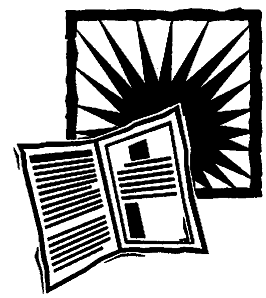
NW Natural. 2001. **Schedule 2: Residential Sales Service.** Accessed through the World Wide Web: <http://www.nwnatural.com/about/rates/rates_tariffs/history_weighted_average.asp> on November 13, 2001.

Oregon Public Utility Commission. 1993. **Before the Public Utility Commission of Oregon in the Matter of the Development of Guidelines for the Treatment of External Environmental Costs.** Order 93-695. Portland, OR.

Ottinger, R.L.; Wooley, D.R.; Robinson, N.A.; Hodas, D.R.; Babb, S.E. 1990. **Environmental Costs of Electricity.** Pace University Center for Environmental Legal Studies, Oceana Publications, Inc. New York.

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

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



Platt, R.H.; Rowntree, R.A.; Muick, P.C., (Eds). 1994. **The Ecological City.** Boston, MA: University of Massachusetts. 292 p.

Portland General Electric Company. 2001. **Schedule 7: Residential Service.** PUC Oregon No. E-17.

Portland Water District. 2001. **Water Rates for Members.** Accessed via the World Wide Web: <http://www.pwd.org/customer_service/Newmay_rates.html#Water Rates for Members> on November 10, 2001.

Puget Sound Energy. 2001a. **Electric Tariff G: Schedule 7 residential service.** Twenty-first revised sheet no. 7.

Puget Sound Energy. 2001b. **Summary of total current prices: residential rate schedules.**

Rain Bird. 1998. **Landscape Irrigation: Design Manual.** Rain Bird International, Inc. Glendora, CA.

Richards, N.A. 1983. **Diversity and stability in a street tree population.** Urban Ecology, 7:159-171.

Richards, N.A.; Mallette, J.R.; Simpson, R.J.; Macie, E.A. 1984. **Residential greenspace and vegetation in a mature city: Syracuse, New York.** Urban Ecology, 8:99-125.

RMLS Multiple Listing Service. 2000. **Market Action: Area Report**, **December 2000.** Portland, OR.

Sand, M. 1991. **Planting for energy conservation in the north.** Minneapolis: Department of Natural Resources: State of Minnesota. 19 p.

Sand, M. 1993. **Energy conservation through community forestry.** St. Paul: University of Minnesota. 40 p.

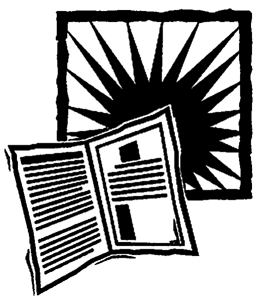
Sand, M. 1994. **Design and species selection to reduce urban heat island and conserve energy.** In Proceedings from the sixth national urban forest conference: growing greener communities. Minneapolis, Minnesota: Sept. 14-18, 1993. Washington DC: American Forests. 282.

Schroeder, T. 1982. **The relationship of local park and recreation services to residential property values.** Journal of Leisure Research. 14: 223-234.

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

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

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



Seattle City Light. 2001. **Electric Rates and Provisions.** Accessed via the World Wide Web: <http://www.ci.seattle.wa.us/light/accounts/rates/ac5_rt2k4.htm> on November 29, 2001.

Simpson, J.R.; McPherson, E.G. 1996. **Potential of tree shade for reducing residential energy use in California.** Journal of Arboriculture. 22(1): 10-18.

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

State of Washington. 2001. **2001 Population Trends for Washington State.** Office of Financial Management, State of Washington.

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

Summit, J.; McPherson, E.G. 1998. **Residential tree planting and care: a study of attitudes and behavior in Sacramento, California.** Journal of Arboriculture. 24(2): 89-97.

Tacoma Public Utilities. 2001. **Electricity Rate Schedules.** Accessed via the World Wide Web: <http://www.ci.tacoma.wa.us/power/rates/rates.htm> on November 21, 2001.

Taha, H. 1996. **Modeling impacts of increased urban vegetation on ozone air quality in the South Coast Air Basin.** Atmospheric Environment. 30: 3423-3420.

Thompson, R.P.; Ahern, J.J. 2000. **The State of Urban and Community Forestry in California.** Urban Forest Ecosystems Institute, California Polytechnic State University, San Luis Obispo, CA.

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

Tschantz, B.A.; Sacamano, P.L. 1994. **Municipal Tree Management in the United States.** Davey Resource Group, Kent, OH.

Tyrvainen, L. 1999. **Monetary Valuation of Urban Forest Amenities in Finland.** Vantaa, Finland: Finnish Forest Research Institute, Research paper 739. 129 p.

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

U.S. Census Bureau. 2001. **2000 census of population and housing, Oregon: Profiles of general demographic characteristics.** U.S. Department of Commerce.

U.S. Environmental Protection Agency. 1998. **Ap-42 Compilation of Air Pollutant Emission Factors** (Fifth Edition). Volume I. Research Triangle Park, NC.

U.S. Environmental Protection Agency. 2001. **E-GRID** (E-GRID2000 Edition).

Wang, M.Q.; Santini, D.J. 1995. **Monetary values of air pollutant emissions in various U.S. regions.** Transportation Research Record 1475.

Watson, G.W.; Himelick, E.B. 1997. **Principles and practice of planting trees and shrubs.** Savoy, IL: International Society of Arboriculture. 199 p.

Winer, A.M.; Karlik, J.; Arey, J.,;Chung, Y.J.; A. Reissell. 1998. **Biogenic Hydrocarbon Inventories for California: Generation of Essential Databases.** Final Report, California Air Resources Board Contract No. 95-309.

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

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

Xiao, Q.; McPherson, E.G.; Simpson, J.R.; Ustin, S.L. 2000. **Winter rainfall interception by two mature open grown trees in Davis, California.** Hydrological Processes 14(4): 763-784.

7. Glossary of Terms

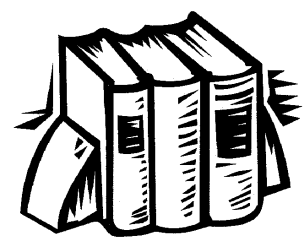
AFUE (Annual Fuel Utilization Efficiency): A measure of space heating equipment efficiency defined as the fraction of energy output/energy input.

Anthropogenic: Produced by humans.

Avoided Power Plant Emissions: Reduced emissions of CO_2 or other pollutants that result from reductions in building energy use due to the moderating effect of trees on climate. Reduced energy use for heating and cooling result in reduced demand for electrical energy, which translates into fewer emissions by power plants.

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 a combination of these elements.

Biogenic: Produced by living organisms.



BVOCs (Biogenic Volatile Organic Compounds): Hydrocarbon compounds from vegetation (e.g. isoprene, monoterpene) that exist in the ambient air and contribute to the formation of smog and/or may themselves be toxic. Emission rates (ug/g/hr) used for this guide follow Winer et al.1998:

- *Quercus rubrum* - 4.72 (Isoprene); 0.68 (Monoprene); 0.20 (Other)
- *Acer platanoides* - 0.00 (Isoprene); 1.05 (Monoprene); 0.32 (Other)
- *Prunus cerasifera* - 0.00 (Isoprene); 0.04 (Monoprene); 0.04 (Other)

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

Cities for Climate Protection TM Campaign: Cities for Climate Protection Campaign (CCP), begun in 1993, is a global campaign to reduce the emissions that cause global warming and air pollution. By 1999, the campaign had engaged in this effort more than 350 local governments, who jointly accounted for approximately 7% of global greenhouse gas emissions.

Climate: The average weather (usually taken over a 30-year time period) for a particular region and time period. Climate is not the same as weather, but rather, it is the average pattern of weather for a particular region. Weather describes the short-term state of the atmosphere. Climatic elements include precipitation, temperature, humidity, sunshine, wind velocity, phenomena such as fog, frost, and hail storms, and other measures of the weather.

Climate Change (also referred to as "global climate change"): The term 'climate change' is sometimes used to refer to all forms of climatic inconsistency, but because the earth's climate is never static, the term is more properly used to imply a significant change from one climatic condition to another. In some cases, 'climate change' has been used synonymously with the term, 'global warming'; scientists, however, tend to use the term in the wider sense to also include natural changes in the climate.

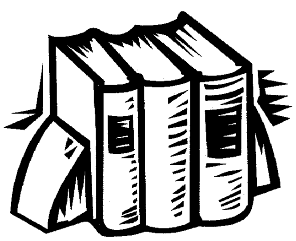
Climate Effects: Impact on residential space heating and cooling (kg CO_2/tree/year) from trees located greater than 15 m (50 ft) from a building due to associated reductions in wind speeds and summer air temperatures.

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 using best available control technologies.

Crown: The branches and foliage at the top of a tree.

Cultivar (derived from "*culti*vated *var*iety"): Denotes certain cultivated plants that are clearly distinguishable from others by any characteristic and that when reproduced (sexually or asexually) retain their distinguishing characters. 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 (DBH): Tree DBH is outside bark diameter at breast height. Breast height is defined as 4.5 feet (1.37m) above ground-line on the uphill side (where applicable) of the tree.

Emission Factor: A rate of CO_2, NO_2, SO_2 and 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 of time. Evapotranspiration calculations used the following equation: $ET=(K_c) \times (PET)$; where, Kc is the crop coefficient or plant factor and equals $(K_{species}) \times (K_{density}) \times (K_{microclimate})$; PET is the average evapotranspiration during the peak irrigation period of the year (Akbari et al. 1992; Rain Bird 1998).

Evergreen: Trees or shrubs that are never entirely leafless. Evergreen trees may be broadleaved or coniferous (cone-bearing with needle-like leaves).

Fossil Fuel: A general term for combustible geologic deposits of carbon in reduced (organic) form and of biological origin, including coal, oil, natural gas, oil shales, and tar sands. A major concern is that they emit carbon dioxide into the atmosphere when burnt, thus significantly contributing to the enhanced greenhouse effect.

Global Warming: An increase in the near surface temperature of the Earth. Global warming has occurred in the distant past as a result of natural influences, but the term is most often used to refer to the warming predicted to occur as a result of increased emissions of greenhouse gases.

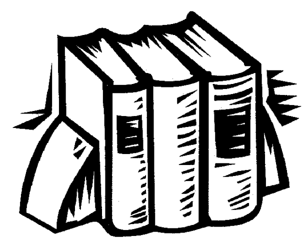
Greenspace: Urban trees, forests, and associated vegetation in and around human settlements, ranging from small communities in rural settings to metropolitan regions.

Heat Sinks: Paving, buildings, and other built surfaces that store heat energy from the sun.

Hourly Pollutant Dry Deposition: Removal of gases from the atmosphere by direct transfer to and absorption of gases and particles by natural surfaces such as vegetation, soil, water or snow.

Initial Abstraction: Rainfall that is caught and held prior to initiation of runoff. Two components are interception (rainfall caught in plant leaf canopies and evaporated before falling to the ground) and depression storage (stormwater held in surface depressions until it evaporates or infiltrates).

Interception: Amount of 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.

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

Leaf Surface Area (LSA): Measurement of area of one side of leaf or leaves.

Leaf Area Index (LAI): Total leaf area per unit crown projection area.

Mature Tree: A tree that has reached a desired size or age for its intended use. Size, age, or economic maturity varies depending on the species, location, growing conditions, and intended use.

Mature Tree Size: The approximate tree size 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: A measure of weight (abbreviate "tonne") equal to 1,000,000 grams (1,000 kilograms) or 2,205 pounds.

MJ: A unit of work or energy, measured as 1,000,000 Joules.

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 one hour. One MWh is equivalent to 3.412 Mbtu.

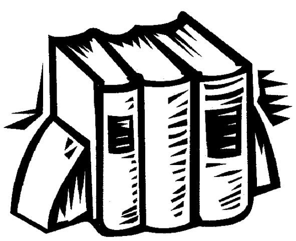
Nitrogen Oxides (Oxides of Nitrogen, NOx): A general term pertaining to compounds of nitric acid (NO), nitrogen dioxide (NO_2), and other oxides of nitrogen. Nitrogen oxides are typically created during combustion processes, and are major contributors to smog formation and acid deposition. NO_2 may result in numerous adverse health effects.

Ozone: 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 atmosphere ozone layer 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 Cooling Demand: The single greatest amount of electricity required at any one time during the course of a year to meet space cooling requirements.

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 carbon dioxide into sugar with 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 inches or less) allows them to enter the air sacs (gas exchange region) deep in the lungs where they may get deposited and result in adverse health effects. PM_{10} also causes visibility reduction.

Resource Unit (Res Unit): The value used to determine and calculate benefits and costs of individual trees. For example, the amount of air conditioning energy saved in kWh/yr/tree, air pollutant uptake in pounds/yr/tree, or rainfall intercepted in gallons/yr/tree.

Riparian Habitats: Narrow strips of land bordering creeks, rivers, lakes, or other bodies of water.

SEER (Seasonal Energy Efficiency Ratio): Ratio of cooling output to power consumption; kBtu-output/kWh-input as a fraction. It is the Btu of cooling output during its normal annual usage divided by the total electric energy input in watt-hours during the same period.

Sequestration: Annual net rate that a tree removes CO_2 from the atmosphere through the processes of photosynthesis and respiration (kg CO_2/tree/year).

Shade Coefficient: The percentage of light striking a tree crown that is transmitted through gaps in the crown.

Shade Effects: Impact on residential space heating and cooling (kg CO_2/tree/year) from trees located within 15 m (50 ft) of a building so as to directly shade the building.

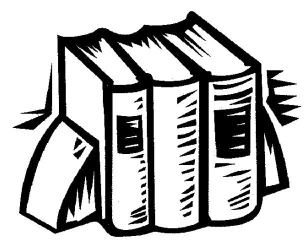
Shade Tree Program: Engaged activities, such as tree planting and stewardship, with the express intent of achieving energy savings and net atmospheric CO_2 reductions.

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, early to drop leaves and late to leaf out, relatively small size, and a slow growth rate (Ames 1987).

SO_2 (Sulfur Dioxide): A strong smelling, colorless gas that is formed by the combustion of fossil fuels. Power plants, 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.

Stem Flow: Amount of rainfall that travels down the tree trunk and onto the ground.

Throughfall: Amount of rainfall that falls directly to the surface below the tree crown or drips onto the surface from branches and leaves.



Transpiration: The loss of water vapor through the stomata of leaves.

Tree or Canopy Cover: The percent of a fixed area covered by the crown of an individual tree or delimited by the vertical projection of its outermost perimeter; small openings in the crown are included. 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 releases that result from activities involved with growing, planting, and caring for program trees.

Tree Height: Total height of tree from base (at groundline) to tree top.

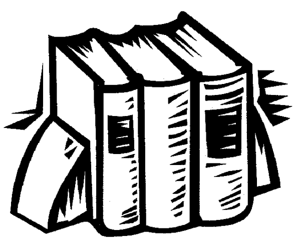
Tree Surface Saturation Storage (or Tree Surface Detention Storage): The volume of water required to fill the tree surface to its overflow level. This part of rainfall stored on the canopy surface does not contribute to surface runoff during and after a rainfall event.

Urban Canyon: A streetscape that is defined spatially by tall buildings so as to create a canyon-like effect.

Urban Heat Island: An "urban heat island" is 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: ❶ they use dark construction materials which absorb solar energy, ❷ they have few trees, shrubs or other vegetation to provide shade and cool the air.

VOCs (Volatile Organic Compounds): Hydrocarbon compounds that exist in the ambient air. VOCs contribute to the formation of smog and/or are 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, for non-market, public goods such as an environmental amenity.



Appendix A.
Benefit-Cost Information Tables

Information in this Appendix can be used to estimate benefits and costs associated with proposed or existing tree programs. The three tables contain data for the small (purple-leaf plum), medium (Norway maple), and large (red oak) trees. Data are presented as annual values for each five-year interval after planting.

There are two columns for each five-year interval. In the first column, values describe resource units (Res units): the amount of air conditioning energy saved in kWh/yr/tree, air pollutant uptake in pounds/yr/tree, rainfall intercepted in gallons/yr/tree. These values reflect the assumption that 23.4% of all trees planted will die over 40 years. Energy and CO_2 benefits for residential yard trees (private) are broken out by tree location to show how shading impacts vary among trees opposite west-, south-, and east-facing building walls. In the Aesthetics and Other Benefits row, the dollar value for private trees replaces values in resource units since there is no resource unit for this type of benefit. For the remaining rows, the first column contains dollar values for private trees.

The second column, for each five-year interval, contains dollar values obtained by multiplying resource units by local prices (e.g., kWh saved [Res unit] x $/kWh). In the Aesthetics and Other Benefits row, and all subsequent rows, the dollar values are for a public tree (street/park).

Costs for the private and public tree do not vary by location. Although tree and planting costs are assumed to occur initially at year one, we divided this value by five years to derive an average annual cost for the first five-year period. All other costs, as well as benefits, are the estimated values for each year and not values averaged over five years.

Total net benefits are calculated by subtracting total costs from total benefits. Data are presented for a private tree opposite west-, south-, and east-facing walls, as well as the public tree.

The last two columns in each table present 40-year average values. These numbers were calculated by dividing the total stream of annual costs and benefits (not shown due to lack of space) by 40 years.

DATA TABLE FOR SMALL TREE (PURPLE-LEAF PLUM)

SMALL TREE	Year 5		Year 10		Year 15		Year 20		Year 25		Year 30		Year 35		Year 40		40 year average	
Benefits	Res units	$	Res units	$	Res units	$	Res units	$	Res units	$	Res units	$	Res units	$	Res units	$	Res units	$
Cooling (kWh)																		
Private: West	4	0.26	24	1.52	47	2.98	62	3.89	70	4.39	75	4.74	79	4.96	81	5.10	55	$3.48
Private: South	2	0.13	12	0.74	24	1.48	32	1.99	37	2.31	40	2.55	43	2.71	45	2.82	29	$1.84
Prvate: East	1	0.09	8	0.51	16	1.03	23	1.42	27	1.69	30	1.89	32	2.03	34	2.13	21	$1.35
Public	0	0.02	2	0.12	5	0.29	8	0.48	10	0.66	13	0.80	15	0.92	16	1.00	9	$0.54
Heating (kBtu)																		
Private: West	-39	-0.36	-126	-1.16	-151	-1.38	-150	-1.38	-141	-1.29	-128	-1.18	-116	-1.07	-106	-0.97	-120	-$1.10
Private: South	-80	-0.73	-265	-2.43	-339	-3.11	-368	-3.37	-376	-3.45	-375	-3.43	-369	-3.38	-360	-3.30	-317	-$2.90
Prvate: East	-65	-0.60	-216	-1.98	-272	-2.49	-290	-2.66	-292	-2.67	-286	-2.62	-278	-2.55	-269	-2.46	-246	-$2.25
Public	3	0.03	19	0.18	47	0.43	77	0.71	106	0.97	129	1.18	148	1.35	161	1.47	86	$0.79
Net Energy (kBtu)																		
Private: West	3	-0.10	116	0.37	323	1.60	468	2.51	557	3.10	624	3.56	672	3.90	704	4.13	433	$2.38
Private: South	-59	-0.60	-148	-1.69	-104	-1.63	-52	-1.38	-9	-1.14	30	-0.89	62	-0.67	87	-0.49	-24	-$1.06
Prvate: East	-52	-0.51	-135	-1.47	-108	-1.46	-64	-1.24	-24	-0.99	14	-0.74	45	-0.52	69	-0.34	-32	-$0.91
Public	6	0.05	38	0.30	93	0.72	153	1.19	210	1.63	257	1.99	293	2.27	319	2.47	171	$1.33
Net CO2 (lb)																		
Private: West	-3	-0.04	1	0.01	16	0.25	28	0.42	35	0.53	40	0.61	43	0.65	44	0.66	26	$0.39
Private: South	-10	-0.15	-28	-0.41	-28	-0.42	-25	-0.38	-23	-0.34	-20	-0.31	-19	-0.29	-19	-0.29	-22	-$0.32
Prvate: East	-8	-0.13	-24	-0.36	-25	-0.37	-22	-0.33	-19	-0.29	-17	-0.26	-16	-0.24	-16	-0.24	-18	-$0.28
Public	-0	-0.00	2	0.04	8	0.12	15	0.22	20	0.31	24	0.37	27	0.40	27	0.40	15	$0.23
Air Pollution (lb)																		
O3 uptake	0.016	0.04	0.050	0.12	0.092	0.22	0.134	0.32	0.173	0.42	0.205	0.49	0.230	0.55	0.246	0.59	0.14	$0.34
NO2 uptake+avoided	0.004	0.01	0.019	0.05	0.047	0.11	0.073	0.18	0.096	0.23	0.114	0.27	0.128	0.31	0.138	0.33	0.08	$0.19
SO2 avoided	0.002	0.00	0.014	0.01	0.028	0.03	0.037	0.04	0.043	0.04	0.048	0.05	0.051	0.05	0.053	0.05	0.03	$0.03
PM10 uptake+avoided	0.027	0.07	0.067	0.18	0.111	0.30	0.152	0.41	0.186	0.51	0.211	0.58	0.229	0.62	0.240	0.65	0.15	$0.42
VOC's avoided	-0.000	-0.00	-0.000	-0.00	0.000	0.01	0.001	0.02	0.001	0.03	0.001	0.03	0.001	0.04	0.002	0.04	0.00	$0.02
BVOC's released	-0.000	-0.00	-0.001	-0.01	-0.002	-0.02	-0.004	-0.02	-0.005	-0.03	-0.006	-0.04	-0.007	-0.05	-0.008	-0.05	-0.00	-$0.03
Avoided + net uptake	0.050	0.12	0.148	0.35	0.276	0.66	0.394	0.94	0.494	1.19	0.574	1.39	0.632	1.53	0.670	1.62	0.40	$0.97
Hydrology (gal)																		
Rainfall Interception	6	0.16	47	1.30	107	2.98	169	4.70	225	6.26	270	7.51	304	8.45	325	9.04	182	$5.05
Aesthetics and	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public
Other Benefits	$7.96	$9.38	$9.61	$11.32	$9.78	$11.53	$9.38	$11.06	$8.75	$10.31	$8.01	$9.43	$7.23	$8.52	$6.46	$7.61	$8.40	$9.90
Total Benefits	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public
Private: West	$8.10		$11.64		$15.26		$17.96		$19.82		$21.07		$21.76		$21.90		$17.19	
Private: South	$7.48		$9.15		$11.37		$13.27		$14.71		$15.71		$16.26		$16.34		$13.04	
Prvate: East	$7.60		$9.43		$11.58		$13.46		$14.91		$15.91		$16.46		$16.54		$13.24	
Public		$9.70		$13.30		$16.00		$18.12		$19.68		$20.69		$21.17		$21.15		$17.48
SMALL TREE	Year 5		Year 10		Year 15		Year 20		Year 25		Year 30		Year 35		Year 40		40 year average	
Costs ($/yr/tree)	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public
Tree & Planting	25.00	29.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$3.13	$3.63
Trimming	1.53	2.86	5.08	8.05	4.94	7.82	4.79	7.59	4.65	7.36	4.50	7.13	4.36	6.90	4.21	6.67	$4.34	$6.94
Remove & Dispose	0.11	0.32	0.16	0.84	0.22	1.15	0.28	1.45	0.33	1.73	0.38	1.99	0.43	2.23	0.47	2.45	$0.28	$1.42
Pest & Disease	0.12	0.03	0.19	0.05	0.25	0.06	0.31	0.08	0.35	0.09	0.39	0.10	0.43	0.11	0.45	0.12	$0.29	$0.07
Infrastructure	0.11	0.43	0.17	0.69	0.23	0.93	0.28	1.13	0.33	1.31	0.36	1.46	0.40	1.58	0.42	1.68	$0.27	$1.08
Irrigation	0.05	0.00	0.11	0.00	0.17	0.00	0.24	0.00	0.29	0.00	0.34	0.00	0.38	0.00	0.42	0.00	$0.23	$0.67
Clean-Up	0.11	0.42	0.17	0.68	0.23	0.91	0.28	1.11	0.32	1.29	0.36	1.43	0.39	1.55	0.41	1.65	$0.26	$1.06
Liability & Legal	0.02	0.09	0.04	0.15	0.05	0.20	0.06	0.25	0.07	0.29	0.08	0.32	0.09	0.35	0.09	0.37	$0.06	$0.24
Admin & Other	0.00	0.46	0.00	1.16	0.00	1.23	0.00	1.29	0.00	1.34	0.00	1.38	0.00	1.41	0.00	1.44	$0.00	$1.61
Total Costs	$27.04	$33.68	$5.92	$11.63	$6.09	$12.31	$6.23	$12.90	$6.34	$13.40	$6.42	$13.81	$6.47	$14.14	$6.48	$14.38	$8.86	$16.73
Total Net Benefits																		
Private: West	-$19		$6		$9		$12		$13		$15		$15		$15		$8	
Private: South	-$20		$3		$5		$7		$8		$9		$10		$10		$4	
Prvate: East	-$19		$4		$5		$7		$9		$9		$10		$10		$4	
Public		-$24		$2		$4		$5		$6		$7		$7		$7		$1

DATA TABLE FOR MEDIUM TREE (NORWAY MAPLE)

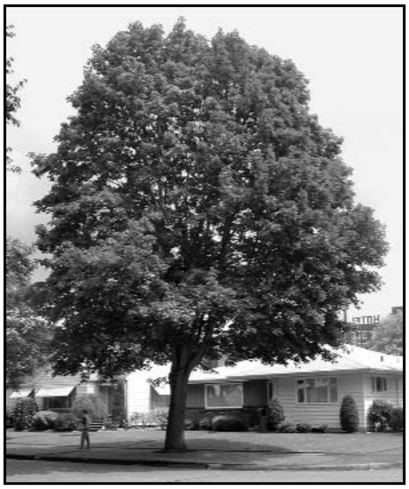
MEDIUM TREE	Year 5		Year 10		Year 15		Year 20		Year 25		Year 30		Year 35		Year 40		40 year average	
Benefits	Res units	$	Res units	$	Res units	$	Res units	$	Res units	$	Res units	$	Res units	$	Res units	$	Res units	$
Cooling (kWh)																		
Private: West	6	0.38	35	2.21	70	4.40	93	5.87	108	6.77	118	7.42	125	7.87	129	8.15	86	$5.38
Private: South	5	0.28	26	1.66	53	3.33	72	4.51	84	5.28	93	5.85	99	6.26	104	6.52	67	$4.21
Prvate: East	3	0.16	15	0.95	31	1.98	44	2.80	54	3.40	62	3.87	67	4.22	71	4.45	43	$2.73
Public	1	0.05	5	0.31	12	0.75	20	1.24	27	1.70	33	2.08	38	2.38	41	2.59	22	$1.39
Heating (kBtu)																		
Private: West	-44	-0.40	-129	-1.18	-121	-1.11	-80	-0.73	-29	-0.27	18	0.17	58	0.53	89	0.81	-30	-$0.27
Private: South	-100	-0.91	-319	-2.93	-380	-3.48	-378	-3.46	-352	-3.22	-319	-2.92	-287	-2.63	-260	-2.38	-299	-$2.74
Prvate: East	-78	-0.72	-246	-2.25	-280	-2.57	-263	-2.41	-227	-2.08	-189	-1.73	-154	-1.41	-125	-1.15	-195	-$1.79
Public	8	0.07	50	0.46	120	1.10	199	1.83	273	2.50	334	3.06	382	3.50	415	3.81	223	$2.04
Net Energy (kBtu)																		
Private: West	17	-0.02	223	1.03	578	3.29	853	5.14	1,046	6.50	1,197	7.59	1,308	8.40	1,383	8.96	826	$5.11
Private: South	-54	-0.63	-56	-1.27	150	-0.15	339	1.05	488	2.06	611	2.93	707	3.62	776	4.14	370	$1.47
Prvate: East	-53	-0.56	-95	-1.30	34	-0.59	182	0.39	313	1.32	427	2.14	516	2.81	582	3.31	238	$0.94
Public	15	0.12	99	0.77	239	1.85	397	3.07	543	4.20	665	5.15	759	5.87	826	6.39	443	$3.43
Net CO2 (lb)																		
Private: West	-2	-0.03	12	0.18	46	0.68	76	1.14	100	1.50	120	1.79	133	2.00	141	2.11	78	$1.17
Private: South	-11	-0.16	-21	-0.31	-3	-0.04	19	0.28	38	0.57	55	0.82	66	1.00	73	1.10	27	$0.41
Prvate: East	-10	-0.14	-20	-0.30	-7	-0.10	12	0.18	31	0.46	47	0.70	58	0.87	65	0.97	22	$0.33
Public	0	0.01	11	0.17	31	0.47	54	0.81	76	1.13	93	1.40	106	1.59	113	1.69	61	$0.91
Air Pollution (lb)																		
O3 uptake	0.024	0.06	0.070	0.17	0.134	0.32	0.212	0.51	0.299	0.72	0.390	0.94	0.482	1.16	0.573	1.37	0.27	$0.65
NO2 uptake+avoided	0.008	0.02	0.037	0.09	0.089	0.21	0.143	0.34	0.195	0.47	0.246	0.59	0.294	0.71	0.337	0.81	0.17	$0.40
SO2 avoided	0.004	0.00	0.025	0.02	0.050	0.05	0.069	0.07	0.082	0.08	0.093	0.09	0.100	0.10	0.104	0.10	0.07	$0.07
PM10 uptake+avoided	0.039	0.11	0.095	0.26	0.165	0.45	0.243	0.66	0.322	0.88	0.403	1.10	0.482	1.31	0.559	1.52	0.29	$0.79
VOC's avoided	-0.000	-0.00	0.000	0.01	0.001	0.04	0.002	0.06	0.003	0.09	0.004	0.10	0.004	0.12	0.005	0.13	0.00	$0.07
BVOC's released	-0.003	-0.02	-0.006	-0.04	-0.009	-0.06	-0.012	-0.08	-0.015	-0.10	-0.018	-0.12	-0.021	-0.14	-0.024	-0.16	-0.01	-$0.09
Avoided + net uptake	0.073	0.17	0.220	0.51	0.431	1.01	0.657	1.56	0.887	2.13	1.117	2.70	1.341	3.25	1.554	3.78	0.78	$1.89
Hydrology (gal)																		
Rainfall Interception	16	0.44	85	2.37	180	4.99	288	8.01	402	11.16	499	13.87	602	16.74	698	19.39	346	$9.62
Aesthetics and	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public
Other Benefits	$23.18	$27.32	$22.17	$26.13	$21.17	$24.95	$20.19	$23.79	$19.21	$22.63	$18.24	$21.49	$17.29	$20.37	$16.35	$19.27	$19.72	$23.24
Total Benefits	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public
Private: West	$23.73		$26.27		$31.15		$36.04		$40.50		$44.19		$47.68		$50.58		$37.52	
Private: South	$22.99		$23.47		$26.99		$31.09		$35.13		$38.56		$41.90		$44.75		$33.11	
Prvate: East	$23.08		$23.45		$26.48		$30.33		$34.28		$37.65		$40.96		$43.79		$32.50	
Public		$28.05		$29.95		$33.27		$37.24		$41.26		$44.61		$47.83		$50.52		$39.09

MEDIUM TREE	Year 5		Year 10		Year 15		Year 20		Year 25		Year 30		Year 35		Year 40		40 year average	
Costs ($/yr/tree)	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public
Tree & Planting	25.00	29.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$3.13	$3.63
Trimming	5.23	8.28	4.98	8.05	4.94	7.82	4.79	7.59	4.65	7.36	10.28	12.82	9.95	12.41	9.62	12.00	$6.59	$9.30
Remove & Dispose	0.20	1.07	0.18	0.98	0.27	1.39	0.34	1.79	0.41	2.18	0.49	2.55	0.56	2.92	0.63	3.28	$0.35	$1.81
Pest & Disease	0.13	0.03	0.22	0.06	0.30	0.08	0.38	0.10	0.44	0.11	0.51	0.13	0.56	0.14	0.61	0.16	$0.36	$0.09
Infrastructure	0.12	0.48	0.20	0.81	0.28	1.12	0.35	1.39	0.41	1.65	0.47	1.87	0.52	2.07	0.56	2.25	$0.36	$1.35
Irrigation	0.17	0.17	0.32	0.00	0.46	0.00	0.60	0.00	0.72	0.00	0.82	0.00	0.92	0.00	1.01	0.00	$0.34	$0.67
Clean-Up	0.12	0.47	0.20	0.80	0.27	1.10	0.34	1.37	0.40	1.62	0.46	1.84	0.51	2.04	0.55	2.21	$0.59	$1.33
Liability & Legal	0.03	0.11	0.04	0.18	0.06	0.25	0.08	0.31	0.09	0.36	0.10	0.41	0.11	0.46	0.12	0.49	$0.33	$0.30
Admin & Other	0.00	1.16	0.00	1.21	0.00	1.30	0.00	1.39	0.00	1.47	0.00	2.18	0.00	2.23	0.00	2.26	$0.07	$1.99
Total Costs	$30.99	$40.83	$6.15	$12.08	$6.58	$13.05	$6.87	$13.94	$7.13	$14.75	$13.13	$21.80	$13.13	$22.26	$13.10	$22.65	$12.13	$20.46
Total Net Benefits																		
Private: West	-$7		$20		$25		$29		$33		$31		$35		$37		$25	
Private: South	-$8		$17		$20		$24		$28		$25		$29		$32		$21	
Prvate: East	-$8		$17		$20		$23		$27		$25		$28		$31		$20	
Public		-$13		$18		$20		$23		$27		$23		$26		$28		$19

DATA TABLE FOR LARGE TREE (RED OAK)

LARGE TREE	Year 5		Year 10		Year 15		Year 20		Year 25		Year 30		Year 35		Year 40		40 year average	
Benefits/tree	Res units	$	Res units	$	Res units	$	Res units	$	Res units	$	Res units	$	Res units	$	Res units	$	Res units	$
Cooling (kWh)																		
Private: West	8	0.48	44	2.80	91	5.70	125	7.85	148	9.32	166	10.45	179	11.25	187	11.78	118	$7.45
Private: South	5	0.30	28	1.78	60	3.75	85	5.38	105	6.62	121	7.59	132	8.31	140	8.80	84	$5.32
Prvate: East	3	0.20	20	1.24	43	2.70	64	4.05	82	5.16	96	6.06	107	6.74	115	7.21	66	$4.17
Public	2	0.10	11	0.67	25	1.60	42	2.66	58	3.64	71	4.46	81	5.09	88	5.54	47	$2.97
Heating (kBtu)																		
Private: West	-38	-0.35	-81	-0.74	3	0.03	133	1.22	267	2.45	384	3.52	477	4.37	546	5.00	211	$1.94
Private: South	-109	-1.00	-325	-2.98	-327	-3.00	-248	-2.27	-145	-1.33	-48	-0.44	35	0.32	100	0.92	-133	-$1.22
Prvate: East	-80	-0.73	-224	-2.05	-190	-1.74	-90	-0.82	25	0.23	131	1.20	218	2.00	285	2.61	10	$0.09
Public	17	0.15	107	0.98	258	2.36	427	3.91	585	5.36	716	6.56	817	7.49	889	8.15	477	$4.37
Net Energy (kBtu)																		
Private: West	38	0.13	364	2.06	909	5.73	1,381	9.08	1,749	11.77	2,043	13.96	2,264	15.61	2,417	16.78	1,396	$9.39
Private: South	-61	-0.70	-42	-1.19	269	0.75	607	3.11	906	5.28	1,158	7.15	1,355	8.63	1,499	9.72	711	$4.09
Prvate: East	-47	-0.53	-27	-0.81	239	0.96	554	3.23	846	5.40	1,094	7.26	1,288	8.73	1,430	9.82	672	$4.26
Public	33	0.25	212	1.64	513	3.97	850	6.57	1,163	9.00	1,424	11.02	1,625	12.57	1,769	13.69	949	$7.34
Net CO2 (lb)																		
Private: West	4	0.06	60	0.90	162	2.42	263	3.95	351	5.27	422	6.34	472	7.08	500	7.50	279	$4.19
Private: South	-8	-0.12	15	0.22	92	1.39	181	2.71	262	3.93	328	4.92	376	5.63	402	6.03	206	$3.09
Prvate: East	-5	-0.08	21	0.32	97	1.46	185	2.77	266	3.99	333	4.99	380	5.70	406	6.10	210	$3.16
Public	6	0.09	58	0.87	143	2.14	236	3.54	321	4.82	390	5.85	439	6.58	466	6.99	257	$3.86
Air Pollution (lb)																		
O3 uptake	0.032	0.08	0.110	0.26	0.220	0.53	0.349	0.84	0.485	1.16	0.618	1.48	0.746	1.79	0.861	2.07	0.43	$1.03
NO2 uptake+avoided	0.013	0.03	0.063	0.15	0.150	0.36	0.244	0.58	0.334	0.80	0.417	1.00	0.491	1.18	0.552	1.33	0.28	$0.68
SO2 avoided	0.005	0.01	0.031	0.03	0.066	0.07	0.096	0.10	0.119	0.12	0.138	0.14	0.151	0.15	0.161	0.16	0.10	$0.10
PM10 uptake+avoided	0.053	0.14	0.150	0.41	0.271	0.74	0.399	1.09	0.523	1.42	0.641	1.75	0.748	2.04	0.844	2.30	0.45	$1.24
VOC's avoided	-0.000	-0.00	0.001	0.00	0.003	0.02	0.005	0.03	0.006	0.04	0.008	0.05	0.009	0.06	0.010	0.06	0.01	$0.03
BVOC's released	-0.004	-0.03	-0.012	-0.08	-0.023	-0.15	-0.034	-0.22	-0.044	-0.29	-0.055	-0.36	-0.064	-0.43	-0.073	-0.49	-0.04	-$0.26
Avoided + net uptake	0.099	0.23	0.343	0.78	0.687	1.56	1.059	2.41	1.422	3.25	1.767	4.06	2.080	4.79	2.355	5.43	1.23	$2.81
Hydrology (gal)																		
Rainfall Interception	14	0.39	109	3.02	265	7.37	449	12.47	636	17.68	816	22.69	978	27.19	1,122	31.17	549	$15.25
Aesthetics and	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public
Other Benefits	$28.27	$33.31	$32.60	$38.42	$35.55	$41.89	$37.27	$43.93	$37.92	$44.69	$37.64	$44.36	$36.57	$43.09	$34.82	$41.03	$35.08	$41.34
Total Benefits	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public
Private: West	$29.08		$39.36		$52.63		$65.18		$75.91		$84.68		$91.24		$95.70		$66.72	
Private: South	$28.07		$35.43		$46.62		$57.97		$68.07		$76.47		$82.81		$87.17		$60.33	
Prvate: East	$28.29		$35.90		$46.90		$58.16		$68.25		$76.64		$82.98		$87.34		$60.56	
Public		$34.28		$44.73		$56.93		$68.92		$79.45		$87.98		$94.22		$98.31		$70.60

LARGE TREE	Year 5		Year 10		Year 15		Year 20		Year 25		Year 30		Year 35		Year 40		40 year average	
Costs ($/yr/tree)	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public
Tree & Planting	25.00	29.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	$3.12	$3.63
Trimming	5.23	8.28	5.08	8.05	4.94	7.82	11.00	13.73	10.68	13.31	10.35	12.90	10.02	12.49	9.69	12.08	$7.78	$10.52
Remove & Dispose	0.26	1.39	0.24	1.26	0.33	1.76	0.42	2.22	0.51	2.66	0.59	3.07	0.66	3.45	0.73	3.80	$0.43	$2.21
Pest & Disease	0.17	0.04	0.28	0.07	0.38	0.10	0.47	0.12	0.54	0.14	0.61	0.16	0.66	0.17	0.70	0.18	$0.45	$0.11
Infrastructure	0.15	0.62	0.26	1.04	0.35	1.41	0.43	1.73	0.50	2.01	0.56	2.25	0.61	2.45	0.65	2.61	$0.41	$1.65
Irrigation	0.18	0.00	0.39	0.00	0.62	0.00	0.86	0.00	1.10	0.00	1.33	0.00	1.55	0.00	1.75	0.00	$0.89	$0.67
Clean-Up	0.15	0.61	0.26	1.02	0.35	1.39	0.43	1.71	0.50	1.98	0.55	2.21	0.60	2.41	0.64	2.56	$0.40	$1.62
Liability & Legal	0.03	0.14	0.06	0.23	0.08	0.31	0.10	0.38	0.11	0.44	0.12	0.50	0.13	0.54	0.14	0.57	$0.09	$0.36
Admin & Other	0.00	1.23	0.00	1.30	0.00	1.42	0.00	2.21	0.00	2.28	0.00	2.34	0.00	2.39	0.00	2.42	$0.00	$2.24
Total Costs	$31.18	$41.36	$6.57	$12.96	$7.05	$14.20	$13.72	$22.10	$13.94	$22.84	$14.11	$23.44	$14.23	$23.90	$14.30	$24.23	$13.57	$23.02
Total Net Benefits																		
Private: West	-$2		$33		$46		$51		$62		$71		$77		$81		$53	
Private: South	-$3		$29		$40		$44		$54		$62		$69		$73		$47	
Prvate: East	-$3		$29		$40		$44		$54		$63		$69		$73		$47	
Public		-$7		$32		$43		$47		$57		$65		$70		$74		$48



The Center for Urban Forest Research

Founded in 1992, the Center for Urban Forest Research is a unit of the USDA Forest Service's Pacific Southwest Research Station. With a small staff of scientists and research associates based in Davis, California, the Center serves the 17 western states and Pacific islands with the mission of increasing urban forest investment and sustainability by improving our understanding of how urban forest structure, function, and value are related.

Research is conducted in four main areas: energy conservation, air quality, stormwater runoff, and firewise landscapes. Results of research in these areas has led to technological advancements to help communities optimize urban forest benefits, training programs for community forest managers, and technical aids to help managers solve local problems and build community capacity. Center products include: a web site, newsletter, fact sheets, research summaries, and community tree guides. For more information about the Center and its products:

(530) 752-7636 ~ http://cufr.ucdavis.edu

The Pacific Northwest Isn't the Only Place Where Trees Are Growing!

The Center for Urban Forest Research, USDA Forest Service, Pacific Southwest Research Station, has also developed versions of this tree guide for the San Joaquin Valley, Southern Coast, and Inland Empire regions of California.

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