Northern Mountain and Prairie Community Tree Guide: Benefits, Costs and Strategic Planting

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The green infrastructure is a significant component of communities in the Northern Mountain and Prairie region

Key Findings

Guide quantifies benefits and costs

This tree guide quantifies benefits and costs for typical large-, medium-, small-stature, deciduous trees, as well as a conifer. The analysis assumed that trees were planted in a residential yard site or a public (street/park) site, under a 40-year time frame, and having a 60% survival rate. Tree care costs were based on findings from a survey of municipal and commercial arborists. Benefits were calculated using tree growth curves and numerical models that considered regional climate, building characteristics, air pollutant concentrations, and prices.

Examples are provided

The results provide a general accounting that can be easily adapted and adjusted for local planting projects. Two examples illustrate how to adjust benefits and costs to reflect different aspects of hypothetical tree planting projects.

Average annual benefits

Average annual benefits increased with mature tree size:

- $14 to $18 for a small tree
- $25 to $30 for a conifer and medium shade tree
- $37 to $43 for a large tree

Average annual costs

Average annual costs for tree planting and care increased with mature tree size:

- $4 to $14 for a small tree
- $5 to $14 for a medium shade tree and conifer
- $7 to $17 for a large tree

Average annual net benefits

Average annual net benefits per computer grown tree for the 40-year period increased with mature tree size. Detailed results are shown in Appendix A:

- $0 to $9 for a small tree
- $8 to $19 for a medium shade tree and large conifer
- $21 to $32 for a large shade tree

Environmental benefits, such as stormwater runoff reduction, air pollutant uptake, and energy savings, were two to four times greater than tree care costs for medium and large trees.

Net benefits summed for 40 years

Net benefits for the residential yard tree opposite a west wall and public street/park tree increased with size when summed over the entire 40-year period:

- $1,280 (yard) and $840 (public) for a large tree
- $720 (yard) and $440 (public) for a conifer
- $760 (yard) and $320 (public) for a medium tree
- $360 (yard) and $0 (public) for a small tree

Yard trees produced higher net benefits than public trees, primarily because of lower maintenance costs.

Benefits associated with property value increase accounted for the largest proportion of total benefits. Rainfall interception, which reduces stormwater runoff, was the second most important benefit, followed by improved air quality and building energy conservation. Energy conservation benefits varied with tree location as well as size. Trees located to shade south-facing walls increased winter heating costs, while trees located opposite west-facing walls provided the greatest net heating and cooling energy savings.

Averaged over the 40-year period, tree pruning was the single greatest cost for public trees ($7-$9/tree/year), while annualized planting and removal costs were greatest for yard trees.

Introduction

From small, rural towns to large, booming cities, there are thousands of communities in the Northern Mountain and Prairie region. With tourism, recreation, and high tech industry joining the economies of agriculture, mining, and ranching, the region is experiencing rapid change. In mountainous areas, forests at the interface of development continue to be an important component of the region'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. In prairie regions the urban forest canopy remains a distinctive feature of the landscape that provides residents protection from the elements and forms a living connection to earlier generations that planted and tended these trees.

1. The Northern Mountain and Prairie region (shaded area) extends from Alaska to Arizona and eastern Washington and Oregon to the Dakotas.

This region extends from Alaska, Northern California, and Western Washington and Oregon on the west to the Dakotas and Nebraska on the east (Figure 1). In the north, it is bounded by Alaska and states along the Canadian border. The region extends south to mountainous areas in New Mexico, Arizona, and California. The region contains all of Alaska, Montana, Wyoming, and the Dakotas, as well as many small communities in Nevada, Utah, Idaho, Colorado, Kansas, and Nebraska. Boundaries correspond with Sunset Climate Zones 4, 5 and 6 (Brenzel 1997) and USDA Hardiness Zones 1-6. The climate of this region is cold and snowy in the winter, limiting the number of tree species that will grow. These guidelines are specific to this region, where cold winters with relatively warm, dry summers predominate.

Quality of life improves with trees

As many Northern Mountain and Prairie 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

Northern Mountain and Prairie communities can promote energy efficiency through tree planting and stewardship programs that strategically locate trees to save energy and minimize conflicts with 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, calming traffic, enhancing community attractiveness and investment, and promoting human health and well-being.

Scope defined

This guide builds upon previous studies by American Forests (2001a) of urban forest benefits in the Northern Mountain and Prairie region to extend existing knowledge in several ways:

- Quantify benefits for open-grown trees on a per tree basis rather than on a canopy cover basis (it should not be used to estimate benefits and costs for trees growing in forest stands).
- Describe managements costs, as well as benefits.
- Detail benefits and costs for trees in residential yards as well as street/park trees.
- Illustrate how to use this information to estimate benefits and costs for local tree planting projects.

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

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

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

- What is the potential of tree planting programs to improve environmental quality, conserve energy, and add value to communities?
- Where should residential yard 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 can assist 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 this Tree Guide

This tree guide is organized as follows:

Chapter 1. Provides background information on the potential of trees in Northern Mountain and Prairie communities to provide benefits, as well as management costs that are typically incurred.

Chapter 2. Provides calculations of tree benefits and costs.

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

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

Chapter 5. Contains a tree selection list with information on tree species recommended for Northern Mountain and Prairie communities.

Chapter 6. Lists references cited in the guide.

Chapter 7. Provides a glossary of definitions for technical terms used in the report.

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

Appendix B. Describes the methods, assumptions, and limitations associated with estimating tree benefits and costs.

This guide will help users quantify the long-term benefits and costs associated with proposed tree planting projects. The guide is available online at http://cufr.ucdavis.edu/products. The Center for Urban Forest Research has developed a computer program called STRATUM to estimate these values for existing street and park trees. More information on STRATUM is available at the CUFR web site.

1. Identifying Benefits and Costs of Urban and Community Forests

This chapter describes benefits and costs of public and privately managed trees. The functional benefits and associated economic value of community forests are described. Expenditures related to tree care and management are assessed – a procedure prerequisite to creating cost-effective programs (Hudson 1983).

Benefits

Saving Energy

How trees save energy

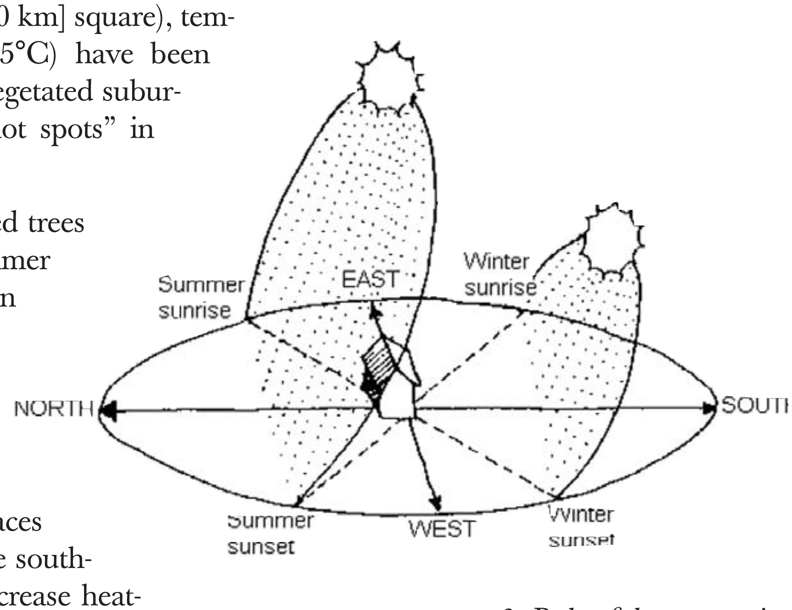
Trees modify climate and conserve building energy use in three principal ways:

- Shading – reduces the amount of radiant energy absorbed and stored by built surfaces.
- Transpiration – converts liquid water 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, especially where thermal conductivity is relatively high (e.g., glass windows) (Simpson 1998).

Trees moderate 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 [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). These "hot spots" in cities are called urban heat islands.

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). Even deciduous trees that shade south- and east-facing walls during winter can increase heating costs.



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

Windbreaks reduce heat loss

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 10-12% (Heisler 1986). Reductions in wind speed reduce heat transfer through conductive materials as well. Cool winter winds, blowing against 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.

Trees can save substantial $

Trees provide greater energy savings in the Northern Mountain and Prairie region than in milder climate regions because of the cold winters and hot summers. A computer simulation of annual cooling savings for an energy efficient home in Denver indicated that the typical household with air conditioning spent about $400 each year for heating and $125 for cooling. Wind protection from two 25-ft tall (7.5 m) trees – on the west side of the house – was estimated to save $15 each year for heating, a 4% reduction (3.5 MBtu) (McPherson et al. 1993). Shade and lower air temperatures from the same two trees during summer reduced annual cooling costs by about $30 (24%). The total $45 savings represented a 9% reduction in annual heating and cooling costs.

Retrofit for more savings

In the Northern Mountain and Prairie region, there is ample opportunity to "retrofit" communities with more sustainable landscapes through strategic tree planting and stewardship of existing trees. Strategically located tree plantings could reduce annual heating and cooling costs by 20-25% for typical households.

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.
- Trees near buildings can reduce the demand for heating and air conditioning, thereby reducing emissions associated with electric power production.

Activities that release CO_2

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

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). 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.

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. The average emission rate for the Northern Mountain and Prairie region is approximately 2.0 lbs (0.9 kg) CO_2/kWh. Due to the large amount of coal in the mix of fuels used to generate the power, this emission rate is higher than in some other regions. For example, the two-state average for Oregon and Washington is much lower, 0.27 lbs (0.12 kg) CO_2/kWh because hydroelectric power predominates. The Northern Mountain and Prairie region's relatively high CO_2 emission rate accentuates CO_2 benefits from reduced energy demand relative to other regions with lower emission rates.

Financial value of CO_2 reduction

One of the most comprehensive studies of atmospheric CO_2 reduction by an urban forest found that Sacramento, California's six million trees removed approximately 335 thousand 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 have been substantially increased through strategic planting and long-term stewardship that maximized future energy savings from new tree plantings.

CO_2 reduction through community forestry

Since 1990, Trees Forever, an Iowa-based nonprofit, has planted trees for energy savings and atmospheric carbon dioxide reduction with utility sponsorships. Over one-million landscape-sized trees have been planted in 400 communities with the help of 120,000 volunteers. These trees are estimated to offset CO_2 emissions by 50,000 tons (45,359 metric tonnes) annually. Based on an Iowa State University study, survival rates are an amazing 91%, indicating a highly trained and committed volunteer force (Ramsay 2002).

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.
- ➢ Transpiring water and shading surfaces, which lowers local air temperatures, thereby reducing ozone levels.

Trees affect ozone formation

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, while planting of medium- and high-emitters would increase overall ozone concentrations (Taha 1996). The contribution of BVOC emissions from trees to ozone formation in Northern Mountain and Prairie communities has not been studied.

Areas with poor air quality

Although many communities in the Northern Mountain and Prairie region do not experience poor air quality, several areas have exceeded U.S. Environmental Protection Agency (EPA) standards and continue to experience periods of poor air quality. These include metro Fairbanks and Anchorage, Alaska; California's Owens Valley; the western metro Denver area and several mountain communities in Colorado; Northern Idaho; Northwest Montana as well as the Butte and Billings areas; Nevada's central Steptoe Valley; south-central Oregon; Yakima county in Washington; and the Sheridan, Wyoming area. Tree planting is one practical strategy for communities in these areas to meet and sustain mandated air quality standards.

Trees effectively reduce ozone and particulate matter concentrations

American Forest's (2001a) study of the Colorado Front Range area found that the existing 6% tree canopy cover removed 1,080 tons (980 metric tonnes) of air pollutants valued at $5.3 million. A similar analysis for the Willamette/ Lower Columbia Region reported that existing tree cover (24%) removed 89,000 tons (80,740 tonnes) of pollutants annually with a value of $419 million (American Forests 2001b). Trees were most effective in removing ozone (O_3), nitrogen dioxide (NO_2), and particulate matter (PM_{10}).

Other 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 U.S. EPA adapted these research findings to the local climate and developed a method for easily estimating evaporative emission reductions from parking lot tree plantings. EPA 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. With increased recognition of the importance of non-point source runoff, 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 four 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.
- Transpiration through tree leaves reduces soil moisture, increasing the soil's capacity to store rainfall.

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), close to values reported for rural forests. 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). Broadleaf evergreens and conifers intercept more rainfall than deciduous species where winter rainfall patterns prevail.

In the Colorado Front Range, existing tree cover was estimated to reduce runoff by 52.9 million ft^3 (1.5 million m^3), valued at $3.2 million annually (American Forests 2001a).

In the Willamette/Lower Columbia region, existing canopy (24%) reduced runoff by 8.5 billion ft^3 (240.7 million m^3). The annualized value of this benefit was $140 million (American Forests 2001b).

Urban forests can dispose of waste water

Urban forests can provide other hydrologic benefits, too. For example, irrigated tree plantations or nurseries can be a safe and productive means of wastewater treatment. 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 (2.3 L) per kWh of electricity provided. Trees that reduce the demand for electricity, therefore, 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

Beautification

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

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, as 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). Urban green also appears to have an "immunization effect," in that people show less stress response if they have had a recent view of trees and vegetation. Hospitalized patients with views of nature and time spent outdoors need less medication, sleep better, 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

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 material, work with area schools, and hands-on training in the care of trees.

Shade can defer street maintenance

Tree shade on streets can help offset pavement management costs by protecting paving from weathering. The asphalt paving on streets contains stone aggregate in an oil binder. Tree shade lowers the street surface temperature and reduces 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 on page 15).

Costs

Planting and Maintaining Trees

Cities spend about $6.40 per tree

The environmental, social, and economic benefits of urban and community forests come with a price. A national survey reported that communities in the Northern Mountain and Prairie region spent an average of about $6.40 per tree, annually, for street and park tree management (Tschantz and Sacamano 1994). This amount was relatively high, with three regions spending more than this and six regions spending less. Generally, the single largest expenditure was for tree pruning, followed by tree removal/disposal, and tree planting.

More trees are removed than planted

Frequently, trees in new residential subdivisions are planted by developers, while cities/counties and volunteer groups plant 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.

Residential costs vary widely

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 analysis of data for Sacramento 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 1998).

Irrigation costs

Due to the region’s warm and arid summer climate, newly planted trees require irrigation for three to five years. Installation of drip or bubbler irrigation can increase planting costs by $100 or more per tree. Once planted, trees typically require 200-400 gal (0.8-1.6 m^3) per year during the establishment period. Assuming a water price of $1.40/Ccf in Fort Collins, annual irrigation water costs are initially less than $1/tree. However, as trees mature their water use can increase with an associated increase in annual costs. Trees planted in lawn areas with existing irrigation may require supplemental irrigation. Trees that are native to the Northern Mountain and Prairie region may not require supplemental irrigation after an establishment period.

Conflicts with Urban Infrastructure

Tree roots and sidewalks can conflict

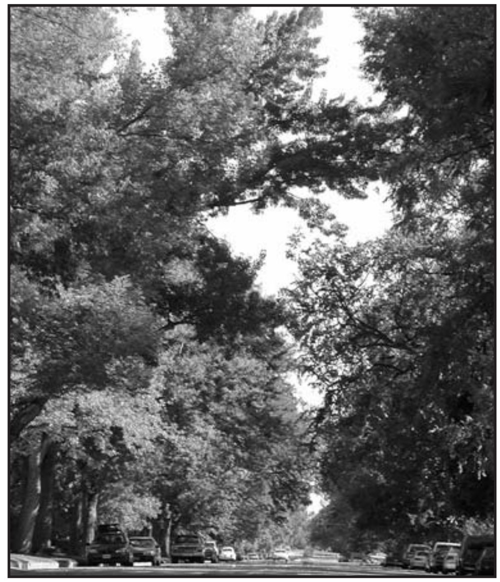
Like other cities across the U.S., communities in the Northern Mountain and Prairie region are spending millions of dollars each year to manage conflicts between trees and powerlines, sidewalks, sewers, and other elements of the urban infrastructure. In California, for example, a 1998 survey showed that 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 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 the Northern Mountain and Prairie region, dwindling budgets are increasing the sidewalk repair backlog and forcing 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. Thousands of healthy urban trees are lost each year and their benefits forgone 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.



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.

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 tree root habit.

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 latter assertion may be due to the fact that sewers are closer to the root zone as they enter houses than at the street. Repair costs typically range from $100 for 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.

Large trees under powerlines are costly

Conflicts between trees and powerlines are reflected in electric rates. Large trees under powerlines require more frequent pruning than better-suited trees. Frequent crown reduction reduces the benefits these trees could otherwise provide. Moreover, increased costs for pruning are passed on to ratepayers.

Wood Salvage, Recycling and Disposal

Hauling and recycling waste wood are primary costs

In our survey, most Northern Mountain and Prairie cities are recycling green waste from urban trees as mulch, compost, and firewood. In some 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 grinding are the primary costs. However, in many cities recycling waste wood is not economical. The costs of grinding wood into mulch can exceed the costs of hauling and burning.

Greenwaste recycling can save $

The city of Colorado Springs trades firewood from its removed trees to a local nursery for new trees (McGannon 2002). Each year about 30 cords of wood are traded for 20-30 shade trees (2-3” caliper), each worth $200. The nursery sells the firewood during winter and the city plants leftover trees the following spring. Both partners benefit from this arrangement.

2. Quantifying Benefits and Costs of Community Forests in Northern Mountain and Prairie Communities

In this chapter we present estimated benefits and costs for trees planted in typical residential yard and public sites. Because benefits and costs vary with tree size, we report results for typical large-, medium-, and small-stature deciduous trees, as well as for a conifer.

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). Limited knowledge about the physical processes at work and their interactions make estimates imprecise (e.g., fate of air pollutants trapped by trees and then washed to the ground by rainfall). Tree growth and mortality rates are highly variable throughout the region. Benefits and costs also vary, depending on differences in climate, air pollutant concentrations, tree maintenance practices, and other factors. Given the region's large geographical area with many different climates, soils, and types of community forestry programs, this approach cannot accurately account for each penny. Rather, it provides a general accounting of the benefits produced by urban trees; an accounting that provides a basis for decisions that set priorities and influence management direction (Maco and McPherson 2003).

Overview of Procedures

(For more details about this study's procedures, see Appendix B.)

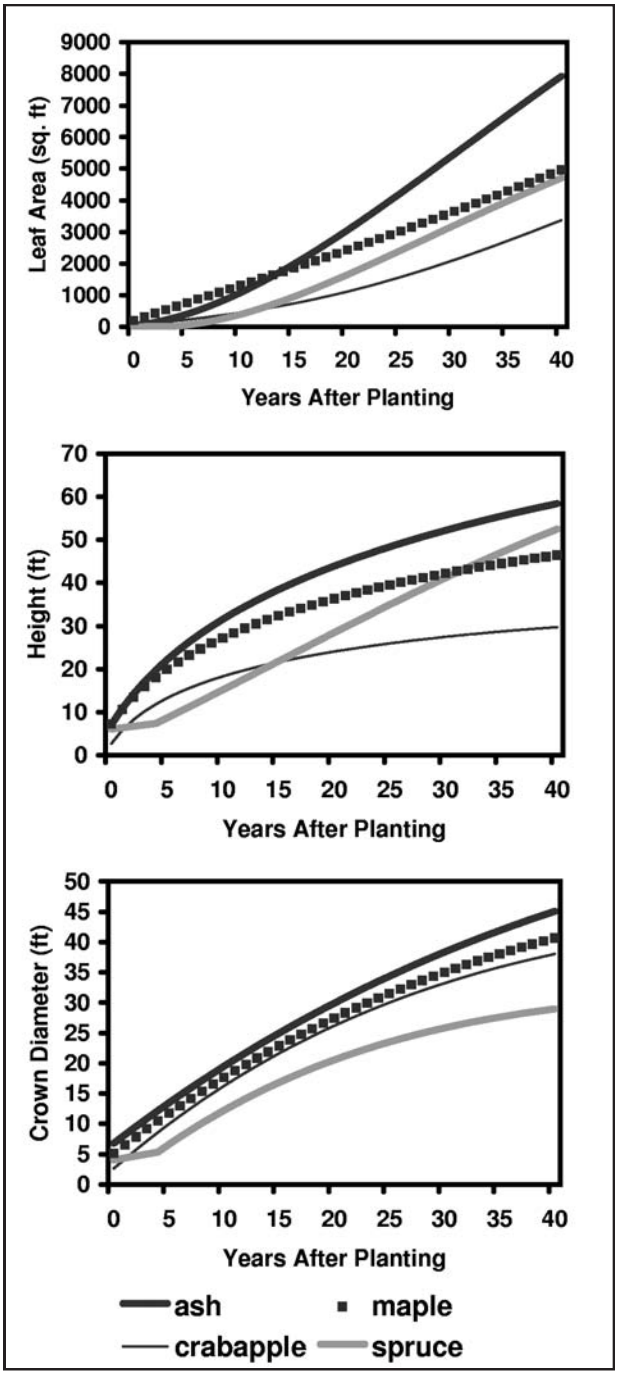
Approach

Benefit and cost estimation

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 over a 40-year planning horizon. Henceforth, we refer to a tree in these hypothetical locations as a "yard" tree and "public" tree. 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 mitigation, 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.

Large, medium, small and conifer trees

To account for differences in the mature size and growth rates of different tree species, we report results for large (*Fraxinus pennsylvanica*, green ash), medium, (*Acer platanoides*, Norway maple), small (*Malus species*, crabapple) deciduous trees, as well as a coniferous (*Picea pungens*, Colorado spruce) tree. Growth curves were developed from street trees sampled in Fort Collins, CO, Cheyenne, WY, and Bismarck, ND (Figure 5).



5. Tree dimensions are based on data from street and park trees in Fort Collins, CO, Cheyenne, WY, and Bismarck, ND. Data for typical" large, medium, small and coniferous trees are from the green ash, Norway maple, crabapple, and Colorado spruce, 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.

Frequency and costs of tree management were estimated based on surveys with municipal foresters (Cheyenne, Bismarck, Lewiston ID, Fargo, Fort Collins, Denver, and Colorado Springs). In addition, commercial arborists were contacted for information on tree management costs on residential properties (Victor, ID; Fort Collins; Colorado Springs; and Denver).

Benefits were calculated with numerical models and input data from both regional (e.g., pollutant emission factors for avoided emissions due to energy savings) and local sources (e.g., Denver climate data for energy effects). Regional electricity and natural gas prices were used in this study to quantify energy savings. Control costs were used to estimate society's willingness to pay for air quality and stormwater runoff improvements. If a developer is willing to pay an average of 1¢ 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 1¢. Appendix B contains a detailed description of modeling assumptions, procedures, and limitations.

Reporting Results

Tree mortality included. Results are reported in terms of annual values per tree planted. However, to make these calculations realistic, mortality rates are included. Based on our survey of regional municipal foresters and commercial arborists, annual mortality rates were 3% for the first five years and 1% for the remaining 35 years. Hence, this accounting approach "grows" trees in different locations and uses computer simulation to directly calculate the annual flow of benefits and costs as trees mature and die (McPherson 1992). In Appendix A, results are reported at five-year intervals for 40 years.

Findings of this Study

Average Annual Net Benefits

Average annual net benefits per tree increased with mature tree size (see Appendix A for detailed results):

Average annual net benefits increase with size of tree

- ➢ $0 to $9 for a small tree
- ➢ $8 to $19 for a medium shade tree and large conifer
- ➢ $21 to $32 for a large shade tree

Large trees provide the most benefits

This finding suggests that average annual net benefits from large-growing trees, like the green ash, can be substantially greater than those from small trees like crabapple. Average annual net benefits for the small, medium, coniferous, and large public (street/park) trees were $0, $8, $11, and $21, respectively. The largest average annual net benefits, however, stemmed from residential yard trees opposite the west-facing wall of a house: $9, $19, $18, and $32 for the small, medium, coniferous, and large trees, respectively. Residential yard trees produced higher net benefits than public trees primarily because of lower maintenance costs.

Net annual benefits at year 40

The large residential tree opposite a west house wall produced a net annual benefit of $54 at year 40. Planting the green ash in a public site produced a reduced annual net benefit – $40 at year 40. Forty years after planting medium, coniferous, and small trees, they produced annual net benefits of $33, $35, and $24 for west-side residential trees, respectively. The small crabapple in a typical public space netted $13 at year 40, while a medium maple and spruce in the same locations produced $19 and $25 in annual net benefits, respectively.

Net benefits summed for 40 years

Net benefits for the residential tree opposite a west house wall and public street/park tree increased with size when summed over the entire 40-year period:

- ➢ $1,280 (yard) and $840 (public) for large trees
- ➢ $720 (yard) and $440 (public) for conifers
- ➢ $760 (yard) and $320 (public) for medium trees
- ➢ $360 (yard) and $0 (public) for small trees

Environmental benefits exceed tree care costs

Twenty years after planting, annual net benefits for a residential yard tree located west of a home were $39 for a large tree, $26 for a medium tree, $23 for a conifer, and $14 for a small tree (Table 1). For a large green ash at 20 years after planting, the total value of environmental benefits alone ($29), was four times greater than annual costs ($7). Similarly, environmental benefits totaled $22 and $19 for the Norway maple and spruce, while tree care costs totaled substantially less ($4 and $6). Annual environmental benefits were $12 for a 20-year old crabapple yard tree, while management costs were $4.

Net annual benefits at year 20 for street/park trees

Twenty years after planting, the annual net benefit from a large public tree was $26 (Table 2). At that time, net annual benefits from the medium, conifer, and small public trees were $14, $17, and $2, respectively.

Average Annual Costs

Costs increase with size of tree

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

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

BENEFIT CATEGORY	SMALL TREE 24 ft tall, 26 ft wide LSA = 1,111 sf		MEDIUM TREE 36 ft tall, 27 ft wide LSA = 2,434 sf		LARGE TREE 44 ft tall, 30 ft wide LSA = 3,056 sf		CONIFER 28 ft tall 21 ft wide LSA=1,646 sf	
Electricity savings ($0.78/kWh)	61 kWh	$4.77	91 kWh	$7.12	118 kWh	$9.19	32 kWh	$2.46
Natural gas ($0.72/therm)	-255 kBtu	-$1.84	-206 kBtu	-$1.48	-117 kBtu	-$0.84	327 kBtu	$2.36
Carbon dioxide ($0.008/lb)	131 lb	$0.99	219 lb	$1.64	315 lb	$2.36	122 lb	$0.92
Ozone ($3.07/lb)	0.26 lb	$0.80	0.30 lb	$0.92	0.35 lb	$1.06	0.25 lb	$0.76
NO_2 ($3.07/lb)	0.20 lb	$0.61	0.33 lb	$1.00	0.43 lb	$1.33	0.26 lb	$0.81
SO_2 ($7.13/lb)	0.22 lb	$1.58	0.37 lb	$2.62	0.48 lb	$3.43	0.23 lb	$1.64
PM_{10} ($5.13/lb)	0.09 lb	$0.47	0.12 lb	$0.61	0.15 lb	$0.74	0.12 lb	$0.60
VOCs ($4.85/lb)	0.000 lb	$0.010	0.002 lb	$0.038	0.003 lb	$0.016	0.003 lb	$0.17
BVOCs ($4.85/lb)	-0.002 lb	-$0.012	-0.002 lb	-$0.493	-0.011 lb	-$0.051	-0.307 lb	-$1.489
Rainfall Interception ($0.011/gal)	434 gal	$4.69	967 gal	$10.44	1,116 gal	$12.06	1,006 gal	$10.87
ENVIRONMENTAL SUBTOTAL		**$12.07**		**$22.43**		**$29.30**		**$18.95**
Other Benefits		$5.96		$8.46		$16.34		$10.71
Total Benefits		$18.02		$30.89		$45.64		$29.66
Total Costs		$4.30		$4.48		$6.52		$6.38
NET BENEFITS		**$13.72**		**$26.41**		**$39.12**		**$23.27**

LSA=leaf surface area

- ➢ $4 to $14 for a small tree
- ➢ $5 to $14 for a medium shade tree and conifer
- ➢ $7 to $17 for a large tree

Given our assumptions and the dimensions of these trees, it is 25% more expensive to maintain a large tree than a small tree (Table 3 on page 23).

Average annual maintenance costs for private trees are $9-11 per tree, considerably less than estimated costs for a public tree ($18-21). In general, public trees are more intensively maintained than yard trees because of their prominence and for public safety.

Public trees require more intensive maintenance

Tree pruning was the single greatest cost for private and public trees, averaging approximately $7-9/year/tree. Annualized expenditures for tree planting are the most important cost whether planted in private yards ($5/tree/yr). The second greatest annual cost for yard trees was for removal and disposal ($3/tree/yr).

Greatest costs for pruning, planting and removal

Table 2. Estimated annual benefits and costs for a public tree 20 years after planting.

BENEFIT CATEGORY	SMALL TREE 24 ft tall, 26 ft wide LSA = 1,111 sf		MEDIUM TREE 36 ft tall, 27 ft wide LSA = 2,434 sf		LARGE TREE 44 ft tall, 30 ft wide LSA = 3,056 sf		CONIFER 28 ft tall 21 ft wide LSA=1,646 sf	
Electricity savings ($0.78/kWh)	6 kWh	$0.48	18 kWh	$1.38	35 kWh	$2.76	32 kWh	$2.46
Natural gas ($0.72/therm)	40 kBtu	$0.29	114 kBtu	$0.83	229 kBtu	$1.65	327 kBtu	$2.36
Carbon dioxide ($0.008/lb)	42 lb	$0.32	89 lb	$0.67	169 lb	$1.26	122 lb	$0.92
Ozone ($3.07/lb)	0.26 lb	$0.80	0.30 lb	$0.92	0.35 lb	$1.06	0.25 lb	$0.76
NO_2 ($3.07/lb)	0.20 lb	$0.61	0.33 lb	$1.00	0.43 lb	$1.33	0.26 lb	$0.81
SO_2 ($7.13/lb)	0.22 lb	$1.58	0.37 lb	$2.62	0.48 lb	$3.43	0.23 lb	$1.64
PM_{10} ($5.13/lb)	0.09 lb	$0.47	0.12 lb	$0.61	0.15 lb	$0.74	0.12 lb	$0.60
VOCs ($4.85/lb)	0.000 lb	$0.010	0.002 lb	$0.038	0.003 lb	$0.016	0.003 lb	$0.17
BVOCs ($4.85/lb)	-0.002 lb	-$0.012	-0.002 lb	-$0.493	-0.011 lb	-$0.051	-0.307 lb	-$1.489
Rainfall Interception ($0.011/gal)	434 gal	$4.69	967 gal	$10.44	1,116 gal	$12.06	1,006 gal	$10.87
ENVIRONMENTAL SUBTOTAL		**$9.24**		**$18.02**		**$24.26**		**$18.95**
Other Benefits		$7.04		$10.00		$19.31		$12.65
Total Benefits		$16.28		$28.02		$43.57		$31.60
Total Costs		$13.90		$14.18		$17.43		$14.41
NET BENEFITS		**$2.38**		**$13.84**		**$26.14**		**$17.19**

LSA=leaf surface area

For public trees in Northern Mountain and Prairie communities, average annual expenditures for program administration were significant (about $3/tree). Strategies to reduce these costs may help municipalities use their limited funds to plant and care for more trees.

Table 3 shows annual management costs 20 years after planting yard trees to the west of a house and public trees. Annual costs for yard trees ranged from $4-6, while public tree care costs were $14-17.

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):

- $14 to $18 for a small tree
- $25 to $33 for a medium shade tree and conifer
- $37 to $43 for a large tree

Aesthetic and Other

Benefits greatest for property values

Benefits associated with property value accounted for the largest proportion of total benefits. Average annual values ranged from $6-7, $8-10, and $14-17 for the small, medium/conifer, and large tree, respectively. These values reflected average region-wide residential real estate sales prices and the potential beneficial impact of urban forests on property values and the municipal tax base. Effects of trees on property values and aesthetics will vary locally based on different conditions.

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.

Aesthetic and other benefits were 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 (Figure 6). This assumption has not been tested so there is a high level of uncertainty associated with this result.

Stormwater Runoff

After aesthetics, values were largest for benefits associated with rainfall interception. Annual averages were substantial for all four trees. The green ash intercepted 1,209 gal/yr (4.6 m^3/yr) on average with an implied value of $13. A large, green ash at 40 years after planting had an interception rate of over 2,143 gal/yr (8.1 m^3/yr) – valued at $23.

Bark and foliage of the Colorado spruce and Norway maple intercepted 1,114 gal/yr (4.2 m^3/yr) and 948 gal/yr (3.6 m^3/yr) on average, with a value of $12 and $10, respectively. By intercepting 549 gallons (2.1 m^3/yr) of rainfall annually, a typical crabapple provided over $6 in stormwater management savings.

These results suggest that water quality benefits associated with rainfall interception exceed irrigation costs. Given our assumptions, stormwater runoff reduction benefits were eight or more times greater than tree irrigation costs.

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

	SMALL TREE 24 ft tall, 26 ft wide LSA = 1,111 sf		MEDIUM TREE 36 ft tall, 27 ft wide LSA = 2,434 sf		LARGE TREE 44 ft tall, 30 ft wide LSA = 3,056 sf		CONIFER 28 ft tall 21 ft wide LSA=1,646 sf	
COSTS ($/YR/TREE)	Private: West	Public Tree	Private: West	Public Tree	Private: West	Public Tree	Private: West	Public Tree
Tree and Planting	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Pruning	$1.38	$8.31	$1.38	$8.31	$3.16	$11.08	$3.16	$8.31
Remove and Dispose	$2.69	$1.98	$2.77	$2.04	$2.98	$2.19	$2.95	$2.17
Pest and Disease	$0.02	$0.19	$0.02	$0.19	$0.02	$0.21	$0.02	$0.21
Infrastructure	$0.06	$0.47	$0.06	$0.48	$0.06	$0.52	$0.06	$0.51
Irrigation	$0.07	$0.07	$0.16	$0.16	$0.20	$0.20	$0.11	$0.11
Clean-up	$0.02	$0.18	$0.02	$0.18	$0.02	$0.19	$0.02	$0.19
Liability and Legal	$0.01	$0.05	$0.01	$0.07	$0.01	$0.09	$0.01	$0.06
Admin. and Other	$0.05	$2.66	$0.05	$2.74	$0.06	$2.95	$0.06	$2.86
TOTAL COSTS	**$4.30**	**$13.90**	**$4.48**	**$14.18**	**$6.52**	**$17.43**	**$6.38**	**$14.41**

LSA=leaf surface area

Carbon Dioxide

Net atmospheric CO_2 reductions accrued for all four tree-types. Average annual net reductions ranged from 161-279 lbs (73-127 kg) ($1-2) for the large tree to 16-108 lbs (7-49 kg) ($1) for the small tree. Trees opposite west-facing house walls produced the greatest CO_2 reduction due to avoided power plant emissions associated with energy savings. Releases of CO_2 associated with tree care activities nearly offset CO_2 sequestration by the small trees.

CO_2 reduction accrues for large and medium trees

Energy

Mature tree size matters when considering energy benefits. A large tree produced three to eight times more energy savings than a small tree due to the greater effects on wind, building shade, and cooling by transpiration. However, energy savings increased as trees matured and their leaf surface area increased, regardless of their mature size (Figures 7 and 8).

Larger trees produce more energy savings

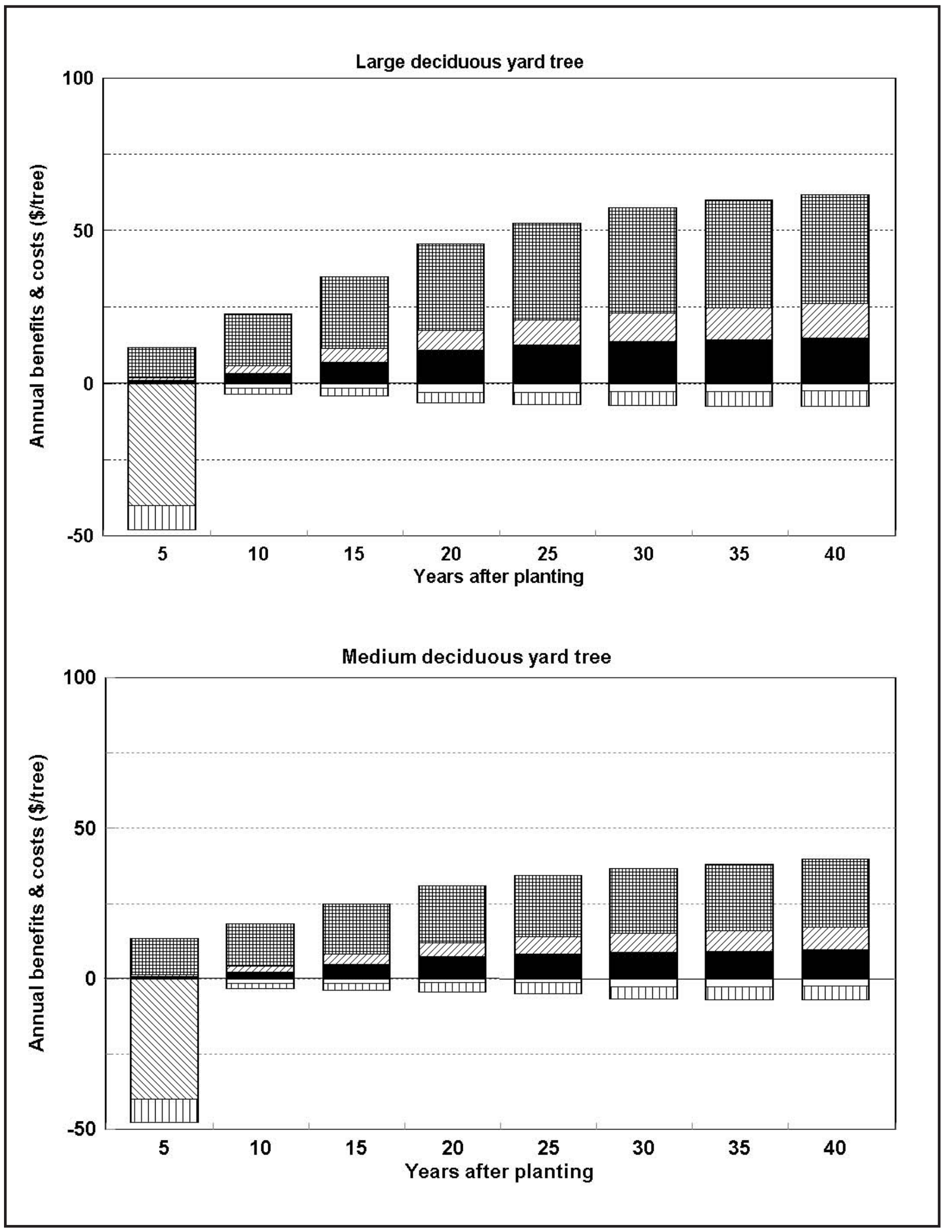
Average annual net energy benefits for residential trees were greatest for a tree located west of a building because the detrimental effects on heating costs associated with winter shade was minimized; a yard tree located south of a building produced the least net energy benefit. Trees located east of a building provided intermediate net benefits. Winter shade, however, was a function of size, branch pattern and density, and foliation period, resulting in better per-

West is best

formance by "solar-friendly" tree species that minimized winter shade. The small crabapple – opposite south-facing walls – increased heating costs more than shading and climate benefits reduced cooling and heating costs. Thus, this small tree was a net energy cost at this location.

The medium-sized Norway maple, Colorado spruce, and large green ash provided net energy benefits at all locations. Their annual average cooling savings during the summer months ($1-8) more than offset heating costs associated with winter shade ($1-2). Average annual cooling ($3) and heating ($5) savings from a conifer windbreak tree located north or northwest of a home was $5/tree/yr.

7. Residential trees. Estimated annual benefits and costs for a large (green ash), medium (Norway maple), conifer (Colorado spruce), and small (crabapple) residential yard tree located west of the building. Costs are greatest during the initial establishment period while benefits increase with tree size.



Air Quality

Air quality benefits were defined as the sum of pollutant uptake by trees and avoided power plant emissions due to energy savings, minus biogenic volatile organic compounds (BVOCs) released by trees. The total average annual air quality benefits were a relatively low $2 for the conifer because it is a moderate emitter of BVOCs. Larger benefits were estimated for the small ($4), medium ($5) and large tree ($7) in Northern Mountain and Prairie communities, largely because they emitted fewer BVOCs than the Colorado spruce. Benefit values were greatest for SO_2 and O_3, followed by NO_2 and PM_{10}.

Large trees remove more air pollutants

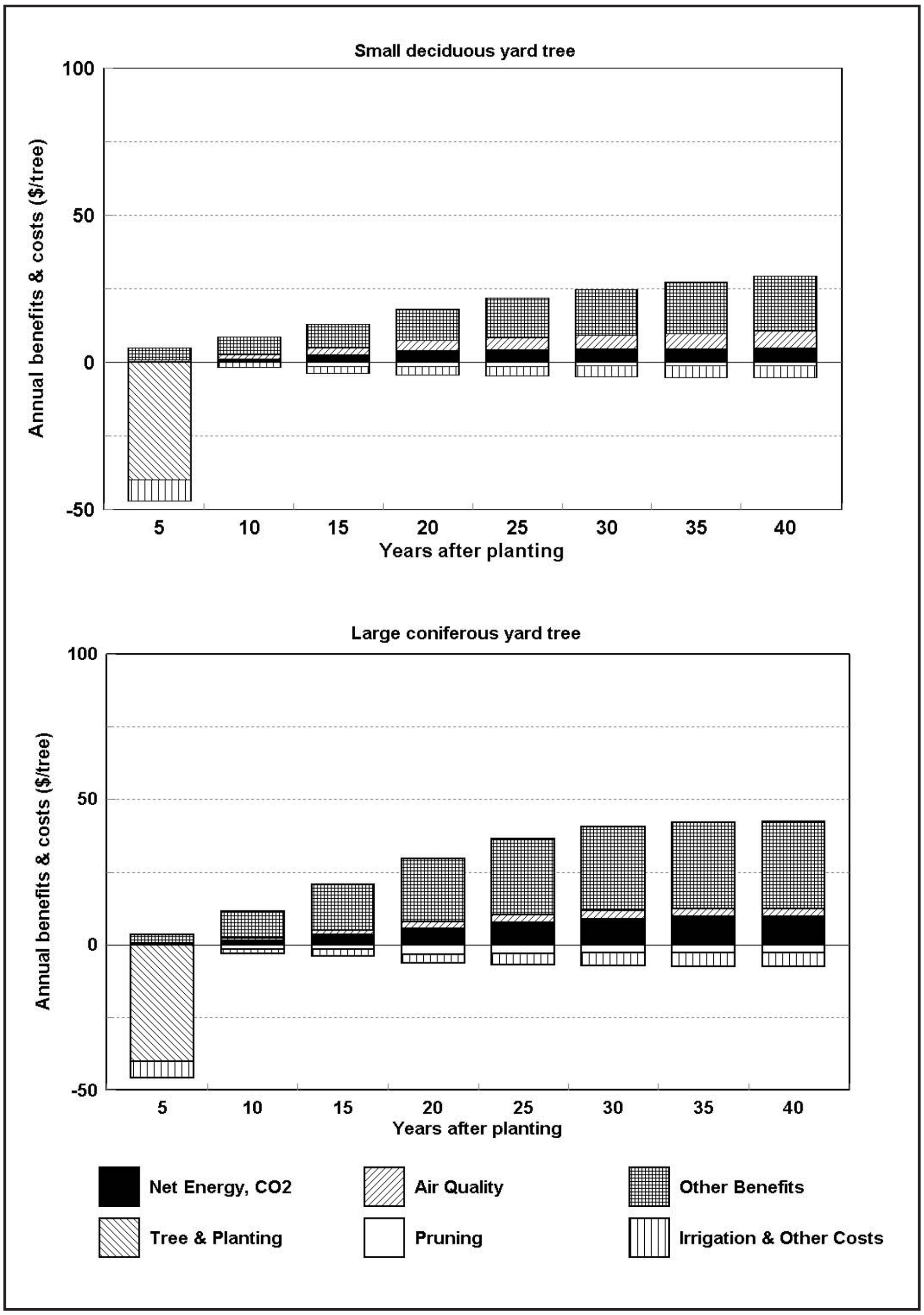
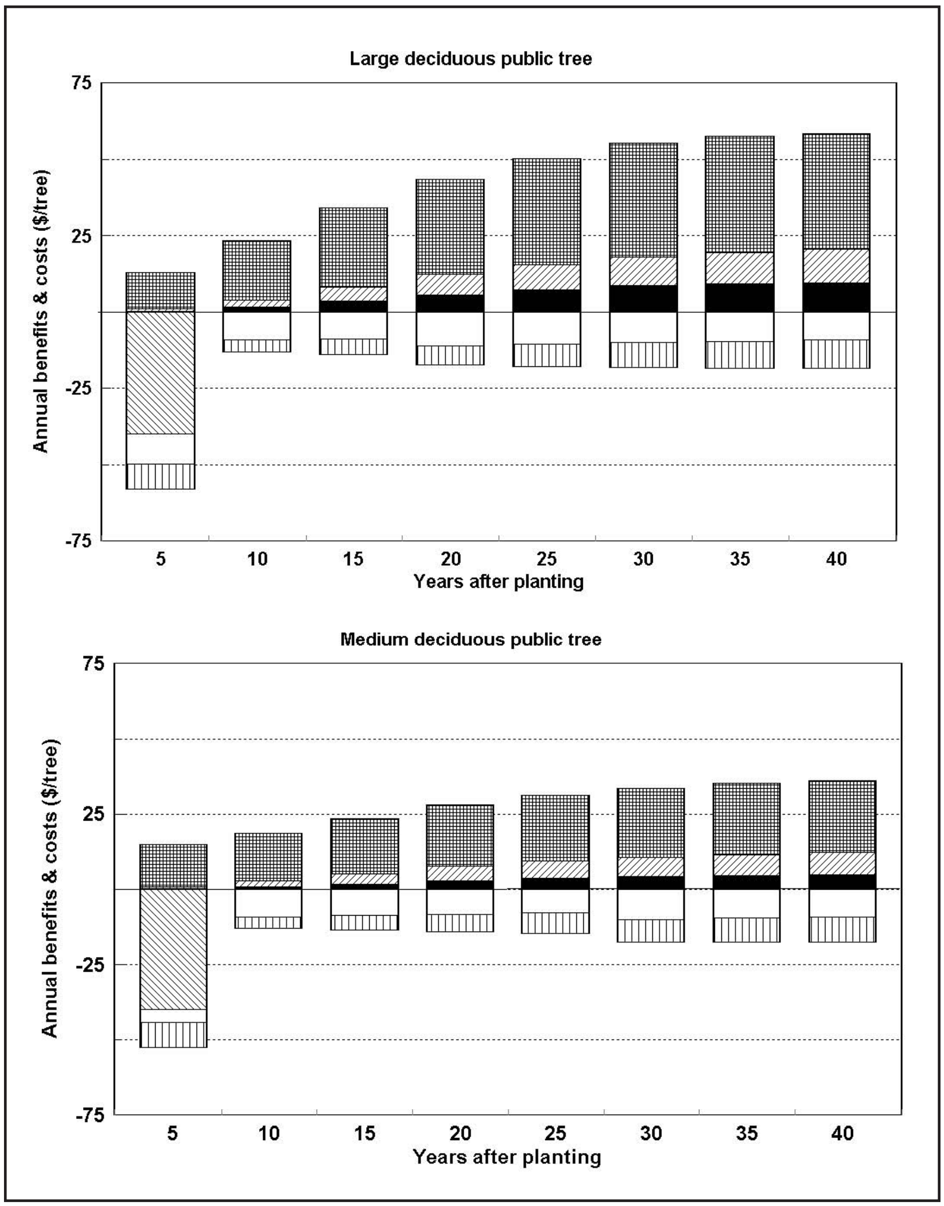


Figure 7 continued.

Though positive, trees had minimal effect on VOCs avoided at the power plant.

The cost of BVOCs released by the low-emitting ash and crabapple was negligible. Pollutant uptake benefits far exceeded the benefits of avoided pollutant emissions. However, the single Norway maple and Colorado spruce emitted about 0.12 lb (0.05 kg) and 0.44 lb (0.2 kg) of BVOCs per year, respectively. These releases offset benefits due to pollutant uptake by $0.57 and $2.11 per tree, respectively.



8. Public street/park trees. Estimated annual benefits and costs for a large (green ash), medium (Norway maple), conifer (Colorado spruce), and small (crabapple) public tree.

Benefit Summary

Average annual benefits for all trees, except the small public tree, exceeded costs of tree planting and management. Surprisingly, in many situations, annual *environmental* benefits, alone, exceeded total costs. Trees that met this standard included all large trees (public or yard) and all other tree-types on residential property. Adding the value of aesthetics and other benefits to these environmental benefits resulted in substantial net benefits except for the small public tree.

Environmental benefits alone can exceed costs for many trees

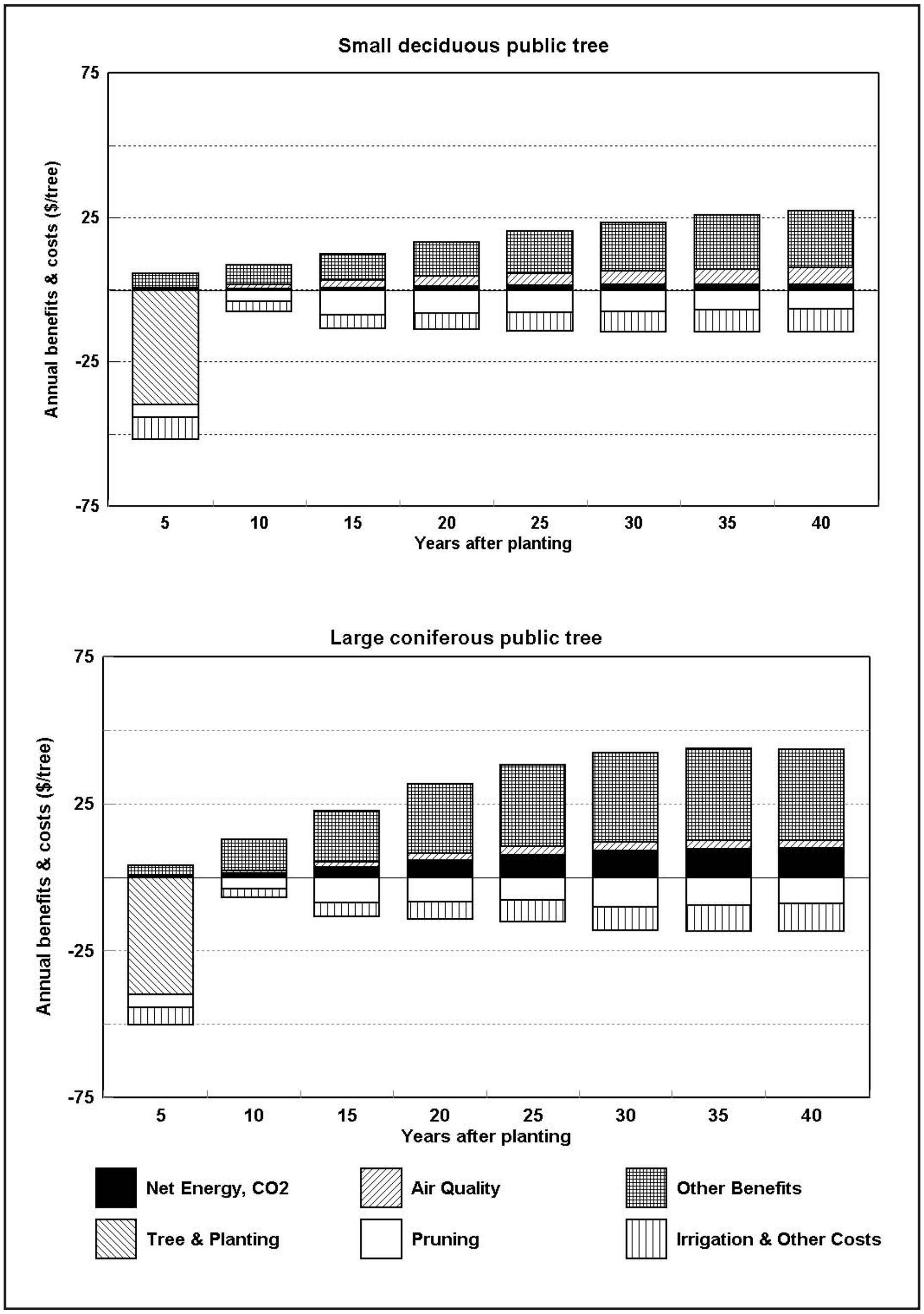


Figure 8 continued.

A mature green ash, used in this tree guide as representative of a large tree.

A mature Colorado spruce, representative of coniferous trees for this tree guide.

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

A mature crabapple, representative of small trees for this tree guide.

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

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

Applying Benefit-Cost Data: Grove Park Example

Grove Park example

The hypothetical city of Grove Park is located in the Northern Mountain and Prairie region and has a population of 24,000. Most of the street trees were planted in the 1930s, with Siberian elm (*Ulmus pumila*) and green ash (*Fraxinus pennsylvanica*) the dominant species. Currently, street tree canopy cover is sparse because most of the trees have died and not been replaced. Many of the remaining street trees are in declining health. The city hired an urban forester two years ago and an active citizen group, the Green Team, has formed.

Initial discussions among the Green Team, local utilities, the urban forester, and other partners progressed to formulate a proposed urban forestry program. The program intends to plant 1,000 trees in Grove Park over a five-year period. It is anticipated that trained volunteers will plant 1-inch caliper trees and the total cost for planting will be $100/tree. Trees will be planted along Main Street, other downtown streets, and in parks. Because shading of streets is a primary objective, most of these public trees will be medium- and large-sized deciduous species. However, 10% (100) will be evergreens planted in parks. Therefore, mature tree sizes are assumed to be 65% large, 20% medium, 5% small, and 10% conifer.

The Grove Park City Council has agreed to maintain the current funding level for management of existing trees. Also, they will advocate formation of a municipal tree district to raise funds for the proposed tree planting project. A municipal tree district would extend the concept of landscape assessment districts by receiving funding from air quality districts, stormwater management agencies, electric utilities, businesses, and residents in proportion to the value of future benefits of trees related to air quality, hydrology, energy, CO_2, and property value. Such a district would require voter approval of a special assessment that taxes recipients of the tangible benefits produced by the new trees. The Council needs to know the amount of funding required for tree planting and maintenance, as well as how the benefits will be distributed over the 40-year life of the project.

The first step: determine tree planting numbers

As a first step, the Grove Park city forester and Green Team decide to use tables in Appendix A to quantify total cumulative benefits and costs over 40 years for the proposed planting of 1,000 public trees. Based on the anticipated percentages of trees by mature size, this includes 650 large trees, 200 medium trees, 50 small trees, and 100 conifers. Before setting up a spreadsheet to calculate benefits and costs they consider aspects of Grove Park's urban and community forestry project that may differ from the region-wide values used in this guide (values assumed for Appendix A are described in Appendix B):

- The price of electricity and natural gas are $0.06/kWh and $0.0085/kBtu, not $0.078/kWh and $0.0072/kBtu assumed in this tree guide. It is assumed that nearby buildings have air conditioning and natural gas heating.
- Administration and other costs are estimated to average $2.50/tree planted each year, or $2,500 annually for the life of the trees. Values in this guide assume an average annual cost of $5/tree for public trees. Thus, an adjustment is necessary.
- Planting will total $100/tree due to labor provided by trained volunteers. The guide assumes planting costs total $200/tree.
- All public and yard trees will be watered by hand during the first five years at an average cost of $7.50/tree per year. After this time there will be no additional irrigation expenses because trees will be established in irrigated landscapes. The guide assumed that 50% of all public and yard trees were irrigated by hand for the first five years after planting at a cost of $10/tree per year.
- Normally, tree mortality is greatest during the first years of establishment. However, in this case a contractor has guaranteed replacement of all dead or dying trees after the first growing season. The replacement guarantee should result in relatively high survival rates for the establishment period. However, to be conservative they agree to apply the survival rate assumed for calculations shown in Appendix A of this guide (i.e., 60% after 40 years).

The second step: adjust for local prices of benefits

To calculate the dollar value of total benefits and costs for the 40-year period, the forester creates a spreadsheet table (Table 4). Each benefit and cost category is listed in the first column. Prices that have to be changed are entered into the second column. Values for the 40-year average from Appendix A (next to last column) are copied for each tree-type. The 40-year total values for each category in the next column are calculated by multiplying these resource unit (RU) values by tree numbers, prices, and 40 years. For example, to adjust for higher electricity prices, the forester multiplied electricity saved for a large public tree in the RU column by the Grove Park price. This value was then multiplied by the number of trees planted and 40 years (36 kWh x $0.06 x 650 trees x 40 years = $56,160) to obtain cumulative air conditioning savings for the large, public trees (Table 4). The same steps were followed to adjust the natural gas prices for all tree-types (large, medium, small, and conifer trees). To find the price for net air pollutant uptake ($4.54 for large, public tree), the 40-year average value of pollutant uptake was divided by the 40-year average amount of pollutant uptake ($6.63/1.46 lb). This adjusted price accounts for differences in uptake amounts and values among the different pollutants in Grove Park.

The third step: adjust for local costs

To adjust cost figures, the city forester changed the planting cost from $200 to $100 (Table 4). This planting cost was annualized by dividing the cost/tree by 40 years ($100/40 = $2.50/tree/yr). Total planting costs were calculated by multiplying this value by 650 large trees and 40 years ($65,000).

The irrigation cost is $7.50/tree per year for the first 5 years, or $37.50/tree total for the project. Therefore, this amount was annualized by dividing the 40-year project life to derive a cost/tree of $0.94/tree. Total irrigation cost for

Table 4. Benefit and cost spreadsheet calculations for the Grove Park planting project (1,000 trees).

PUBLIC TREES:	650 LARGE		200 MEDIUM		50 SMALL		100 CONIFER		1,000 TOTAL TREES		
Benefits	RU/ tree/yr	Total $	RU/ tree/yr	Total $	RU/ tree/yr	Total $	RU/ tree/yr	Total$	Total$	$/tree/yr	%benefits
Electricity ($0.06/kWh)	36	56,160	18	8,703	6	760	32	7,680	73,304	1.83	5.0%
Natural Gas ($0.0085/kBtu)	235	51,935	117	7,973	41	696	335	11,390	71,994	1.80	5.0%
Net Energy (kBtu)	597	108,095	299	16,676	104	1,457	659	19,070	145,298	3.63	10.0%
Net CO_2 ($0.008/lb)	161	33,488	85	5,471	37	587	123	3,936	43,482	1.09	3.0%
Air Pollution ($4.54/lb)	1.46	172,380	1.03	37,336	0.81	7,348	0.51	9,264	226,327	5.66	15.6%
Hydrology ($0.0108/gal)	1,209	339,487	948	81,885	549	11,859	1,114	48,125	481,357	12.03	33.1%
Aesthetics and Other	16.55	430,300	9.84	78,720	6.86	13,720	8.38	33,520	556,260	13.91	38.3%
Total Benefits		**1,083,750**		**220,088**		**34,971**		**113,915**	**1,452,724**	**36.32**	**100%**
Costs	$/tree/yr	Total $	$/tree/yr	Total $	$/tree/yr	Total $	$/tree/yr	Total $	Total $	$/tree/yr	%costs
Tree & Planting ($100)	2.50	65,000	2.50	20,000	2.50	5,000	2.50	10,000	100,000	2.50	14.1%
Pruning	9.14	237,640	8.46	67,680	6.77	13,540	7.17	28,680	347,540	8.69	49.2%
Remove & Dispose	2.19	56,940	2.03	16,240	1.94	3,880	2.06	8,240	85,300	2.13	12.1%
Pest & Disease	0.20	5,200	0.18	1,440	0.17	340	0.19	760	7,740	0.19	1.1%
Infrastructure Repair	0.49	12,740	0.45	3,600	0.43	860	0.46	1,840	19,040	0.48	2.7%
Irrigation ($37.50/5 yrs)	0.94	24,375	0.94	7,500	0.94	1,875	0.94	3,750	37,500	0.94	5.3%
Clean-Up	0.18	4,680	0.17	1,360	0.16	320	0.17	680	7,040	0.18	1.0%
Liabiity & Legal	0.08	2,080	0.07	560	0.04	80	0.05	200	2,920	0.07	0.4%
Admin & Other ($100)	2.50	65,000	2.50	20,000	2.50	5,000	2.50	10,000	100,000	2.50	14.1%
Total Costs		**473,655**		**138,380**		**30,895**		**64,150**	**707,080**	**17.68**	**100%**
Net Benefit		**610,095**		**81,708**		**4,076**		**49,765**	**745,644**	**18.64**	
Benefit/Cost Ratio		**2.29**		**1.59**		**1.13**		**1.78**	**2.05**		

RU=resource unit

the large, public tree was calculated by multiplying this value by 650 large trees and 40 years ($24,375). Similarly, administration, inspection, and outreach costs are expected to average $2.50/tree per year, or a total of $100/tree for the project's life. Consequently, the total administration costs for large, public trees is $2.50/tree times 650 large trees and 40 years ($65,000). The same procedure was followed to calculate costs for the other tree types.

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

Net benefits for the planting project were calculated by subtracting total costs from total benefits for the large ($610,095, $23.47/tree/yr), medium ($81,708, $10.21/tree/yr), small ($4,076, $2.04/tree/yr), and coniferous ($49,765, $12.44/tree/yr) trees. Benefits total $1.45 million ($36/tree/yr) and costs total $707,080 ($18/tree/year). The total net benefit for all 1,000 trees over the 40-year period is $745,644, or $19/tree/yr. To calculate the average annual net benefit per tree, the forester divided the total net benefit by the number of trees planted (1,000) and 40 years ($745,644/1,000 trees/40 yrs. = $18.64). Dividing total benefits by total costs yielded the benefit-cost ratios (BCRs) that ranged from 1.13 for small trees–where benefits slightly exceed costs–to 2.29 for large, public trees. The BCR for all public trees is 2.05, indicating that $2.05 will be returned for every $1 invested.

It is important to remember that this analysis assumes 40% of the planted trees die and does not account for the time value of money from a municipal capital investment perspective. Use the municipal discount rate to compare this investment in tree planting and management with alternative municipal investments.

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

The city forester and Green Team now know that the project will cost $707,080, and the average annual cost will be $17,677 ($707,080 / 40 years). However, more funds will be needed initially for planting and irrigation. The fifth and last step is to identify the distribution of functional benefits that the trees will provide. The last column in Table 4 shows the distribution of benefits as a percentage of the total:

- Energy savings = 10% (cooling = 5%, heating = 5%)
- Carbon dioxide reduction = 3%
- Air pollution reduction = 15.6%
- Stormwater runoff reduction = 33.1%
- Aesthetics/property value increase = 38.3%

Distributing costs of tree management to multiple parties

With this information the planning team can determine how to distribute the costs for tree planting and management based on who benefits from the services the trees will provide. For example, assuming the goal is to generate enough annual revenue to cover the costs of managing the trees ($707,080), fees could be distributed in the following manner:

- $70,720 from electric and natural gas utilities for energy savings (10%)
- $21,164 from local business and industry for atmospheric carbon dioxide reductions (3%)

- ➢ $110,160 from the air quality management district for net reduction of air pollutants (15.6%)
- ➢ $234,289 from the stormwater management district for water quality improvement associated with reduced runoff (33.1%)
- ➢ $270,747 from property owners for increased property values (38.3%).

Whether project funds are sought from partners, the general fund, or other sources, this information can assist managers in developing policy, setting priorities, and making decisions. The Center for Urban Forest Research has developed a computer program called STRATUM that simplifies these calculations for analyses of existing street tree populations (Maco and McPherson, 2003).

Applying Benefit-Cost Data: Evergreen Example

Evergreen example

As a municipal cost-cutting measure, the hypothetical city of Evergreen is planning to no longer plant street trees with new development. Instead, developers will be required to plant front yard trees, thereby reducing costs to the city. The community forester and concerned citizens believe that, although this policy will result in lower planting costs, developers may plant more small-stature trees than the city. Currently, Evergreen's policy is to plant as large a tree as possible given each site's available growing space. Planting more small-stature trees could result in benefits "forgone" that will exceed cost savings. To evaluate this possible outcome the community forester and concerned citizens decided to compare costs and benefits of planting large, medium, and small trees for a hypothetical street tree planting project in Evergreen.

Determine tree planting numbers

As a first step, the city forester and concerned citizens decide to quantify the total cumulative benefits and costs over 40 years for a typical street tree planting of 1,500 trees in Evergreen. For comparison purposes, the planting includes 500 large trees, 500 medium trees, and 500 small trees. Data in Appendix A were 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 $0.078kWh assumed in the guide.
- ➢ No funds are spent on pest and disease control.
- ➢ Planting costs are $160/tree for city trees instead of the $200/tree municipal average presented in the 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) was 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 multiplied electricity saved for a large public tree in the resource unit column by the Evergreen price (36 kWh x

$0.09 = $3.24). This value was multiplied by 40 years and 500 trees ($3.24 x 40 x 500 = $64,800) to obtain cumulative air conditioning savings for the project (Table 5). The same steps were followed for medium and small trees.

Adjust for local costs

To adjust the cost figures, we did not use a row for pest and disease control costs in Table 5. We multiplied 500 large trees by the unit planting cost ($160) to obtain the adjusted cost for Evergreen (500 x $160 = $80,000). The average annual 40-year costs for other items were multiplied by 40 years and the appropriate number of trees to compute total costs. These 40-year cost values were entered into Table 5.

Calculate cost savings and benefits forgone

Net benefits were calculated by subtracting total costs from total benefits for the large ($597,000), medium ($279,600), and small ($81,000) trees. The total net benefit for the 40-year period was $957,600 (total benefits – total costs), or $638/tree ($957,600/1500 trees) on average (Table 5).

By not investing in street tree planting, the city would save $240,000 in initial planting costs. If the developer planted 1,500 small-stature trees, benefits total $1.1 million (3 x $364,200 for 500 small trees). If 1,500 large-stature trees were planted, benefits total $2.8 million. Planting of small-stature trees causes the city to forego benefits valued at $1.7 million. This amount exceeds the savings of $240,000 obtained by requiring developers to plant new street trees, and suggests that the City review developer's planting plans to maintain its policy of planting large-stature trees where feasible.

Net benefit per tree

The net benefit per public tree planted was:

- $1,194 for a large tree
- $559 for a medium tree
- $162 for a small tree

This analysis assumed 40% of the planted trees died. It did not account for the time value of money from a municipal capital investment perspective, but this could be done using the municipal discount rate.

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.

Conifers and broadleaf evergreens intercept rainfall and particulates year-round as well as reduce wind speeds, which lowers winter heating costs. Locating these types of trees in yards, parks, school grounds, and other open space areas can increase benefits.

Target tree plantings with highest pay back

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 with air conditioning. By customizing tree locations to increase numbers in high-yield sites, energy savings can be boosted.

Customize planting locations

Reduce Program Costs

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

Reduce up-front and establishment costs

Cost-effectiveness = Total Net Benefit / Total Program Cost

Table 5. Estimated 40-year total benefits and costs for Evergreen's street tree planting (1,500 trees).

STREET TREES:	500 LARGE		500 MEDIUM		500 SMALL		1,500 TREES TOTAL		AVERAGE
Benefits	RUs	$	RUs	$	RUs	$	RUs	$	$/tree
Electricity (kWh)	720,000	64,800	360,000	32,400	120,000	10,800	1,200,000	108,000	72
Natural Gas (kBtu)	4,700,000	33,800	2,340,000	17,000	820,000	6,000	7,860,000	56,800	38
Net Energy (kBtu)	11,940,000	90,400	5,980,000	45,200	2,080,000	15,800	20,000,000	151,400	101
Net CO_2 (lb)	3,220,000	24,200	1,700,000	12,800	740,000	5,600	5,660,000	42,600	28
Air Pollution (lb)	20,000	132,600	20,000	92,200	20,000	70,200	60,000	295,000	197
Hydrology (gal)	24,180,000	261,200	18,960,000	204,800	10,980,000	118,600	54,120,000	584,600	390
Aesthetics & Other		331,000		196,800		137,200		665,000	443
Total Benefits		**$938,000**		**$601,200**		**$364,200**		**$1,903,400**	**$1,269**
Costs		$		$		$		$	
Tree & Planting		80,000		80,000		80,000		240,000	160
Pruning		182,800		169,200		135,400		487,400	325
Remove & Dispose		43,800		40,600		38,800		123,200	82
Infrastructure		4,000		3,600		3,400		11,000	7
Irrigation		9,800		9,000		8,600		27,400	18
Clean-Up		15,400		14,400		13,000		42,800	29
Liability & Legal		3,600		3,400		3,200		10,200	7
Admin & Other		1,600		1,400		800		3,800	3
Total Costs		**$341,000**		**$321,600**		**$283,200**		**$945,800**	**$631**
Total Net Benefits		**$597,000**		**$279,600**		**$81,000**		**$957,600**	**$638**

RUs=resource units

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

- ➢ Plant bare root or smaller tree stock.
- ➢ Use trained volunteers for planting and pruning of young trees.
- ➢ 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 purchase and 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 five 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

Although organizing and training volunteers requires labor and resources, it is usually less costly than contracting the work. A cadre of trained volunteers can easily maintain trees until they reach a height of about 20 ft (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 can provide a strong branching structure that requires less frequent thinning and shaping (Costello 2000). Ideally, young trees are inspected and pruned every other year for the first five years after planting.

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 to eight years is usually sufficient for older trees (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, reduced violence, 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:

- *Urban and Community Forestry: A Guide for the Interior Western United States*. U.S. Forest Service, Intermountain Region, Ogden, UT. 1990.
- *An Introductory Guide to Community and Urban Forestry in Washington, Oregon, and California*. World Forestry Center, Portland, OR. Undated.
- *A Technical Guide to Urban and Community Forestry*. World Forestry Center, Portland, OR. 1993.

Copies are available from your state's urban and community forestry program coordinator.

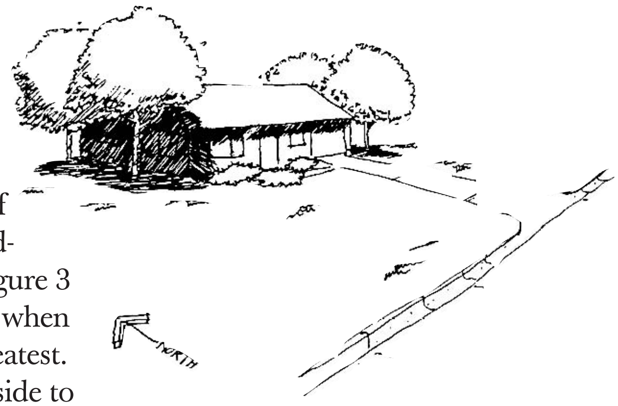
4. General Guidelines for Selecting and Siting Trees

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

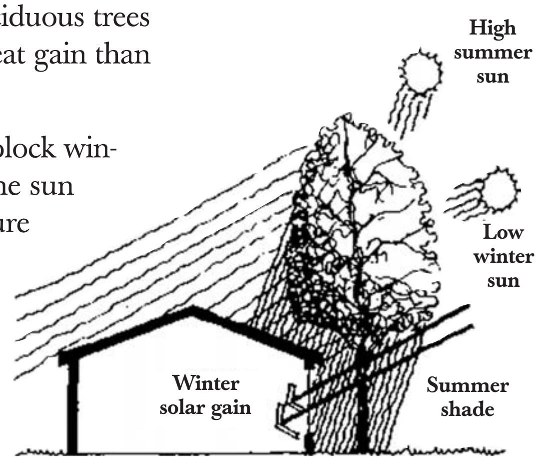
Where should shade trees be planted? The right tree in the right place can save energy and reduce tree are costs. In midsummer, the sun shines on the east side of a building in the morning, passes over the roof near midday, and then shines on the west side in the afternoon (Figure 3 on page 7). Electricity 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. Evergreens on the west side can provide both summer shade and winter wind protection.



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

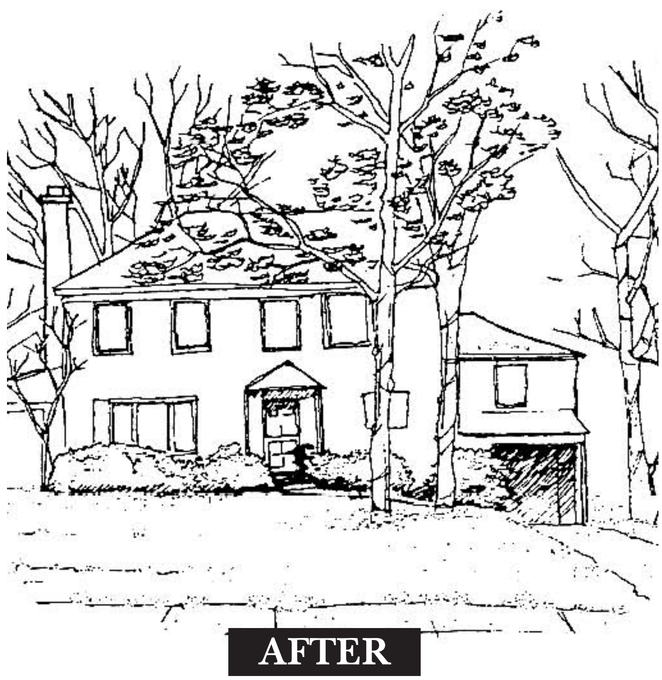
Depending on building orientation and window placement, sun shining through windows can heat a home quickly during the morning hours. The east side is the second most important side to shade when considering the net impact of tree shade on cooling and heating costs (Figure 9). Deciduous trees on the east side provide summer shade and more winter solar heat gain than evergreens.

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 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).



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

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.

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.

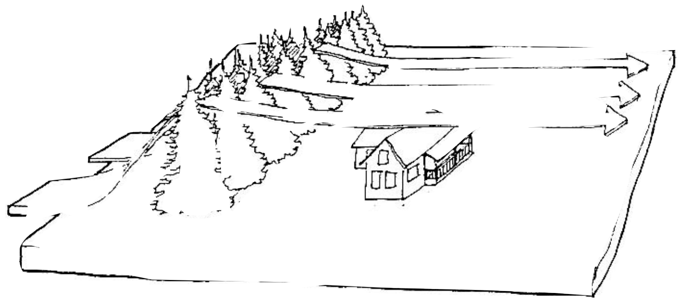
Planting Windbreaks for Heating Savings

With the long winter heating season in the Northern Mountain and Prairie region, additional energy savings can be obtained in situations where lot sizes are large enough to plant evergreen windbreaks. A tree's size and porosity can make it ideal at blocking wind, thereby reducing the impacts of cold winter weather and drying effects of summer winds.

Locating windbreaks. Locate rows of trees perpendicular to the prevailing wind (Figure 12), usually the north and west side of homes in this region. Remember that snow collects behind a windbreak. This can be a problem if the driveway is located between the trees and the home.

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 communities in the Northern Mountain and Prairie region include Colorado and Black Hills spruce (*P. pungens* and *P. glauca var. densata*), and Austrian and ponderosa pine (*Pinus nigra* and *P. ponderosa*). Good windbreak species for smaller sites include Eastern red cedar (*Juniperus virginiana*) and Rocky Mountain juniper (*J. scopulorum*).



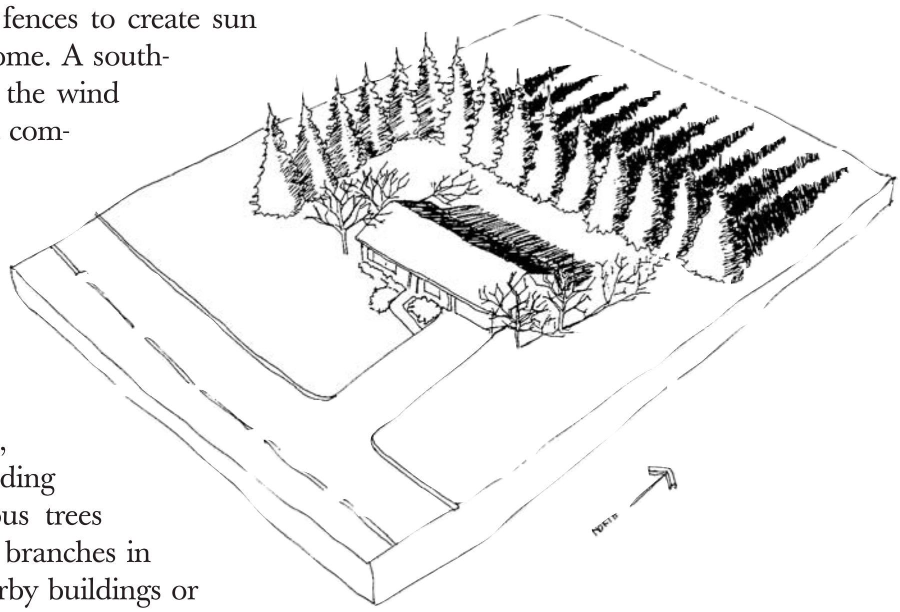
12. Evergreens guide wind over the building (from Sand, 1993).

In urban settings where vegetation is not a fire hazard, evergreens planted close to the home create dead airspaces that reduce air infiltration and heat loss. Allow shrubs to form thick hedges, especially along north, west, and east walls.

Consider using shrubs, trees, and fences to create sun pockets on the south side of the home. A south-facing patio that is protected from the wind can be used during sunny, cool but comfortable winter days.

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 and capable of 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.



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).

Picking the right tree. When selecting trees, match the tree's water requirements with those of surrounding plants. For instance, select low water-use species for planting in areas that receive little irrigation. Also, match the tree's maintenance requirements with the amount of care and the type of use different areas in the landscape receive. For instance, tree species that drop fruit that can be a slip-and-fall problem should not be planted near paved areas that are frequently used by pedestrians. 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.

Trees in Public Places

Locating and Selecting Trees to Maximize Climate Benefits

Large trees shade more

In common areas, along streets, in parking lots, and commercial areas locate trees to maximize shade on paving and parked vehicles. Shade trees reduce heat that is stored or reflected by paved surfaces. By cooling streets and parking areas, 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 guidelines listed below may help you maximize their ability to serve as CO_2 sinks:

- Provide as much pervious surface as possible (including use of porous concrete near trees) 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.
- 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), brooms, and 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.
- Provide a suitable soil environment for the trees in plazas, parking lots, and other difficult sites to maximize initial CO_2 sequestration and longevity. Encourage use of structural soils where appropriate.

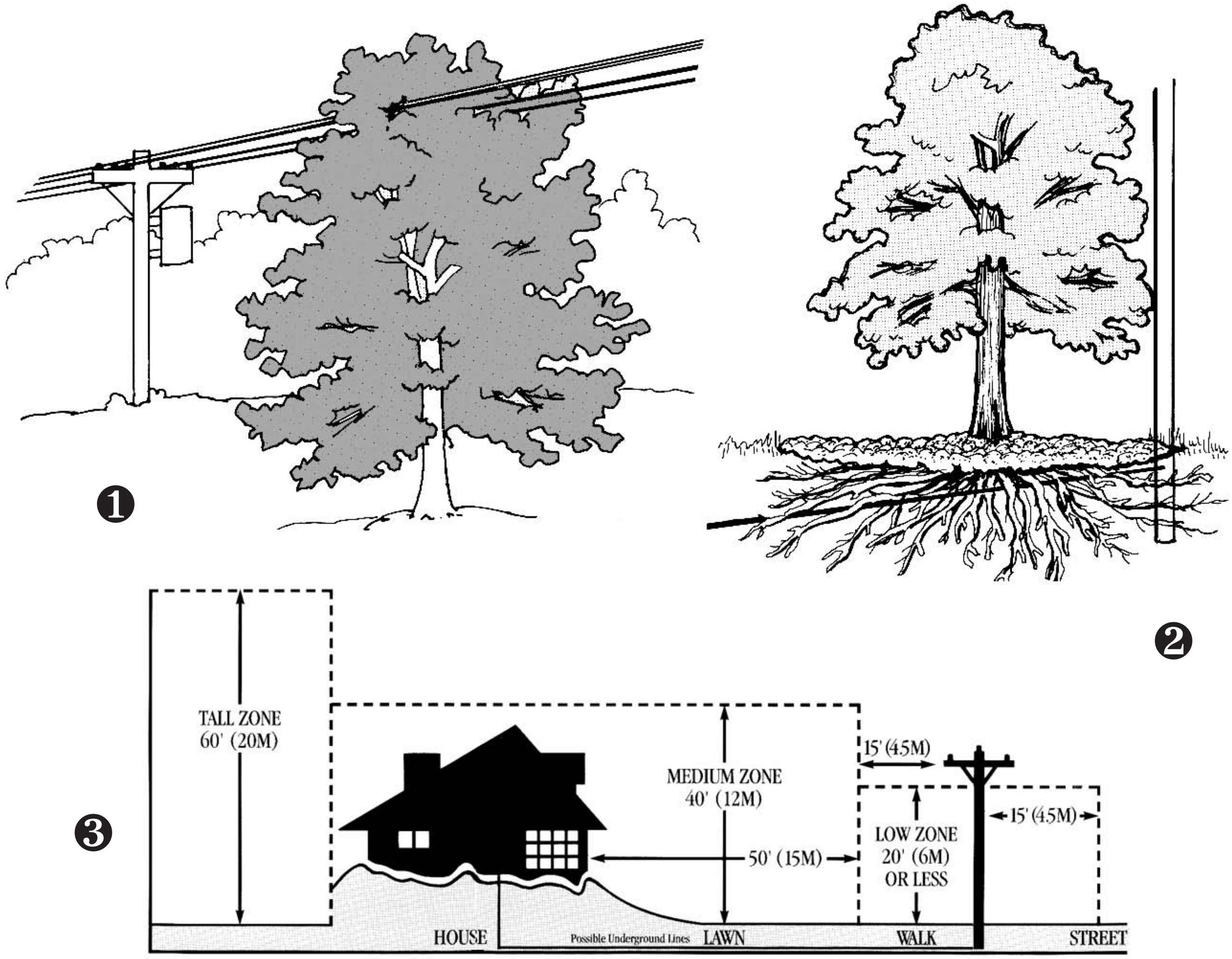
Locating and Selecting Trees to Maximize Stormwater Runoff Reduction Benefits

Strategies to control stormwater runoff through urban forestry include:

- Match trees to rainfall patterns so that they are in-leaf when precipitation is greatest.
- Select species with architectural features that maximize interception, such as large leaf surface area and rough surfaces that store water. Conifers intercept more rainfall than similar sized deciduous trees.
- Plant low-water use species and natives that, once established, require little supplemental irrigation.
- Plant more trees in appropriate areas.
- Improve the maintenance of existing trees.
- Plant species with rapid growth rates where appropriate.

Pay attention to infrastructure

Before planting contact your local utility company 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.



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)

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.

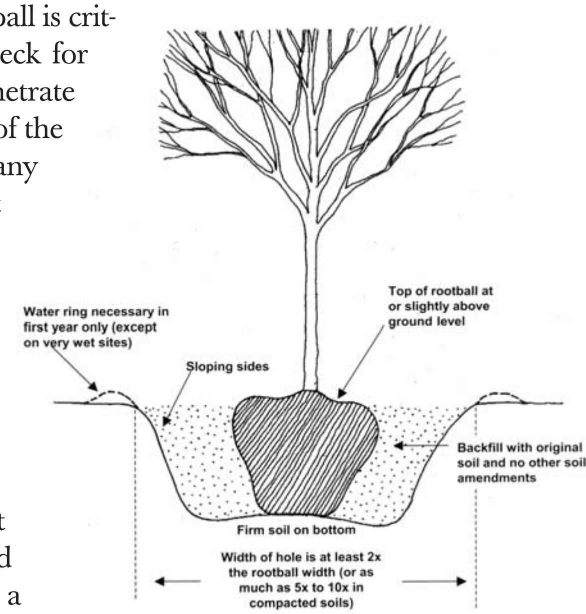
Match tree to site on case-by-case basis. Maintenance requirements and public safety issues influence the type of trees selected for public places. The ideal public tree is not susceptible to wind damage and branch drop, does not require frequent pruning, produces negligible litter, is deep-rooted, has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



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).

Mulch and water. 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 settle 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 more information

For additional information on tree planting, establishment, and care see the *Tree City USA Bulletin* series (Fazio undated), *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. Tree Selection List for Northern Mountain and Prairie Communities

In this chapter, recommended trees and their attributes are presented to help select the right tree for specific planting situations throughout the Northern Mountain and Prairie region.

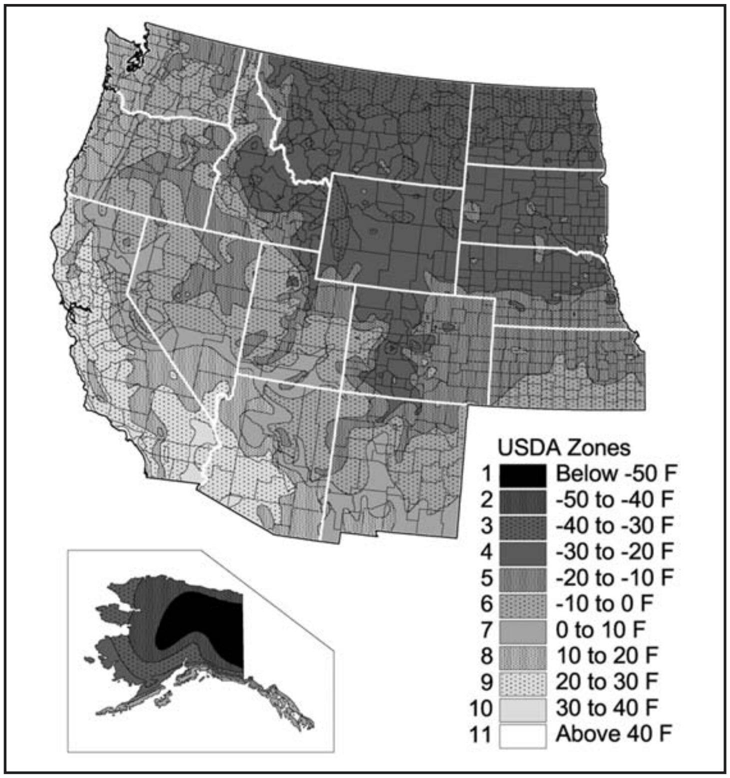
What is the geographic scope?

The Northern Mountain and Prairie Region is extensive and diverse. It covers much of the northern interior western states. Parts of 13 states make up this region. (Alaska was not included in this tree list, even though most of it is considered cold and snowy.) Elevations range from 1,000 feet (305 m) to over 14,000 feet (4,267 m). One of the highest communities is in Colorado at 10,000 feet (3,048 m). There is also a 900 mile (1,448 km) latitude change extending from approximately the 37th parallel in the south to the 49th parallel in the north.

Soil characteristics within this region vary greatly. Most soils will be alkaline. Semi-arid and arid regions found further west will be more alkaline than conditions found in the eastern half of the plains states. Selecting trees that can tolerate soils with high alkalinity is especially important in these areas.

Average rainfall ranges from seven inches (180 mm) in the western arid regions to 30 inches (762 mm) in the mountains and eastern end of the Great Plains. However, supplemental irrigation often occurs in landscapes to provide the necessary moisture for tree survival. Mulching and other moisture saving practices are encouraged to save water.

USDA Hardiness Zones found in this region range from 3 to 7 (Figure 16). Of course, the higher elevations of the Rockies get into Zones 1 and 2.



16. Recommended trees for the Northern Mountain and Prairie region grow well in USDA Hardiness Zones 1-6 and are acceptable for use by a number of municipalities in the region.

A characteristic common to this area, and detrimental to many trees, is the great fluctuation of temperature. This can occur between night and day, but even more devastating are the rapid fluctuations associated with winter conditions. Balmy conditions can occur during winter, but a cold front can cause temperatures to drop as much as 70-80°F (40-45°C) in less than 24 hours.

What are the selection criteria? A large number of tree species can grow in this region with proper irrigation and cultivation. The trees in this list were selected by urban and community forestry professionals in the 13-state area.

These are trees that are commonly found on arborist certification exams given by the International Society of Arboriculture. It is a broad selection of trees but does not include every possible selection. Microclimates exist, or are created, to support trees that normally grow in USDA Hardiness Zones greater than 7.

Tree and site characteristics provided in this list have to be used cautiously because of the wide geographic and climatic range involved. A tree noted with a slow growth rate may actually grow fast in another hardiness zone or protected site.

Shade for cooling is usually an important consideration when selecting a tree and one that is emphasized in many articles. However, in the Northern Mountain and Prairie Region, shade can be detrimental in the winter. Shade reduces the amount of solar penetration that can warm homes and melt snow. Be sure to analyze a tree's winter characteristics and select the appropriate one for the site.

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 pH, irrigation availability, 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, shade tolerance can effect growth, flowering, and disease susceptibility of some genera (e.g., *Prunus* and *Malus*) should be carefully considered when matching a tree to a site. Information in this chapter will assist in finding the best match possible.

What information is included?

Physical characteristics and definitions used for this matrix are listed below.

Tree Form: These are the basic shapes of the trees at maturity.

- **P**yrimidal – triangular in cross-section
- **O**val – elliptical in a vertical fashion
- **R**ound – self explanatory
- **V**ase – wider at top than at the base
- **I**rregular – no fundamental shape
- **C**olumnar – very upright in its growth
- **S**hrub **L**ike – small tree, often multi-stemmed.

Hardiness Zone: The U.S. Department of Agriculture's hardiness zone map was used. Range of zones in the Northern Mountain and Prairie Region is 3 to 7 (with higher elevations reaching zones 1 and 2).

Growth rate: Height growth was judged based on the ranges set below. Growth rates are markedly lower than in most other areas of the United States.

- **F**ast – more than 2 feet (> 0.6 m) per year
- **M**edium – 1 foot to 2 feet (0.3-0.6 m) per year
- **S**low – less than 1 foot (< 0.3 m) per year.

Relative size: This is the size of the tree at maturity.

- **S**mall – less than 25 feet (7.6 m) tall and wide. Trunk diameters are less than 20 inches (51 cm). Small trees fit nicely in 4- or 5-foot (1.2-1.5 m) tree lawns or landscape strips.
- **M**edium – 25-40 feet (7.6-12.2 m) tall and wide. Trunk diameters can be 20-30 inches (51-76 cm).
- **L**arge – greater than 40 feet (12.2 m) tall and wide. Trunk diameters are commonly over 30 inches (> 76 cm). Large trees need at least an 8-foot (2.4 m) tree lawn or landscape strip.

Shade Tolerance: Indicates the ability of the tree to grow well in shaded areas.

- **H**igh
- **M**oderate
- **L**ow

Longevity: Indicates how long the tree will live if properly planted and maintained.

- **S**hort – 50 years or less
- **M**edium – 50 to 200 years
- **L**ong – 200 years or more.

Root Habit: Indicates whether roots tend to grow deeply in the soil or nearer the surface. This is a very difficult to determine for some species because it depends greatly on the soil characteristics at the planting site.

- **S**hallow
- **D**eep

Tree List References

For more information

References used to develop the tree list include:

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

Johnson, C.W.; Baker, F.A.; Johnson, W.S. 1990. **Urban and Community Forestry: A Guide for the Interior Western United States**. USDA Forest Service, Intermountain Region, Ogden, UT.

Kuhns, M. 1998. **A Guide to the Trees of Utah and the Intermountain West**. Utah State University, Logan, UT.

Little, E. 1995. **Field Guide to Trees (Eastern and Western Editions)**. National Audubon Society, Knopf Publishing.

TREE SELECTION LIST

BOTANICAL NAME	COMMON NAME	Form	Zone (USDA)	Growth Rate	Relative Size	Shade Tolerance	Longevity	Root habit
Coniferous								
Abies concolor	white (concolor) fir	P	3-7	S	M-L	H	L	S
Abies lasiocarpa	subalpine fir	P	1-5	S	M	H	L	S
Juniperus chinensis	upright juniper	O	3-7	M	S	L	M	D
Juniperus osteosperma	Utah juniper	R	3-7	S	S	L	L	D
Juniperus scopulorum	Rocky Mountain juniper	O	3-7	M	S	L	L	D
Juniperus virginiana	Eastern red cedar	O	2-9	M	S	L	M	D
Picea abies	Norway spruce	P	2-7	M	M	H	M	S
Picea engelmannii	Engelmann spruce	P	2-5	S	M	H	M	S
Picea pungens	blue spruce	P	2-7	F	L	H	M	S
Picea glauca	white spruce	P	2-6	M	M	H	M	S
Pinus aristata	bristlecone pine	O	4-7	S	S	L	M	S
Pinus contorta	lodgepole pine	O	2-3	S	M	L	M	S
Pinus edulis	pinyon pine	R	4-7	S	S	L	L	D
Pinus flexilis	limber pine	R	2-4	S	M	L	L	D
Pinus nigra	Austrian pine	O	4-7	M	L	L	M	D
Pinus ponderosa	ponderosa pine	O	3-7	M	L	L	L	D
Pinus resinosa	Red pine	O	2-5	M	M	L	L	D
Pinus strobes	Eastern white pine	O	3-7	F	M	L	M	D
Pinus sylvestris	Scotch pine	O	3-7	F	M	L	M	D
Pseudotsuga menziesii	Douglas-fir	P	3-6	M	L	L-H	L	D
Taxodium distichum	Bald cypress	P	4-7	F	L	L	M	S
Deciduous								
Acer ginnala	amur (ginnala) maple	O	2-7	M	S	M	M	S
Acer glabrum	Rocky Mountain maple	R	3-7	M	S	H	M	S
Acer grandidentatum	bigtooth (Wasatch) maple	R	3-7	M	S	M	M	S
Acer negundo	boxelder	O	2-9	F	M	M	S	S
Acer platanoides	Norway maple	R	3-8	M	L	M	M	S
Acer pseudoplatanus	sycamore maple	O	4-7	M	L	M	M	S
Acer rubrum	red maple	R	3-9	M	L	M	M	S
Acer saccharinum	silver maple	O	3-9	F	L	M	M	S
Acer saccharum	sugar maple	O	4-8	F	L	H	M	D
Acer tataricum	tatarian maple	R	3-8	S	S	L	M	S

TREE SELECTION LIST

BOTANICAL NAME	COMMON NAME	Form	Zone (USDA)	Growth Rate	Relative Size	Shade Tolerance	Longevity	Root habit
Aesculus glabra	Ohio buckeye	R	3-7	S	M	H	L	D
Aesculus hippocastanum	Horsechestnut	O	3-7	S	M	H	L	D
Aesculus x carnea	red horsechestnut	O	3-7	S	M	H	L	D
Ailanthus altissima	tree-of-heaven	O	4-8	F	M	M	M	S
Albizia julibrissin	silk-tree (mimosa)	R	6-9	M	S	L	S	S
Alnus glutinosa	black alder	SL	3-7	F	S	M	S	S
Alnus incana	gray (speckled) alder	SL	3-7	F	S	M	S	S
Alnus sinuate	mountain alder	SL	2-7	F	S	M	S	S
Alnus tenuifolia	thinleaf alder	SL	2-7	F	S	M	S	S
Amelanchier aborea	serviceberry	SL	4-9	M	S	M	S	S
Betula nigra	river birch	P	3-9	F	M	M	M	D
Betula occidentalis	Western water birch	P	3-7	M	M	M	M	D
Betula papyrifera	paper birch	P	2-7	M	M	M	M	S
Betula pendula	European white birch	P	2-7	F	M	L	M	S
Betula platyphylla japonica	Japanese white birch	P	4-7	M	S	L	M	S
Carpinus betulus	European hornbeam	O	4-7	S	M	H	M	D
Carya ovata	Shagbark hickory	O	4-7	M	L	L	L	D
Catalpa bignonioides	Southern catalpa	I	5-9	F	L	L	L	D
Catalpa speciosa	Western catalpa	I	4-9	F	L	L	L	D
Celtis occidentalis	common hackberry	V	2-9	M	L	M	M	D
Celtis reticulata	netleaf hackberry	V	4-9	M	M	H	M	D
Cercis canadensis	Eastern redbud	R	3-9	M	S	H	M	D
Cercis occidentalis	Western redbud	R	7-9	M	S	H	M	D
Cornus florida	flowering dogwood	SL	5-9	F	S	H	M	S
Crategus spp.	hawthorn	R	2-8	M	S	H	M	D
Eleagnus angustifolia	Russian olive	R	2-7	F	M	M	M	D
Fagus sylvatica	European beech	O	4-7	S	L	H	L	D
Fraxinus americana	white ash	O	3-9	F	L	M	M	D
Fraxinus excelsior	European ash (single leaf)	R	5-8	M	L	M	M	D
Fraxinus mandshurica 'Mancana'	Mancana ash	R	3-5	M	L	M	M	D
Fraxinus nigra	black ash	O	2-5	M	M	M	M	D
Fraxinus pennsylvanica	green ash	O	3-9	F	L	M	M	D
Fraxinus velutina var. 'Modesto'	Modesto ash	O	5-9	M	M	M	M	D
Fraxinus quadrangulata	Blue ash	R	4-7	F	M	M	M	D

TREE SELECTION LIST

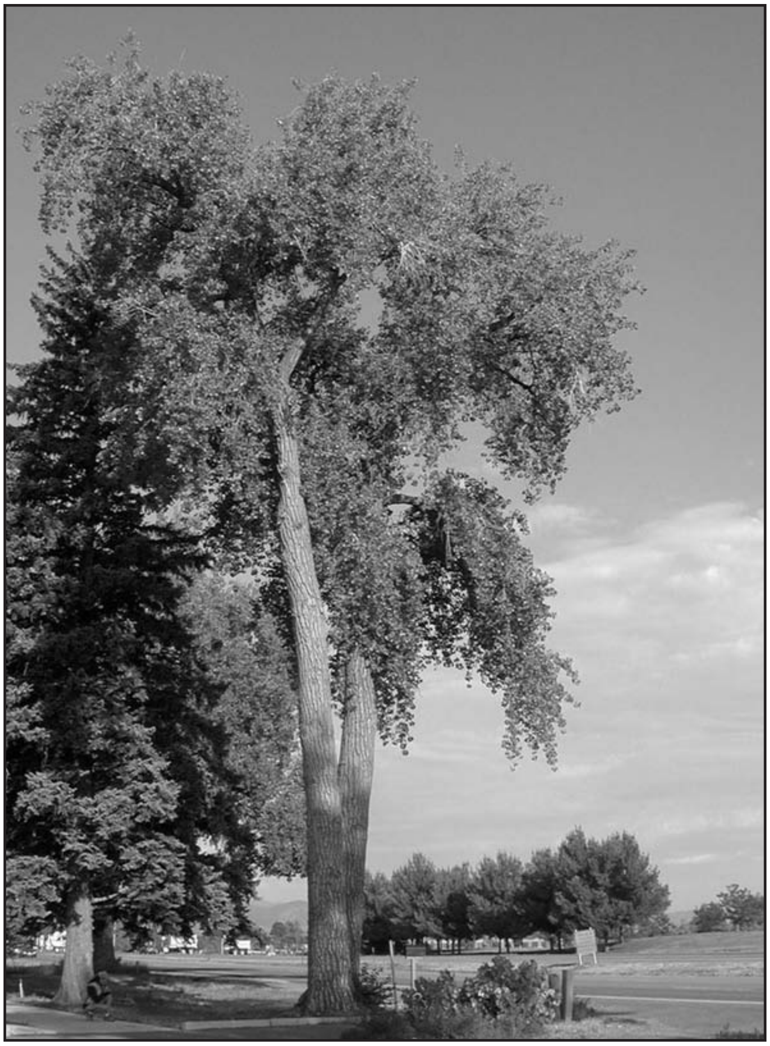
BOTANICAL NAME	COMMON NAME	Form	Zone (USDA)	Growth Rate	Relative Size	Shade Tolerance	Longevity	Root habit
Ginkgo biloba	Ginkgo	O	3-9	S	M	M	M	D
Gleditsia triacanthos	Honeylocust	O	3-9	F	L	L	M	S
Gymnocladus dioica	Kentucky coffeetree	O	3-8	S	L	L	M	D
Juglans nigra	black walnut	O	4-9	M	L	L	M	D
Juglans regia	English walnut	O	5-8	M	L	L	M	D
Koelreuteria paniculata	goldenrain tree	O	4-8	M	S	L	M	D
Laburnum x watereri	goldenchain tree	O	5-7	S	S	M	M	S
Liquidambar styraciflua	Sweetgum	P	5-9	M	L	L	M	S
Liriodendron tulipifera	tulip tree	O	4-9	M	L	L	M	S
Magnolia stellata	star magnolia	R	4-9	S	S	L	S	S
Magnolia x soulangiana	Magnolia	SL	4-9	S	S	L	S	S
Malus spp	apples and crabapples	R	3-9	F	S	L	M	D
Morus spp	Mulberry	R	4-9	F	L	H	M	S
Phellodendron amurense	Amur corktree	O	3-8	M	M	L	M	S
Platanus occidentalis	American sycamore	P	4-9	M	L	L	M	D
Platanus x acerifolia	London plane tree	P	4-9	M	L	L	M	D
Populus 'Highland'	Highland cottonwood	O	3-8	F	M	L	M	S
Populus alba	white (silver) poplar, bolleana ("pyramidalis")	P	3-9	F	L	L	S	S
Populus angustifolia	narrowleaf cottonwood	O	3-9	F	L	L	M	S
Populus canescens 'Tower'	Tower poplar	C	3-8	F	M	L	S	S
Populus deltoids	Eastern cottonwood	O	2-9	F	L	L	M	S
Populus fremontii	Fremont poplar	O	5-9	F	L	L	M	S
Populus nigra "italica"	Lombardy polar	C	3-9	F	M	L	S	S
Populus sargentii	plains cottonwood	O	3-8	F	L	L	M	S
Populus tremula 'Erecta'	Swedish aspen	C	2-5	F	M	L	M	S
Populus tremuloides	quaking aspen	O	2-6	F	S	L	S	S
Populus tricocarpa	black cottonwood	O	3-8	F	L	L	S	S
Populus x acuminata	lanceleaf cottonwood	O	3-9	F	L	L	M	S
Populus x canadensis	Carolina poplar	C	4-9	F	L	L	M	S
Populus x jackii 'Northwest'	Northwest poplar	O	4-9	F	L	L	M	S
Populus x robusta	Robusta poplar	O	3-9	F	L	L	M	S
Prunus americana	American plum	SL	2-7	F	S	L	S	S

TREE SELECTION LIST

BOTANICAL NAME	COMMON NAME	Form	Zone (USDA)	Growth Rate	Relative Size	Shade Tolerance	Longevity	Root habit
Prunus cerasifera "Newport"	Newport plum	O	4-9	M	S	L	M	S
Prunus cerasus	sour cherry	O	3-9	M	S	L	M	S
Prunus maackii	amur chokecherry	O	3-6	M	M	L	M	S
Prunus nigra 'Princess Kay'	Princess Kay plum	R	4-8	M	S	L	M	D
Prunus padus	European bird cherry	R	3-7	M	M	L	M	D
Prunus persica	Peach	R	5-9	F	S	L	S	D
Prunus serotina	black cherry	P	3-9	M	M	L	M	D
Prunus serrulata 'Kwanzan'	Japanese flowering cherry	R	5-9	M	M	L	M	D
Prunus virginiana	chokecherry(Canada red cherry)	O	2-6	F	S	L	M	D
Pyrus calleryana	Callery pear (Bradford)	P	5-9	F	S	L	M	D
Pyrus ussuriensis	Ussurian pear	O	3-7	F	S	L	M	D
Quercus alba	White oak	O	3-9	S	L	M	L	D
Quercus bicolor	swamp white oak	O	3-8	S	L	M	L	D
Quercus gambelii	scrub (gambel) oak	O	4-8	M	M	M	L	D
Quercus imbricaria	Shingle oak	P	4-8	S	L	M	L	D
Quercus macrocarpa	bur oak	O	2-8	S	L	M	L	D
Quercus palustris	pin oak	O	4-7	S	L	M	L	D
Quercus robur	English oak	P	4-8	M	M	M	L	D
Quercus rubra	Northern red oak	O	4-8	S	L	M	L	D
Quercus shumardii	Shumard oak	O	4-8	M	L	M	L	D
Quercus muehlenbergii	Chinkapin oak	P	5-9	M	L	M	L	D
Rhus glabra	smooth sumac	SL	3-9	S	F	M	S	S
Rhus typhina	staghorn sumac	SL	4-8	S	F	M	S	S
Robinia neomexicana	New Mexico locust	O	3-9	F	M	L	M	S
Robinia psuedoacacia	black locust	O	4-8	F	M	L	M	S
Robinia x ambigua 'Idahoensis'	Idaho flowering locust	O	3-9	F	M	L	M	S
Salix alba	white willow	R	2-9	F	L	L	M	S

TREE SELECTION LIST

BOTANICAL NAME	COMMON NAME	Form	Zone (USDA)	Growth Rate	Relative Size	Shade Tolerance	Longevity	Root habit
Salix amygdaloides	peach leaf willow	R	2-8	F	L	L	M	S
Salix babylonica	weeping willow	R	5-8	F	L	L	M	S
Salix discolor	pussy willow	SL	2-5	F	S	M	M	S
Salix gooddingii	black willow	R	4-9	F	L	L	M	S
Salix matsudana	globe willow	R	4-9	F	M	L	M	S
Salix pentandra	laurel willow	O	2-5	F	M	L	M	S
Salix x 'Prairie Cascade'	Prairie Cascade willow	O	3-5	F	M	L	M	S
Sophora japonica	Japanese pagoda tree	O	4-7	M	L	L	M	S
Sorbus aucuparia	European mountain-ash	P	3-7	M	M	L	M	S
Sorbus decora	showy mountain-ash	O	2-5	M	S	L	M	S
Sorbus x hybrida	oakleaf mountain-ash	P	4-5	M	S	L	M	S
Syringa reticulata	Japanese tree lilac	O	3-7	F	S	L	M	D
Tilia americana	American linden	P	2-9	M	L	H	M	D
Tilia cordata	littleleaf linden	P	2-9	M	L	H	M	D
Tilia mongolica	Mongolian linden	R	3-5	M	S	H	M	D
Tilia tomentosa	silverleaf linden	P	4-7	M	L	H	M	D
Ulmus americana	American elm	V	3-9	F	L	M	M	D
Ulmus carpinifolia	smooth-leaf elm	P	5-7	F	L	M	M	D
Ulmus parvifolia	lacebark (Chinese) elm	O	5-9	F	M	M	M	D
Ulmus procera	English elm	O	4-6	M	L	M	M	D
Ulmus pumila	Siberian elm	V	3-9	F	L	M	M	D
Zelkova serrata	Japanese zelkova	V	4-8	M	L	M	M	D



6. References

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

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

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.

CO2e.com. 2002. CO_2e Market Size and Pricing. Accessed via the World Wide Web <http://www.co2e.com/strategies/AdditionalInfo.asp?PageID=273#1613> on October 23, 2002.

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.

Dirr, M. A. 1998. **Manual Of Woody Landscape Plants**. 5th ed. Stipes Publishing, L.L.C., Champaign, Illinois.

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.

EIA. 2001b. **Natural Gas Annual 2000**, DOE/EIA-0131(00). Energy Information Administration, Office of Oil and Gas, U.S. Department of Energy, Washington, DC. 281 pp.

EIA. 2001a. **Electric Power Annual 2000 Volume I**, DOE/EIA-0348(2000)/1. Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, U.S. Department of Energy, Washington, DC. 66 pp.

Fazio, J.R. Undated. **Tree City USA Bulletin Series**. The National Arbor Day Foundation, Lincoln, NE.

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.; 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.

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**. Journal of Arboriculture. 9(10):253-258.

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

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

Johnson, C.W.; Baker, F.A.; Johnson, W.S. 1990. **Urban and Community Forestry: A Guide for the Interior Western United States**. USDA Forest Service, Ogden, UT: Intermountain Region.

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. 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 Experiment Station.

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

Kuhns, M. 1998. **A Guide to the Trees of Utah and the Intermountain West**. Utah State University, Logan, UT.

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

Little, E. 1995. **Field Guide to Trees (Eastern and Western Editions**). National Audubon Society, Knopf Publishing.

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

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.

McBride, K. 2002. **Personal communication on October 16**. Senior Stormwater Engineer, City of Fort Collins, CO.

McGannon, J. 2002. **Personal communication on September 26**. City Forester, City of Colorado Springs, CO.

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. 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.

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.

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.

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

Ramsay S. 2002. **Personal communication on December 19, 2002**. Executive Director, Trees Forever, Marion, IA.

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.

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.

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

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.

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. 2002. State and County Quick Facts. Accessed via the World Wide Web at <http://quickfacts.census.gov/qfd/states/08/08001.html> on October 22, 2002.

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). Accessed via the World Wide Web at <http://www.epa.gov/airmarkets/egrid/index.html> on November 4, 2002.

U.S. Environmental Protection Agency. 2002. **Monitor summary report: Colorado air quality summary (1999)**. Accessed via the World Wide Web at <http://www.epa.gov/air/data/monsum.html?st~CO~Colorado> on October 28, 2002.

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

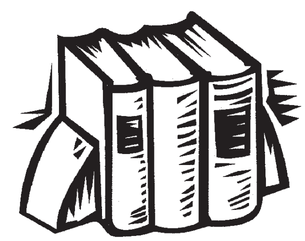
AFUE (Annual Fuel Utilization Efficiency): A measure of space heating equipment efficiency defined as the fraction of energy output/energy input.

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:

- *Fraxinus pennsylvanica* - 0.04 (Isoprene); 0.04 (Monoterprene); 0.12 (Other)
- *Acer platanoides* - 0.04 (Isoprene); 1.05 (Monoterprene); 0.32 (Other)
- M*alus spp.* - 0.04 (Isoprene); 0.04 (Monoterprene); 0.04 (Other)
- *Picea pungens* - 1.28 (Isoprene); 0.41 (Monoterprene); 0.12 (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 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.

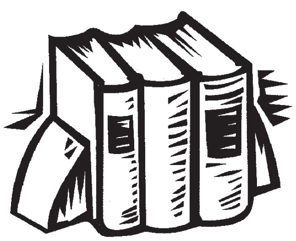
Contract Rate: The percentage of residential trees cared for by commercial arborists; the proportion of trees contracted out for a specific service (e.g., pruning or pest management).

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.

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

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.

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.

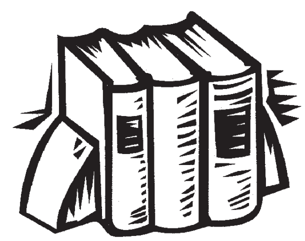
Mature Tree: A tree that has reached a desired size or age for its intended use. Size, age, or economic maturity varies depending on the species, location, growing conditions, and intended use.

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.

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.

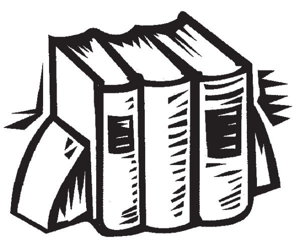
Photosynthesis: The process in green plants of converting water and carbon dioxide into sugar with light energy; accompanied by the production of oxygen.

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.

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.

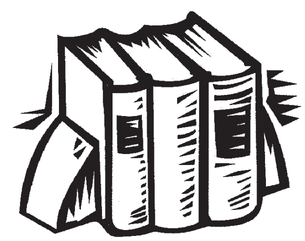
Tree Litter: Fruit, leaves, twigs, and other debris shed by trees.

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 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: (1) they use dark construction materials which absorb solar energy, (2) 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 tree plantings. The four tables contain data for the small (crabapple), medium (Norway maple), large (green ash), and conifer (Colorado spruce) 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 (RUs): the amount of air conditioning energy saved in kWh/yr/tree, air pollutant uptake in pounds/yr/tree, and rainfall intercepted in gallons/yr/tree. These values reflect the assumption that 40% of all trees planted will die over 40 years. Energy and CO_2 benefits for residential yard trees are broken out by tree location to show how shading impacts vary among trees opposite west-, south-, and east-facing building walls. In the row for Aesthetics and Other Benefits, the dollar value for Yard trees replaces values in RUs because there is no RU for this type of benefit. For the remaining rows the first column contains dollar values for Yard trees.

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

Costs for the Yard 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 Yard 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 annual values. These numbers were calculated by dividing the total stream of annual costs and benefits by 40 years.

Data table for large tree (green ash)

LARGE TREE	Year 5		Year 10		Year 15		Year 20		Year 25		Year 30		Year 35		Year 40		40 year average	
Benefits/tree	RU	$	RU	$	RU	$	RU	$	RU	$	RU	$	RU	$	RU	$	RU	$
Cooling (kWh)																		
Yard: West	24	1.87	52	4.04	86	6.69	118	9.19	131	10.23	139	10.81	140	10.96	146	11.42	104	$8.15
Yard: South	7	0.56	20	1.57	38	2.99	57	4.41	68	5.34	76	5.96	80	6.26	83	6.47	54	$4.19
Yard: East	12	0.96	30	2.33	53	4.13	75	5.88	88	6.85	96	7.45	99	7.71	103	8.00	69	$5.41
Public	1	0.11	9	0.72	22	1.71	35	2.76	47	3.65	55	4.28	60	4.64	61	4.77	36	$2.83
Heating (kBtu)																		
Yard: West	-181	-1.30	-218	-1.58	-182	-1.31	-117	-0.84	-49	-0.35	8	0.06	50	0.36	79	0.57	-76	-$0.55
Yard: South	-277	-2.00	-360	-2.60	-347	-2.50	-293	-2.11	-228	-1.65	-169	-1.22	-120	-0.87	-83	-0.60	-235	-$1.69
Yard: East	-219	-1.58	-274	-1.98	-247	-1.78	-186	-1.34	-120	-0.86	-62	-0.45	-17	-0.12	15	0.11	-139	-$1.00
Public	9	0.07	59	0.43	142	1.02	229	1.65	303	2.18	355	2.56	385	2.78	395	2.85	235	$1.69
Net Energy (kBtu)																		
Yard: West	59	0.57	299	2.46	676	5.38	1,062	8.35	1,263	9.88	1,393	10.86	1,455	11.32	1,542	11.98	969	$7.60
Yard: South	-205	-1.44	-159	-1.03	36	0.48	273	2.30	456	3.69	594	4.74	682	5.39	747	5.87	303	$2.50
Yard: East	-95	-0.61	24	0.35	282	2.34	568	4.54	758	5.98	893	7.00	971	7.58	1,040	8.10	555	$4.41
Public	23	0.18	151	1.15	361	2.73	583	4.41	771	5.83	904	6.84	980	7.42	1,006	7.62	597	$4.52
Net CO2 (lb)																		
Yard: West	41	0.30	119	0.90	220	1.65	315	2.36	361	2.71	386	2.90	391	2.93	399	2.99	279	$2.09
Yard: South	-12	-0.09	27	0.20	87	0.65	148	1.11	191	1.43	217	1.63	228	1.71	229	1.72	139	$1.05
Yard: East	8	0.06	61	0.46	135	1.01	207	1.55	250	1.88	276	2.07	285	2.14	287	2.16	189	$1.42
Public	13	0.10	57	0.43	114	0.86	169	1.26	211	1.58	237	1.78	247	1.85	241	1.81	161	$1.21
Air Pollution (lb)																		
O3 uptake	0.032	0.10	0.110	0.34	0.220	0.67	0.346	1.06	0.482	1.48	0.618	1.90	0.749	2.30	0.868	2.67	0.43	$1.32
NO2 uptake+avoided	0.047	0.14	0.146	0.45	0.287	0.88	0.433	1.33	0.535	1.64	0.613	1.88	0.667	2.05	0.716	2.20	0.43	$1.32
SO2 uptake+avoided	0.073	0.52	0.184	1.31	0.333	2.37	0.480	3.43	0.571	4.07	0.634	4.52	0.669	4.77	0.703	5.01	0.46	$3.25
PM10 uptake+avoided	0.020	0.10	0.055	0.28	0.099	0.51	0.145	0.74	0.184	0.94	0.218	1.12	0.246	1.26	0.273	1.40	0.16	$0.79
VOC's avoided	-0.000	-0.00	0.000	0.00	0.002	0.01	0.003	0.02	0.004	0.02	0.005	0.02	0.005	0.03	0.006	0.03	0.00	$0.02
BVOC's released	-0.001	-0.00	-0.003	-0.02	-0.006	-0.03	-0.011	-0.05	-0.015	-0.07	-0.020	-0.10	-0.025	-0.12	-0.030	-0.14	-0.01	-$0.07
Avoided + net uptake	0.172	0.86	0.492	2.37	0.934	4.41	1.398	6.53	1.762	8.09	2.068	9.35	2.312	10.29	2.536	11.16	1.46	$6.63
Hydrology (gal)																		
Rainfall Interception	115	1.24	381	4.12	737	7.96	1,116	12.06	1,442	15.57	1,755	18.95	1,984	21.43	2,143	23.14	1,209	$13.06
Aesthetics and	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public
Other Benefits	$8.86	$10.47	$12.99	$15.35	$15.35	$18.14	$16.34	$19.31	$16.29	$19.25	$15.49	$18.30	$14.17	$16.74	$12.54	$14.81	$14.00	$16.55
Total Benefits	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public
Yard: West	$11.84		$22.83		$34.76		$45.64		$52.54		$57.55		$60.14		$61.81		$43.39	
Yard: South	$9.44		$18.65		$28.87		$38.34		$45.07		$50.15		$52.99		$54.43		$37.24	
Yard: East	$10.41		$20.28		$31.09		$41.02		$47.81		$52.86		$55.61		$57.09		$39.52	
Public		$12.85		$23.41		$34.11		$43.57		$50.33		$55.22		$57.73		$58.54		$41.97

LARGE TREE	Year 5		Year 10		Year 15		Year 20		Year 25		Year 30		Year 35		Year 40		40 year average	
Costs ($/yr/tree)	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public
Tree & Planting	40.00	40.00	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	0.00	$5.00	$5.00
Pruning	0.06	9.66	1.53	9.19	1.46	8.74	3.16	11.08	3.00	10.54	2.86	10.02	2.72	9.53	2.58	9.06	$2.08	$9.14
Remove & Dispose	3.49	2.56	1.85	1.36	2.46	1.81	2.98	2.19	3.43	2.52	3.80	2.79	4.10	3.02	4.35	3.20	$2.99	$2.19
Pest & Disease	0.01	0.08	0.01	0.13	0.02	0.17	0.02	0.21	0.02	0.24	0.03	0.27	0.03	0.29	0.03	0.30	$0.02	$0.20
Infrastructure	0.02	0.20	0.04	0.32	0.05	0.43	0.06	0.52	0.07	0.60	0.08	0.66	0.09	0.71	0.09	0.76	$0.06	$0.49
Irrigation	4.29	4.29	0.08	0.08	0.13	0.13	0.20	0.20	0.26	0.26	0.32	0.32	0.37	0.37	0.42	0.42	$0.77	$0.77
Clean-Up	0.01	0.07	0.02	0.12	0.02	0.16	0.02	0.19	0.03	0.22	0.03	0.25	0.03	0.27	0.04	0.28	$0.02	$0.18
Liability & Legal	0.01	0.05	0.01	0.07	0.01	0.08	0.01	0.09	0.01	0.09	0.01	0.09	0.01	0.09	0.01	0.09	$0.01	$0.08
Admin & Other	0.02	1.13	0.04	1.83	0.05	2.44	0.06	2.95	0.07	3.39	0.07	3.76	0.08	4.06	0.08	4.31	$0.05	$2.79
Total Costs	$47.91	$58.05	$3.57	$13.09	$4.20	$13.96	$6.52	$17.43	$6.90	$17.86	$7.20	$18.16	$7.44	$18.35	$7.61	$18.43	$11.02	$20.85
Total Net Benefits																		
Yard: West	-$36		$19		$31		$39		$46		$50		$53		$54		$32	
Yard: South	-$38		$15		$25		$32		$38		$43		$46		$47		$26	
Yard: East	-$37		$17		$27		$35		$41		$46		$48		$49		$29	
Public		-$45		$10		$20		$26		$32		$37		$39		$40		$21

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	RU	$	RU	$	RU	$	RU	$	RU	$	RU	$	RU	$	RU	$	RU	$
Cooling (kWh)																		
Yard: West	21	1.63	43	3.32	68	5.30	91	7.12	99	7.70	102	7.97	102	7.96	107	8.32	79	$6.17
Yard: South	8	0.61	18	1.41	31	2.43	44	3.42	50	3.91	54	4.21	55	4.32	58	4.49	40	$3.10
Yard: East	13	1.03	28	2.19	46	3.61	63	4.93	70	5.46	74	5.74	74	5.81	78	6.05	56	$4.35
Public	1	0.05	5	0.36	11	0.85	18	1.38	23	1.82	27	2.14	30	2.32	31	2.38	18	$1.41
Heating (kBtu)																		
Yard: West	-171	-1.23	-228	-1.64	-229	-1.65	-206	-1.48	-174	-1.26	-144	-1.04	-118	-0.85	-96	-0.69	-171	-$1.23
Yard: South	-252	-1.82	-347	-2.50	-368	-2.65	-353	-2.55	-325	-2.34	-293	-2.11	-261	-1.88	-231	-1.67	-304	-$2.19
Yard: East	-202	-1.46	-273	-1.97	-281	-2.03	-261	-1.89	-231	-1.67	-200	-1.44	-172	-1.24	-147	-1.06	-221	-$1.59
Public	5	0.03	30	0.21	71	0.51	114	0.83	151	1.09	177	1.28	192	1.39	197	1.42	117	$0.85
Net Energy (kBtu)																		
Yard: West	37	0.39	198	1.68	451	3.65	707	5.64	813	6.45	877	6.93	902	7.11	971	7.63	620	$4.93
Yard: South	-174	-1.21	-166	-1.09	-56	-0.22	84	0.87	176	1.56	247	2.09	293	2.44	344	2.82	94	$0.91
Yard: East	-70	-0.43	8	0.22	181	1.58	371	3.04	469	3.79	536	4.30	573	4.57	629	5.00	337	$2.76
Public	12	0.09	76	0.57	180	1.37	291	2.21	385	2.92	452	3.42	490	3.71	503	3.81	299	$2.26
Net CO2 (lb)																		
Yard: West	31	0.23	84	0.63	154	1.15	219	1.64	245	1.84	258	1.94	259	1.94	266	2.00	189	$1.42
Yard: South	-11	-0.08	11	0.08	49	0.37	88	0.66	111	0.83	126	0.94	131	0.98	133	1.00	80	$0.60
Yard: East	9	0.06	45	0.33	96	0.72	146	1.09	170	1.28	184	1.38	187	1.40	192	1.44	128	$0.96
Public	7	0.05	30	0.22	60	0.45	89	0.67	112	0.84	126	0.95	131	0.98	128	0.96	85	$0.64
Air Pollution (lb)																		
O3 uptake	0.045	0.14	0.113	0.35	0.201	0.62	0.300	0.92	0.406	1.25	0.512	1.57	0.615	1.89	0.711	2.19	0.36	$1.11
NO2 uptake+avoided	0.049	0.15	0.124	0.38	0.225	0.69	0.327	1.00	0.389	1.19	0.437	1.34	0.471	1.45	0.510	1.57	0.32	$0.97
SO2 uptake+avoided	0.071	0.51	0.157	1.12	0.264	1.88	0.368	2.62	0.420	2.99	0.454	3.24	0.472	3.36	0.499	3.56	0.34	$2.41
PM10 uptake+avoided	0.025	0.13	0.053	0.27	0.086	0.44	0.120	0.61	0.147	0.75	0.172	0.88	0.193	0.99	0.214	1.10	0.13	$0.65
VOC's avoided	-0.000	-0.01	0.000	0.00	0.001	0.02	0.002	0.04	0.002	0.05	0.003	0.05	0.003	0.06	0.003	0.06	0.00	$0.04
BVOC's released	-0.025	-0.12	-0.050	-0.24	-0.076	-0.37	-0.102	-0.49	-0.129	-0.62	-0.157	-0.76	-0.186	-0.90	-0.217	-1.05	-0.12	-$0.57
Avoided + net uptake	0.165	0.80	0.397	1.88	0.701	3.29	1.015	4.71	1.235	5.61	1.420	6.33	1.566	6.84	1.721	7.42	1.03	$4.61
Hydrology (gal)																		
Rainfall Interception	216	2.34	469	5.06	751	8.11	967	10.44	1,126	12.16	1,245	13.44	1,366	14.75	1,443	15.58	948	$10.24
Aesthetics and	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public
Other Benefits	$9.71	$11.47	$9.14	$10.80	$8.76	$10.35	$8.46	$10.00	$8.18	$9.67	$7.87	$9.30	$7.49	$8.85	$7.03	$8.31	$8.33	$9.84
Total Benefits	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public
Yard: West	$13.46		$18.39		$24.96		$30.89		$34.24		$36.50		$38.14		$39.66		$29.53	
Yard: South	$11.56		$15.08		$20.30		$25.13		$28.35		$30.67		$32.50		$33.86		$24.68	
Yard: East	$12.48		$16.64		$22.45		$27.75		$31.02		$33.32		$35.06		$36.47		$26.90	
Public		$14.75		$18.54		$23.56		$28.02		$31.20		$33.43		$35.14		$36.08		$27.59
MEDIUM TREE	Year 5		Year 10		Year 15		Year 20		Year 25		Year 30		Year 35		Year 40		40 year average	
Costs ($/yr/tree)	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public
Tree & Planting	40.00	40.00	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	0.00	$5.00	$5.00
Pruning	0.06	4.29	1.53	9.19	1.46	8.74	1.38	8.31	1.32	7.90	2.86	10.02	2.72	9.53	2.58	9.06	$1.73	$8.46
Remove & Dispose	3.28	2.41	1.73	1.27	2.30	1.69	2.77	2.04	3.17	2.33	3.49	2.57	3.76	2.76	3.96	2.91	$2.77	$2.03
Pest & Disease	0.01	0.07	0.01	0.12	0.02	0.16	0.02	0.19	0.02	0.22	0.02	0.24	0.03	0.26	0.03	0.28	$0.02	$0.18
Infrastructure	0.02	0.19	0.04	0.30	0.05	0.40	0.06	0.48	0.07	0.55	0.08	0.61	0.08	0.65	0.09	0.69	$0.06	$0.45
Irrigation	4.29	4.29	0.09	0.09	0.13	0.13	0.16	0.16	0.19	0.19	0.21	0.21	0.24	0.24	0.26	0.26	$0.72	$0.72
Clean-Up	0.01	0.07	0.01	0.11	0.02	0.15	0.02	0.18	0.03	0.21	0.03	0.23	0.03	0.25	0.03	0.26	$0.02	$0.17
Liability & Legal	0.01	0.05	0.01	0.06	0.01	0.07	0.01	0.07	0.01	0.07	0.01	0.08	0.01	0.08	0.01	0.07	$0.01	$0.07
Admin & Other	0.02	1.06	0.03	1.71	0.04	2.27	0.05	2.74	0.06	3.14	0.07	3.46	0.07	3.72	0.08	3.92	$0.05	$2.58
Total Costs	$47.69	$52.43	$3.46	$12.86	$4.02	$13.60	$4.48	$14.18	$4.86	$14.61	$6.77	$17.42	$6.93	$17.48	$7.04	$17.46	$10.38	$19.67
Total Net Benefits																		
Yard: West	-$34		$15		$21		$26		$29		$30		$31		$33		$19	
Yard: South	-$36		$12		$16		$21		$23		$24		$26		$27		$14	
Yard: East	-$35		$13		$18		$23		$26		$27		$28		$29		$17	
Public		-$38		$6		$10		$14		$17		$16		$18		$19		$8

Data table for small tree (crabapple species)

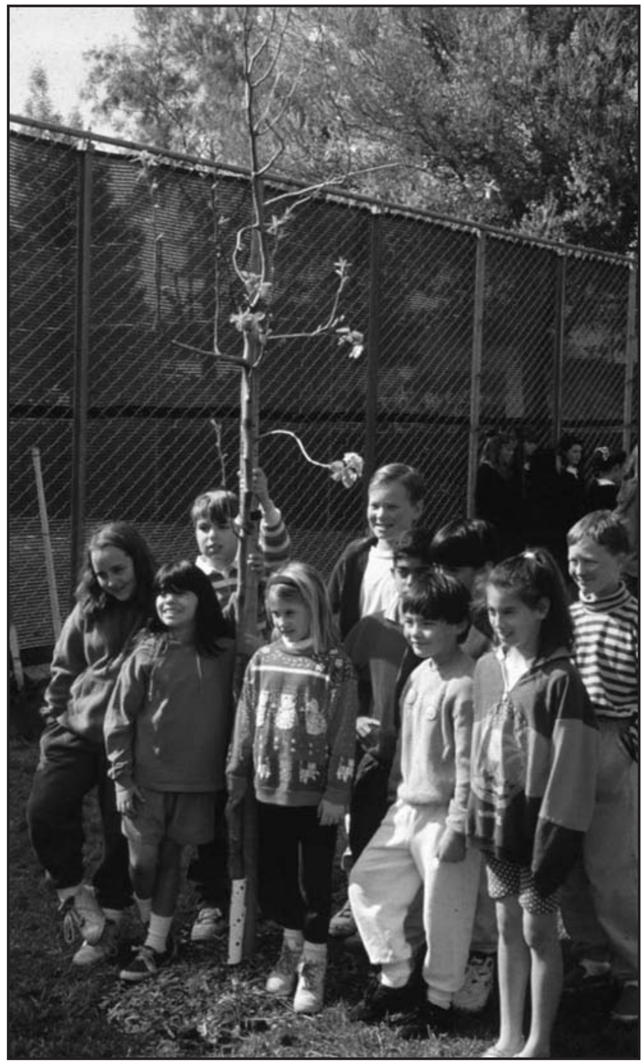
SMALL TREE Benefits	Year 5 RU	Year 5 $	Year 10 RU	Year 10 $	Year 15 RU	Year 15 $	Year 20 RU	Year 20 $	Year 25 RU	Year 25 $	Year 30 RU	Year 30 $	Year 35 RU	Year 35 $	Year 40 RU	Year 40 $	40 year average RU	40 year average $
Cooling (kWh)																		
Yard: West	15	1.19	30	2.34	46	3.62	61	4.77	64	5.03	65	5.10	64	5.02	68	5.27	52	$4.04
Yard: South	4	0.33	9	0.71	15	1.18	21	1.62	23	1.80	24	1.90	25	1.93	26	2.01	18	$1.43
Yard: East	9	0.68	18	1.37	28	2.17	37	2.90	40	3.11	41	3.20	41	3.18	43	3.33	32	$2.49
Public	0	0.02	2	0.13	4	0.30	6	0.48	8	0.64	10	0.75	10	0.81	11	0.83	6	$0.49
Heating (kBtu)																		
Yard: West	-160	-1.16	-227	-1.64	-252	-1.82	-255	-1.84	-248	-1.79	-235	-1.69	-219	-1.58	-202	-1.45	-225	-$1.62
Yard: South	-219	-1.58	-314	-2.26	-353	-2.55	-363	-2.62	-357	-2.58	-343	-2.47	-323	-2.33	-300	-2.17	-321	-$2.32
Yard: East	-186	-1.34	-265	-1.91	-295	-2.13	-302	-2.18	-295	-2.13	-281	-2.03	-264	-1.90	-244	-1.76	-266	-$1.92
Public	2	0.01	10	0.07	25	0.18	40	0.29	53	0.38	62	0.45	67	0.49	69	0.50	41	$0.30
Net Energy (kBtu)																		
Yard: West	-8	0.03	72	0.70	212	1.80	356	2.93	397	3.24	419	3.40	424	3.44	474	3.81	293	$2.42
Yard: South	-177	-1.25	-223	-1.55	-202	-1.37	-155	-1.00	-126	-0.78	-99	-0.57	-76	-0.41	-43	-0.16	-138	-$0.89
Yard: East	-99	-0.66	-89	-0.54	-17	0.04	70	0.72	104	0.98	129	1.17	144	1.28	183	1.57	53	$0.57
Public	4	0.03	26	0.20	63	0.48	102	0.77	135	1.02	158	1.19	171	1.30	176	1.33	104	$0.79
Net CO2 (lb)																		
Yard: West	16	0.12	50	0.37	92	0.69	131	0.99	142	1.07	145	1.09	140	1.05	144	1.08	108	$0.81
Yard: South	-17	-0.13	-11	-0.08	6	0.04	23	0.17	31	0.23	34	0.26	34	0.25	33	0.25	16	$0.12
Yard: East	-2	-0.02	16	0.12	43	0.32	69	0.52	78	0.59	82	0.61	79	0.60	80	0.60	56	$0.42
Public	3	0.02	15	0.11	30	0.22	42	0.32	51	0.38	54	0.40	52	0.39	47	0.35	37	$0.28
Air Pollution (lb)																		
O3 uptake	0.044	0.14	0.102	0.31	0.176	0.54	0.261	0.80	0.352	1.08	0.444	1.37	0.536	1.65	0.622	1.91	0.32	$0.97
NO2 uptake+avoided	0.032	0.10	0.078	0.24	0.138	0.42	0.199	0.61	0.235	0.72	0.266	0.82	0.290	0.89	0.321	0.98	0.19	$0.60
SO2 uptake+avoided	0.049	0.35	0.101	0.72	0.163	1.16	0.222	1.58	0.248	1.77	0.265	1.89	0.274	1.95	0.293	2.09	0.20	$1.44
PM10 uptake+avoided	0.022	0.11	0.042	0.22	0.066	0.34	0.091	0.47	0.112	0.58	0.132	0.68	0.150	0.77	0.168	0.86	0.10	$0.50
VOC's avoided	-0.000	-0.01	-0.000	-0.01	0.000	0.00	0.000	0.01	0.001	0.01	0.001	0.02	0.001	0.02	0.001	0.02	0.00	$0.01
BVOC's released	-0.000	-0.00	-0.001	-0.00	-0.002	-0.01	-0.002	-0.01	-0.004	-0.02	-0.005	-0.02	-0.006	-0.03	-0.008	-0.04	-0.00	-$0.02
Avoided + net uptake	0.146	0.69	0.322	1.48	0.542	2.46	0.772	3.46	0.944	4.14	1.103	4.74	1.244	5.24	1.398	5.83	0.81	$3.51
Hydrology (gal)																		
Rainfall Interception	63	0.68	171	1.85	286	3.09	434	4.69	616	6.65	788	8.51	960	10.36	1,075	11.61	549	$5.93
Aesthetics and	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public
Other Benefits	$3.50	$4.14	$4.11	$4.86	$5.03	$5.94	$5.96	$7.04	$6.69	$7.90	$7.11	$8.40	$7.17	$8.47	$6.88	$8.12	$5.81	$6.86
Total Benefits	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public
Yard: West	$5.03		$8.51		$13.07		$18.02		$21.78		$24.84		$27.27		$29.21		$18.47	
Yard: South	$3.49		$5.81		$9.25		$13.28		$16.93		$20.04		$22.63		$24.41		$14.48	
Yard: East	$4.19		$7.02		$10.94		$15.35		$19.05		$22.14		$24.65		$26.49		$16.23	
Public		$5.56		$8.50		$12.19		$16.28		$20.09		$23.24		$25.77		$27.25		$17.36

SMALL TREE Costs ($/yr/tree)	Year 5 Yard	Year 5 Public	Year 10 Yard	Year 10 Public	Year 15 Yard	Year 15 Public	Year 20 Yard	Year 20 Public	Year 25 Yard	Year 25 Public	Year 30 Yard	Year 30 Public	Year 35 Yard	Year 35 Public	Year 40 Yard	Year 40 Public	40 year average Yard	40 year average Public
Tree & Planting	40.00	40.00	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	0.00	$5.00	$5.00
Pruning	0.06	4.29	0.09	4.08	1.46	8.74	1.38	8.31	1.32	7.90	1.25	7.51	1.19	7.15	1.13	6.80	$0.97	$6.77
Remove & Dispose	2.92	2.15	1.65	1.21	2.22	1.63	2.69	1.98	3.07	2.25	3.36	2.47	3.58	2.63	3.73	2.74	$2.65	$1.94
Pest & Disease	0.01	0.07	0.01	0.12	0.02	0.16	0.02	0.19	0.02	0.21	0.02	0.23	0.02	0.25	0.03	0.26	$0.02	$0.17
Infrastructure	0.02	0.17	0.04	0.29	0.05	0.39	0.06	0.47	0.07	0.53	0.07	0.58	0.08	0.62	0.08	0.65	$0.05	$0.43
Irrigation	4.29	4.29	0.03	0.03	0.05	0.05	0.07	0.07	0.10	0.10	0.12	0.12	0.15	0.15	0.18	0.18	$0.65	$0.65
Clean-Up	0.01	0.06	0.01	0.11	0.02	0.14	0.02	0.18	0.02	0.20	0.03	0.22	0.03	0.23	0.03	0.24	$0.02	$0.16
Liability & Legal	0.00	0.03	0.00	0.04	0.01	0.04	0.01	0.05	0.01	0.05	0.01	0.05	0.01	0.05	0.01	0.05	$0.01	$0.04
Admin & Other	0.02	0.95	0.03	1.63	0.04	2.20	0.05	2.66	0.06	3.03	0.07	3.32	0.07	3.54	0.07	3.69	$0.05	$2.46
Total Costs	$47.33	$52.01	$1.87	$7.50	$3.86	$13.35	$4.30	$13.90	$4.66	$14.28	$4.93	$14.52	$5.12	$14.62	$5.25	$14.60	$9.41	$17.63
Total Net Benefits																		
Yard: West	-$42		$7		$9		$14		$17		$20		$22		$24		$9	
Yard: South	-$44		$4		$5		$9		$12		$15		$18		$19		$5	
Yard: East	-$43		$5		$7		$11		$14		$17		$20		$21		$7	
Public		-$46		$1		-$1		$2		$6		$9		$11		$13		-$0

Data table for conifer (Colorado spruce)

CONIFER Benefits/tree	Year 5 RU	Year 5 $	Year 10 RU	Year 10 $	Year 15 RU	Year 15 $	Year 20 RU	Year 20 $	Year 25 RU	Year 25 $	Year 30 RU	Year 30 $	Year 35 RU	Year 35 $	Year 40 RU	Year 40 $	40 year average RU	40 year average $
Cooling (kWh)																		
Yard (no shade)	1	0.10	8	0.64	20	1.53	32	2.46	42	3.26	49	3.82	53	4.15	55	4.25	32	$2.53
Public	1	0.10	8	0.64	20	1.53	32	2.46	42	3.26	49	3.82	53	4.15	55	4.25	32	$2.53
Heating (kBtu)																		
Yard (no shade)	13	0.09	85	0.61	202	1.46	327	2.36	432	3.12	507	3.66	550	3.97	564	4.07	335	$2.42
Public	13	0.09	85	0.61	202	1.46	327	2.36	432	3.12	507	3.66	550	3.97	564	4.07	335	$2.42
Net Energy (kBtu)																		
Yard (no shade)	26	0.19	167	1.25	398	2.99	643	4.82	850	6.38	997	7.48	1,081	8.11	1,110	8.32	659	$4.94
Public	26	0.19	167	1.25	398	2.99	643	4.82	850	6.38	997	7.48	1,081	8.11	1,110	8.32	659	$4.94
Net CO2 (lb)																		
Yard (no shade)	4	0.03	30	0.22	74	0.56	122	0.92	162	1.22	189	1.42	202	1.52	202	1.51	123	$0.92
Public	4	0.03	30	0.22	74	0.56	122	0.92	162	1.22	189	1.42	202	1.52	202	1.51	123	$0.92
Air Pollution (lb)																		
O3 uptake	0.017	0.05	0.068	0.21	0.153	0.47	0.249	0.76	0.344	1.06	0.431	1.32	0.506	1.55	0.568	1.74	0.29	$0.90
NO2 uptake+avoided	0.013	0.04	0.069	0.21	0.163	0.50	0.263	0.81	0.352	1.08	0.421	1.29	0.468	1.44	0.494	1.52	0.28	$0.86
SO2 uptake+avoided	0.010	0.07	0.060	0.43	0.142	1.01	0.230	1.64	0.306	2.18	0.362	2.58	0.398	2.84	0.415	2.96	0.24	$1.71
PM10 uptake+avoided	0.011	0.05	0.037	0.19	0.077	0.39	0.118	0.60	0.154	0.79	0.185	0.95	0.208	1.07	0.225	1.16	0.13	$0.65
VOC's avoided	0.000	0.00	0.001	0.00	0.002	0.01	0.003	0.02	0.005	0.02	0.005	0.03	0.006	0.03	0.006	0.03	0.00	$0.02
BVOC's released	-0.004	-0.02	-0.052	-0.25	-0.161	-0.78	-0.307	-1.49	-0.476	-2.31	-0.654	-3.17	-0.831	-4.02	-0.999	-4.84	-0.44	-$2.11
Avoided + net uptake	0.047	0.20	0.182	0.79	0.376	1.61	0.555	2.34	0.685	2.83	0.751	3.01	0.756	2.90	0.709	2.56	0.51	$2.03
Hydrology (gal)																		
Rainfall Interception	11	0.12	174	1.87	539	5.83	1,006	10.87	1,415	15.28	1,741	18.80	1,936	20.91	2,092	22.59	1,114	$12.03
Aesthetics and	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public
Other Benefits	$2.85	$3.37	$7.34	$8.67	$9.77	$11.54	$10.71	$12.65	$10.61	$12.54	$9.84	$11.62	$8.66	$10.23	$7.27	$8.60	$8.38	$9.90
Total Benefits	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public
Yard: West	$3.39		$11.48		$20.74		$29.66		$36.31		$40.55		$42.09		$42.27		$28.31	
Yard: South	$3.39		$11.48		$20.74		$29.66		$36.31		$40.55		$42.09		$42.27		$28.31	
Yard: East	$3.39		$11.48		$20.74		$29.66		$36.31		$40.55		$42.09		$42.27		$28.31	
Public		$3.90		$12.81		$22.52		$31.60		$38.24		$42.33		$43.66		$43.59		$29.83

CONIFER Costs ($/yr/tree)	Year 5 Yard	Year 5 Public	Year 10 Yard	Year 10 Public	Year 15 Yard	Year 15 Public	Year 20 Yard	Year 20 Public	Year 25 Yard	Year 25 Public	Year 30 Yard	Year 30 Public	Year 35 Yard	Year 35 Public	Year 40 Yard	Year 40 Public	40 year average Yard	40 year average Public
Tree & Planting	40.00	40.00	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	0.00	$5.00	$5.00
Pruning	0.06	4.29	1.53	4.08	1.46	8.74	3.16	8.31	3.00	7.90	2.86	10.02	2.72	9.53	2.58	9.06	$2.13	$7.17
Remove & Dispose	1.39	1.02	1.45	1.06	2.27	1.67	2.95	2.17	3.48	2.56	3.90	2.87	4.21	3.10	4.42	3.25	$2.81	$2.06
Pest & Disease	0.00	0.03	0.01	0.10	0.02	0.16	0.02	0.21	0.02	0.24	0.03	0.27	0.03	0.29	0.03	0.31	$0.02	$0.19
Infrastructure	0.01	0.08	0.03	0.25	0.05	0.40	0.06	0.51	0.08	0.61	0.08	0.68	0.09	0.73	0.10	0.77	$0.06	$0.46
Irrigation	4.29	4.29	0.03	0.03	0.06	0.06	0.11	0.11	0.15	0.15	0.19	0.19	0.22	0.22	0.25	0.25	$0.68	$0.68
Clean-Up	0.00	0.03	0.01	0.09	0.02	0.15	0.02	0.19	0.03	0.23	0.03	0.25	0.03	0.27	0.04	0.29	$0.02	$0.17
Liability & Legal	0.00	0.02	0.00	0.03	0.01	0.05	0.01	0.06	0.01	0.07	0.01	0.07	0.01	0.08	0.01	0.08	$0.01	$0.05
Admin & Other	0.01	0.44	0.03	1.41	0.04	2.21	0.06	2.86	0.07	3.38	0.08	3.79	0.08	4.09	0.09	4.29	$0.05	$2.59
Total Costs	$45.76	$50.20	$3.09	$7.06	$3.93	$13.43	$6.38	$14.41	$6.84	$15.14	$7.17	$18.14	$7.39	$18.31	$7.51	$18.31	$10.78	$18.39
Total Net Benefits																		
Yard: West	-$42		$8		$17		$23		$29		$33		$35		$35		$18	
Yard: South	-$42		$8		$17		$23		$29		$33		$35		$35		$18	
Yard: East	-$42		$8		$17		$23		$29		$33		$35		$35		$18	
Public		-$46		$6		$9		$17		$23		$24		$25		$25		$11



Appendix B. Procedures for Estimating Benefits and Costs

Methods 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 over a 40-year planning horizon. Trees in these hypothetical locations are called "yard" and "public" trees, respectively. Prices were assigned to each cost (e.g., planting, pruning, removal, irrigation, infrastructure repair, liability) and benefit (e.g., heating/cooling energy savings, air pollution reduction, stormwater runoff reduction) through direct estimation and implied valuation of benefits as environmental externalities. This approach made it possible to estimate the net benefits of plantings in "typical" locations 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 (*Fraxinus pennsylvanica*, green ash), medium, (*Acer platanoides*, Norway maple), and small (*Malus species*, crabapple) deciduous trees, and a coniferous (*Picea pungens*, Colorado spruce) tree. Results are reported at five-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 diameter were also used to differentiate mature tree size. These additional measurements are useful indicators for many functional 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 35-70 street and park trees of each species in Fort Collins, CO, Cheyenne, WY, and Bismarck, ND.

Reporting Results

Tree mortality included

Results are reported in terms of annual values per tree planted. However, to make these calculations realistic, mortality rates are included. Based on our survey of regional municipal foresters and commercial arborists, this analysis assumed that 40% of the hypothetical planted trees died over the 40-year period. Annual mortality rates were 3% for the first five years and 1% for the remaining 35 years. Hence, this accounting approach "grows" trees in different locations and uses computer simulation to directly calculate the annual flow of benefits and costs as trees mature and die (McPherson 1992).

Benefits and costs are 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). In this analysis 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 estimated based on surveys with municipal foresters (Cheyenne, WY; Bismarck, ND; Lewiston, ID; Fargo, ND; Fort Collins, CO; Denver, CO; and Colorado Springs, CO). In addition, commercial arborists were contacted for information on tree management costs on residential properties (Victor, ID; Fort Collins, CO; Colorado Springs, CO; and Denver, CO).

Pricing benefits

Regional electricity and natural gas prices were used in this study to quantify energy savings (EIA 2001a, b). 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 1¢ 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 1¢.

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 represents 60-80% of the total single-family residential housing stock in the Northern Mountain and Prairie Region when older units that have been thermally improved are included.

This house was a two story, wood frame building with basement and a conditioned floor area of 2,070 ft^2 (192 m^2), window area (double-glazing) of 252 ft^2 (24 m^2), and wall, ceiling and floor insulation of R13, R31, and R11, 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 larger and more energy efficient than most other construction types, our projected energy savings are similar to those for older, less thermally efficient, construction. The energy simulations relied on typical year meteorological data from Denver (Marion and Urban 1995).

Calculating energy savings

The dollar value of energy savings was based on average residential electricity and natural gas prices of $0.078 per kWh (EIA 2001a) and $0.0072 per kBtu (EIA 2001b), respectively. Electricity and natural gas prices were year 2000 baseline averages for West North Central, Mountain, and Pacific census divisions. 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-to-building distances, following methods outlined by McPherson and Simpson (1999). The conifer (Colorado spruce) was assumed to be a windbreak tree that did not directly shade the home. The large tree (green ash) had a visual density of 78% during summer and 50% during winter. The medium tree (Norway maple) had a density of 88% during summer and 31% during winter. The small tree's (crabapple species) leaf-on visual density was 55% and 15% in winter. Small and medium trees were leafless October 20-May1, large trees from October 15-May 1. Results for each tree were averaged over distance and weighted by occurrence 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, CA, 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 Fort Collins, over 65% of street trees sampled were within 60 ft (18 m) of conditioned structures.

Calculating climate effects

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 tree canopy plus building cover was estimated to be 32% (American Forests 2001a). Canopy cover was calculated to increase by 6%, 3%, 1%, and 5% for mature large, medium, small, and coniferous 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 20,000 ft^2 (1,858 m^2), and assumed one tree per lot on average. Climate effects were estimated by simulating effects of wind and air temperature reductions on energy use. Climate effects accrued for both public and yard trees.

Trees sheltering nearby buildings act as windbreaks, producing additional wind speed reductions over and above that from the aggregate effect of trees throughout the neighborhood. This leads to a small additional reduction in annual heating energy use of about 0.6% per tree for the Northern Mountain and Prairie region (McPherson and Simpson 1999). Yard and public conifer trees were assumed to be windbreaks, and therefore located where they did not increase heating loads by obstructing winter sun. Windbreak effects were not attributed to deciduous trees, since crowns are leafless and raised above the ground, therefore not conducive to blocking winds near ground level.

Atmospheric Carbon Dioxide Reduction

Conserving energy in buildings can reduce 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 B1). Pollutant emission factors were based on average data for the states of Colorado, Wyoming, Montana, North Dakota and South Dakota, and were weighted based on average fuel mixes: 16% hydro, 5% natural gas, 78% coal, and 1% other (U.S. EPA 2001) (Table B1).

The value of $15/ton CO_2 reduction (Table B1) was based on the average of high and low estimates by CO2e.com (2002).

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). 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

In a national survey of 13 municipal forestry programs it was found that the use of vehicles, chain saws, chippers, and other equipment powered by gasoline or diesel resulted in the average annual release of 0.78 lb of CO_2/inch trunk diameter at breast height or DBH (0.14 kg CO_2/cm DBH) (McPherson and Simpson 1999). This value for tree-related emissions was utilized for yard 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 were removed and mulched in the year that death occurred, and that 80% of their stored carbon was released to the atmosphere as CO_2 in the same year (McPherson and Simpson 1999).

Air Quality Improvement

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). The price of emissions savings was derived from models that calculate the marginal cost of controlling different pollutants to meet air quality standards (Wang and Santini 1995). Emissions concentrations were obtained from U.S. EPA (2002), and population estimates from the U.S. Census Bureau (2002) (Table B1).

Table B1. Emissions factors and prices for air pollutants.

	– Emission Factor* –		
	Electricity lbs/MWh	Natural gas lbs/MBtu	Price $/lb
CO_2	2,033	118	0.008
NO_2	5.003	0.1020	3.07
SO_2	6.245	0.0006	7.13
PM_{10}	0.792	0.0075	5.13
VOCs	0.397	0.0054	4.85

* $15/ton for CO_2 from CO2e.com (2001), values for all other pollutants are based on methods of Wang and Santini (1995) using emissions concentrations from U.S. EPA (1999) and population estimates from the U.S. Census Bureau (2002).

Calculating pollutant uptake by trees

Trees also remove pollutants from the atmosphere. The modeling method we applied was developed by Scott et al. (1998). It calculates hourly pollutant dry deposition per tree expressed as the product of 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 (R_a, R_b, R_c) for each hour throughout the year. Hourly concentrations for NOv, SO_2, O_3, and PM_{10} and hourly meteorological data (i.e., air temperature, wind speed, solar radiation) for 1999 were obtained from the Colorado Department of Public Health and Environment. We used implied values based on the work of Wang and Santini (1995) to price pollutant uptake by trees (Table B1). 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 four tree species (Colorado spruce, green ash, Norway maple, and crabapple) 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 (µg-C g^{-1} dry foliar biomass hr^{-1}), adjusted for sunlight and temperature 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 on values reported in the literature (Benjamin and Winer 1998). Hourly emissions were summed to get monthly and annual emissions.

Annual dry foliar biomass was derived from field data collected in Fort Collins, CO during summer 2002. The amount of foliar biomass present for each year of the simulated tree's life was unique for each species. Year 1999 hourly air temperature and solar radiation data from the Denver area 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 did 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 exceeded 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. 2000). The interception model accounted for water intercepted by the tree, as well as throughfall and stem flow. Intercepted water is stored temporarily on canopy leaf and bark surfaces. 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 included 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 the depth of water captured by the canopy surface. Species-specific shade coefficients and tree surface saturation (0.04 in for all four trees) values influence the amount of projected throughfall. Hourly meteorological and rainfall data for 1998 from Colorado Agricultural Meteorological network (station ID: FTC01. Station name: Fort Collins AERC) were used for this simulation. Annual precipitation during 1998 was 18.0 inches (452 mm), close to the recent 10-year average annual precipitation of 17.8 inches (452 mm). Storm events less than one-tenth (2.54 mm) inch were assumed to not produce runoff and dropped from the analysis. More complete descriptions of the interception model can be found in Xiao et al. (1998, 2000).

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 based on construction and operation costs for a recently built detention/retention basin in Fort Collins, CO. The drainage area was 660 acres (267 ha). The basin was designed to hold 17.2 acre feet

(21,216 m^3) of runoff and cost $1.04 million to construct (McBride 2002). With operating and maintenance costs of $700/month for 20 years, the total project costs were $1.21 million. Assuming that the basin filled once annually for 20 years, the control cost was $0.0108/gal ($0.000041/m^3).

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 services 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.

All else being equal, 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 in the sales price both the benefits and costs of trees as perceived by the buyers. Limitations to 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 the Northern Mountain and Prairie region, 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 $1,014 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 the Northern Mountain and Prairie region 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 2001 average home prices ranged from $106,000 in Lewiston, ID to $246,000 in Denver, CO. We assumed an average home price for Northern Mountain and Prairie communities of $115,000. Therefore, the value of a large tree that added 0.88% to the sales price of such a home was $1,014. Based on growth data for a 40-year old green ash, such a tree was 58-ft tall (17.8 m), had a 45-ft (13.7 m) crown diameter, a 21-inch DBH (53 cm), and 7,930 ft^2 (737 m^2) of leaf surface area.

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 green ash in the front yard increased the property's sales price by $1,014. Approximately 75% of all yard trees, however, are in backyards (Richards et al. 1984). Lacking specific research findings, it was assumed that backyard trees had 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$ ($1.12/$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 from aerial photographs (8% of population), 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 \$0.12 and \$0.13/ft^2 (\$1.31 and \$1.38/m^2) LSA, respectively. Assuming that 80% of all municipal trees were on streets and 20% in parks, a weighted average benefit of \$0.123/ft^2 (\$1.32/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 Northern Mountain and Prairie municipal and commercial arborists, planting costs depend on tree size. Costs ranged from \$300-\$1,000 for a large tree (2- to 5-inch caliper). In this analysis we assumed that a 2-2.5 inch caliper tree was planted. The tree cost was \$150, while planting, staking, and mulching the public and residential yard tree cost \$50 assuming some volunteer and resident participation in public and yard tree planting, respectively.

Pruning Costs

Calucating pruning costs

After studying data from municipal forestry programs and their contractors we assumed that young public trees were pruned once during the first four years after planting, at a cost of \$15/tree. Thereafter, pruning occurred once every six years for small trees (< 20 ft tall), every eight years for medium trees (20-40-ft tall), and every 10 years for large trees (>40-ft tall). Pruning of small public trees cost \$30/tree. More expensive equipment and more time was required to prune medium-sized (\$90/tree) and large trees (\$150/tree). After factoring in pruning frequency, annualized costs were \$3.75 \$5.00, \$11.25, and \$15.00 for public young, small, medium, and large trees, respectively.

Pruning residential trees

Based on findings from our survey of commercial arborists in the Northern Mountain and Prairie region, only 15% of residential trees were professionally pruned. Using this contract rate, along with average pruning prices ($15, $37, $125, and $285 for young, small, medium, and large trees, respectively), the average annual cost for pruning a residential yard tree was $0.07, $0.11, $1.88, and $4.28 for young, small, medium, and large trees.

Tree and Stump Removal

The costs for removing public and yard trees were $20 and $30 per inch ($7.87 and $11.81/cm) DBH, respectively. Stump removal costs were $5/in ($1.97/cm) and $4/in ($1.57/cm) DBH for public and yard trees, respectively. The total cost for public and yard trees was $26/in and $34/in ($10.24/cm and $13.39/cm) DBH.

Pest and Disease Control

Public trees receive treatments to control pests and disease on an as needed basis. The most frequently reported treatments were to control aphids and mites, mountain pine beetle, Zimmerman pine moth, Ips beetle, and ash sawfly. In Northern Mountain and Prairie communities, this expenditure averaged about $0.36/tree/yr, or approximately $0.024 per inch ($0.009/cm) DBH.

Results of our survey indicated that only 10% of all trees were treated for pests or disease. Based on these figures the average annual cost for pest and disease control was calculated at $0.04 per residential yard tree per year; this averages $0.002 per inch ($0.001/cm) DBH.

Irrigation Costs

Tany street and park trees are planted in areas where supplemental irrigation during the establishment period can increase survival rates. We assumed that 50% of public street or park trees were irrigated for the first five years after planting at a cost of $10/tree per year. This price was the average price of labor and equipment to irrigate young trees with a water truck during the arid summer weeks. We apply the same assumptions to newly planted yard trees because many will require hand watering during the establishment period.

Based on survey results the evapotranspiration (ET) demand for a large residential yard tree can reach 1,000 gallons per year. Many trees in Northern Mountain and Prairie landscape situations require relatively little supplemental irrigation after establishment because they are planted in irrigated areas or can use existing soil moisture. Therefore, after establishment it was assumed that 50% of all public and yard trees were irrigated regularly for the remainder of the 40-year period. Assuming that water was purchased at a price of $1.04 Ccf (2002 price for City of Fort Collins), and the mature tree had 7,930 ft^2 (737 m^2) of LSA, the annual price of water for an irrigated large tree was $1.39 or $0.0002/$ft^2$ LSA. Hence, annual irrigation water costs were assumed to increase with tree leaf area after the five-year establishment period.

Other Costs for Public and Private Trees

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

Infrastructure conflicts

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 Northern Mountain and Prairie municipalities reported that these costs were relatively low. As a result, infrastructure related expenditures for public trees were less than in other regions, averaging approximately $1.12/tree ($0.06/in [$0.02/cm] DBH) on an annual basis. Roots from most trees in residential yards do not damage sidewalks and sewers. Therefore, the cost for yard trees was assumed to be 10% of the cost for public trees.

Liability costs

Urban trees can, and do, incur costly payments and 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). Our survey found that Northern Mountain and Prairie communities spend only $0.05/tree per year on average ($0.003/in [$0.001/cm] DBH). Because street trees are in closer proximity to sidewalks and sewer lines than most trees on yard property, we assumed that legal costs for yard trees were 10% 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, storm damage clean-up) was $0.42 ($0.02/in [$0.008/cm] DBH). This value was based on average annual litter clean-up costs and storm clean-up, assuming a large storm results in extraordinary costs about once a decade. Because most residential yard trees are not littering the street with leaves, it was assumed that clean-up costs for yard trees were 10% of those for public trees.

Green waste disposal costs

Green waste disposal and recycling costs were relatively small in our survey of Northern Mountain and Prairie communities. The average annual municipal expenditure was $0.10/tree ($0.007/in [$0.003/cm] DBH). Although most residents do not pay tipping fees directly for disposal of green waste, these costs are included in the taxes paid for solid waste management. Therefore, this expenditure was applied to residential yard trees, as well as street and park trees.

Inspection and administration costs

Municipal tree programs have administrative costs for salaries of supervisors and clerical staff, operating costs, and overhead. Our survey found that the average annual cost for inspection and administration associated with street and park tree management was $5/tree ($0.33/in DBH). 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."

Calculating net 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 CO_2 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 (B) was:

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

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

A = value of annual aesthetics and other benefits

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 are

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

Limitations of this Study

More research needed

This analysis does not account for the wide variety of trees planted in Northern Mountain and Prairie 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 because the science in this area 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.

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.