



CONTRIBUTING ORGANIZATIONS

Center for Urban Forest Research
Pacific Southwest Research Station
USDA Forest Service
Davis, CA

Department of Land, Air, and Water Resources
University of California
Davis, CA



SPONSORING ORGANIZATIONS

USDA Forest Service, Southwestern Region
State & Private Forestry, Urban and Community Forestry Program
Albuquerque, NM



USDA Forest Service, Pacific Southwest Region
State & Private Forestry, Urban and Community Forestry Program
Vallejo, CA

Arizona Community Tree Council, Inc.
Phoenix, AZ

Arizona State Land Department
Phoenix, AZ



ACKNOWLEDGEMENTS

ARIZONA COMMUNITY
Tree Council, Inc.

Numerous people assisted with data collection and provided technical assistance: Tommy Mouton (CUFR), Jesse Hoekstra (UC Davis), Guadalupe Rodriguez, Tom Wilkinson, Bob Coons, and Kandy Van Meeteren (City of Glendale), Richard Harris (Arizona State University, Tempe), Alan Markley and Steve Priebe (City of Phoenix), Jimmy Torres (Groundscape Maintenance, Glendale), Larry Brown (All Year Round Tree Service, Phoenix), Juan Barba (Juan J. Barba & Assoc., Tucson), George Hull (Mountain States Nursery, Glendale), John Hall (Westside Wholesale Nursery, Glendale). Terry Mikel (University of Arizona, Cooperative Extension), Dennis Swartzell (Mountain States Wholesale Nursery), Jack Kelly (Pima County Cooperative Extension) and Jim Geiger (CUFR) provided helpful reviews of this work. John Hinz (US Forest Service, S&PF, Region 3), Ron Romatzke (Arizona Department of State Lands) provided invaluable support for this project.



Arizona State
Land Department



Desert Southwest Community Tree Guide: “Benefits, Costs, and Strategic Planting”

July 2004

by

E. Gregory McPherson

Center for Urban Forest Research, Pacific Southwest Research Station, USDA Forest Service

James R. Simpson

Center for Urban Forest Research, Pacific Southwest Research Station, USDA Forest Service

Paula J. Peper

Center for Urban Forest Research, Pacific Southwest Research Station, USDA Forest Service

Scott E. Maco

Center for Urban Forest Research, Pacific Southwest Research Station, USDA Forest Service

Qingfu Xiao

Department of Land, Air, and Water Resources, University of California, Davis

Ed Mulrean

Arid Zone Trees, Queen Creek, AZ

Published by

Arizona State Land Department Natural Resources Division, Urban & Community Forestry
Section & Arizona Community Tree Council, Inc.

Printed by

BEAR Industries, Printing & Publishing, Reno, NV, (775) 358-8822 , (800) 766-6755

Designed by

Lisa Roth, Visionpoint Graphic Design, Chandler, AZ, (480) 821-1177, visionpoint@msn.com

Production Coordination by

Doreen Orist, Urban Environmental Enterprises, Inc., Chandler, AZ, (480) 899-9831

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CHAPTER 1. KEY FINDINGS

Benefits and costs quantified

This report quantifies benefits and costs for typical large-, medium-, small-stature, deciduous trees (*Fraxinus uhdei*, *Prosopis chilensis*, *Acacia farnesiana*), as well as a conifer (*Pinus halapensis*). The analysis assumed that trees were planted in a residential yard site or a public (street/park) site, a 40-year time frame, and 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 consider regional climate, building characteristics, air pollutant concentrations, and prices.

Adjust values for local planting projects

Given the Desert Southwest region's large geographical area, the approach is not accurate to the penny. Rather, it provides a general accounting that can be easily adapted and adjusted for local planting projects. Two examples are provided that illustrate how to adjust benefits and costs to reflect different aspects of local planting projects.

Average annual net benefits

Average annual net benefits per computer-grown tree for a 40-year period were:

- \$3 to \$16 for a small tree
- \$21 to \$43 for larger shade trees and a conifer

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

Net benefits summed for 40 years

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

- \$1,520 (yard) and \$920 (public) for large trees
- \$1,720 (yard) and \$840 (public) for conifers
- \$640 (yard) and \$120 (public) for medium trees
- \$360 (yard) and \$0 (public) for small trees

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

Costs

Average annual costs 20 years after planting for tree planting and care ranged from \$7 to \$20 per tree:

- \$7-\$17 for a small tree
- \$9-\$20 for a medium shade tree and conifer
- \$7-\$17 for a large tree

Tree pruning was the single greatest cost for trees (\$12-\$14/tree/year), while annualized planting and removal costs were also important. Rapid growth rates in the Desert Southwest region require more frequent pruning than in other regions.



Large trees provide the most 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

Benefits associated with property value increase and air conditioning savings accounted for the largest proportion of total benefits. Rainfall interception, which reduces stormwater runoff, and improved air quality were the next most important benefits, followed by atmospheric carbon dioxide reduction.

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. Air quality benefits were influenced by species-related emissions of *biogenic volatile organic compounds** (BVOCs).

The amount of rainfall trees intercept is approximately one-half the amount they consume through irrigation. Because the price of irrigation water is considerably less than the cost of treating stormwater per gallon, water quality benefits associated with rainfall interception were 3-5 times greater than irrigation costs.

The Mineral City example calculated net benefits and benefit-cost ratios (BCRs) for a hypothetical planting of 1,000 trees (15 gal) assuming a cost of \$75/tree, 60% survival rate, and 40-year analysis. Total costs were \$7.7 million, benefits totaled \$17.3 million, and net benefits were \$9.5 million (\$24/tree). The BCR was 2.23, indicating that \$2.23 was returned for every \$1 invested. The net benefits and BCRs by *mature tree size* were:

- \$-26,252, 0.92 for small Sweet acacia trees
- \$525,732, 1.66 for coniferous Aleppo pines
- \$1.7 million, 2.04 for medium Mesquite trees
- \$7.34 million, 2.48 for large Evergreen ash

Increased property values (37%) and energy savings (33%) accounted for 70% of the estimated benefits. Air quality (13%) and stormwater management (12%) benefits were 25% of total benefits.

In the City of Mesquite example, long-term planting and tree care costs and benefits are compared to determine if a new policy that favors planting small-stature trees will be cost-effective compared to the current policy of planting large-stature trees where space permits. The net benefit for small Sweet acacias was \$307/tree, considerably less than \$950/tree for the large Evergreen ash, and \$1,242/tree for the medium Mesquite.

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

* *Italicized words are defined in the Glossary*

CHAPTER 2. INTRODUCTION

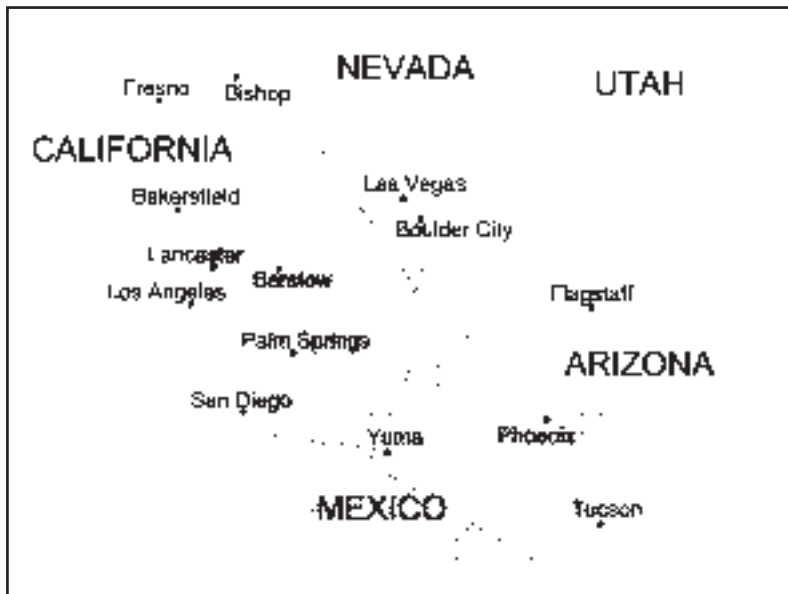
Desert Southwest communities can derive many benefits from community trees

Definitions for italicized words are in the glossary

From small, rural towns to large, booming cities, there are thousands of communities in the Desert Southwest region. With tourism, recreation, and high tech industry joining the economies of agriculture, mining, and ranching, the region is experiencing rapid change. As the region's metropolitan areas grow, urban and community forests bring opportunity for economic renewal, combating development woes, and increasing the quality of life for community residents. In desert 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.

Geographic scope

This region includes communities located in the Mojave and Sonoran deserts. It extends from the Southern California cities of Palm Springs, Lancaster, and Bishop on the west to Tucson and Safford, Arizona on the east (Figure 1). In the north, it is bounded by Las Vegas and Boulder City, Nevada. The region extends south to Mexico bordering western Arizona and eastern California.



Nearly 3 million people live in the Phoenix metropolitan area, the region's largest settlement. The total population in the region is approximately 6 million.

Boundaries correspond with Sunset Climate Zones 11, 12, and 13 (Brenzel 2001) and USDA Hardiness Zones 8-10. The climate of the Desert Southwest is characterized by short, mild winters, long, hot summers, and wide swings in temperatures. Winter and summer rains help with watering, but trees require irrigation for establishment. Landscape water conservation efforts have led to widespread use of desert-adapted species that need relatively little irrigation once established.

Figure 1. The Desert Southwest region—shaded area—extends from Bishop, CA and Las Vegas, NV to Palm Springs, CA, Yuma, Phoenix, and Tucson, AZ.

Quality of life improves with trees

As many Desert Southwest 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).



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



Trees provide environmental benefits

Desert Southwest 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 (CO₂), providing wildlife habitat, increasing property values, calming traffic, enhancing community attractiveness and investment, and promoting human health and well-being.

Scope defined

This Guide describes urban forest benefits in the Desert Southwest region and adds new knowledge in several ways:

- Benefits for open-grown trees are quantified on a per tree basis (it should not be used to estimate benefits and costs for trees growing in forest stands).
- Managements costs, as well as benefits, are described.
- Benefits and costs for trees in residential yards as well as steet/park trees are included.
- Practical illustrations showing how to use this information to estimate benefits and costs for tree planting projects are described.

Audience and objective

Street, park, and shade trees are components of all Desert Southwest 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 Desert Southwest communities—providing a tool for municipal tree managers, arborists, and tree enthusiasts to increase public awareness and support for trees (Dwyer and Miller 1999).

What will this Tree Guide do?

This tree guide addresses a number of questions about the environmental and aesthetic benefits of community tree plantings in Desert Southwest 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 power lines, sidewalks, and buildings?

Answers to these questions should 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. Presents key findings.

Chapter 2. Introduces readers to the geographic scope of the region, content of the Guide, and intended audience.

Chapter 3. Provides background information on the potential of trees in Desert Southwest communities to provide benefits, as well as management costs that are typically incurred.

Chapter 4. Provides calculations of tree benefits and costs.

Chapter 5. Illustrates how to estimate urban forest benefits and costs for tree planting projects in your community and tips to increase cost-effectiveness.

Chapter 6. Presents guidelines for selecting and placing trees in residential yards and public open spaces.

Chapter 7. Contains a tree selection list with information on tree species recommended for Desert Southwest communities.

Chapter 8. Lists references cited in the report.

Chapter 9. Provides a glossary of definitions for technical terms used in the report. *Terms in the glossary are in italics the first time they appear in the text.*

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://cuf.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 web-site: <http://cuf.ucdavis.edu/stratum.asp>.



CHAPTER 3.

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 work

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

- 1) Shading—reduces the amount of radiant energy absorbed and stored by built surfaces.
- 2) Transpiration—converts liquid water to water vapor and thus cools by using solar energy that would otherwise result in heating of the air.
- 3) 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 lower temperatures

Trees and other *greenspace* (definitions of italicized words are in the glossary) 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*.

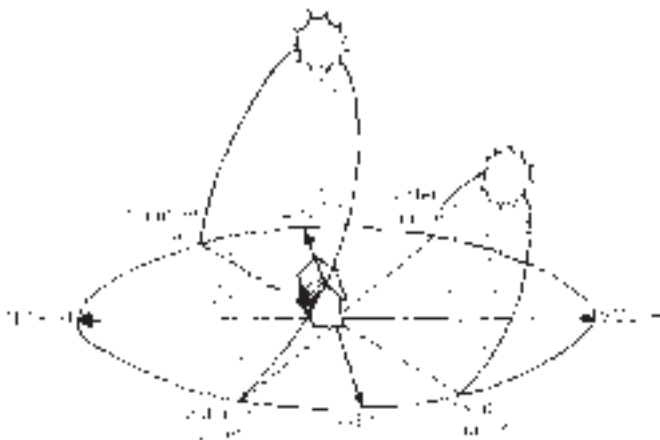


Figure 3. Paths of the sun at winter and summer solstices (from Sand 1991).

Trees increase home energy efficiency

For individual buildings, strategically placed trees can increase energy efficiency in the summer and winter. Solar angles are important when the summer sun is low in the east and west for several hours each day. Tree shade to protect east—and especially west—walls help keep buildings cool. In the winter, solar access on the southern side of buildings can warm interior spaces (Figure 3). *Evergreens* and even some *deciduous trees* that shade south- and east-facing walls during winter can increase heating costs.



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 Desert Southwest region than in milder climate regions because of the long, hot summers. A computer simulation of annual cooling savings for an energy efficient home in Tucson indicated that the typical household with air conditioning spent about \$400 each year for cooling and \$50 for heating. Shade and lower air temperatures from three 25-ft tall (7.5 m) trees—two on the west side of the house and one on the east—was estimated to save \$100 each year for cooling, a 25% reduction (1,350 kWh) (McPherson et al. 1993). Wind protection from the same three trees during winter was offset by increased heating loads due to obstructed winter sunlight by the trees.

Retrofit for more savings

In the Desert Southwest 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 cooling costs by 20-25% for typical households.

Reducing Atmospheric Carbon Dioxide

Trees reduce CO₂

Urban forests can reduce atmospheric CO₂ in two ways:

- 1) Trees directly sequester CO₂ as woody and foliar biomass as they grow.
- 2) Trees near buildings can reduce the demand for heating and air conditioning, thereby reducing emissions associated with electric power production.

Activities that release CO₂

On the other hand, vehicles, chain saws, chippers, and other equipment release CO₂ during the process of planting and maintaining trees. And eventually, all trees die and most of the CO₂ that has accumulated in their woody biomass is released into the atmosphere through decomposition. Typically, CO₂ released due to tree planting, maintenance, and other program-related activities is about 2-8% of annual CO₂ reductions obtained through *sequestration* and *avoided power plant emissions* (McPherson and Simpson 1999). To provide a complete picture of atmospheric CO₂ reductions from tree planting it is important to consider CO₂ released into the atmosphere through tree planting and care activities, as well as decomposition of wood from pruned or dead trees.

Avoided CO₂ emissions

Regional variations in climate and the mix of fuels that produce energy to heat and cool buildings influence potential CO₂ emission reductions. The average emission rate for the Desert Southwest region is approximately 1.5 lbs (0.7 kg) CO₂/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) CO₂/kWh because hydroelectric power predominates. The Desert Southwest region’s relatively high CO₂ emission rate accentuates CO₂ benefits from reduced energy demand relative to other regions with lower emission rates.

Financial value of CO₂ reduction

One of the most comprehensive studies of atmospheric CO₂ reduction by an urban forest found that Sacramento, California's six million trees removed approximately 335 thousand tons (304,000 *metric tonnes*) of atmospheric CO₂ 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 CO₂ reduction by Sacramento's urban forest offset 1.8% of total CO₂ 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.

CO₂ reduction through community forestry in Tucson

Tucson Electric Power and Trees for Tucson have partnered in a successful shade tree program for energy conservation and atmospheric CO₂ reduction. Over 30,000 trees have been distributed through the Trees for Tucson program since it began in 1993. For more information on the program visit the web-site at <http://www.ci.tucson.az.us/tcb/tcbtothp.htm>.

Since 1997, Trico Electrical Cooperative and the University of Arizona, Pima County Cooperative Extension have partnered to distribute 9,561 trees to customers in Pima County through the 'Coolshade' program.

Improving Air Quality

Trees improve air quality

Urban trees provide air quality benefits in four main ways:

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

Trees and ozone relationship

In the absence of the cooling effects of trees, higher air temperatures contribute to ozone formation. Most trees emit various *biogenic volatile organic compounds (BVOCs)* such as isoprenes and monoterpenes that can contribute to ozone formation. The ozone-forming potential of different tree species varies considerably. A computer simulation study for the Los Angeles basin found that increased tree planting of low BVOC emitting tree species would reduce ozone concentrations and exposure to ozone, 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 Desert Southwest communities has not been studied.

Areas with poor air quality

Although many communities in the Desert Southwest 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 Phoenix, Tucson, Las Vegas, and Palm Springs. 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 (O₃), nitrogen dioxide (NO₂), and particulate matter (PM₁₀).

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:

- 1) Leaves and branch surfaces intercept and store rainfall, thereby reducing runoff volumes and delaying the onset of *peak flows*.
- 2) Root growth and decomposition increase the capacity and rate of soil infiltration by rainfall and reduce overland flow.
- 3) Tree canopies reduce soil erosion by diminishing the impact of raindrops on barren surfaces.
- 4) 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 deciduous species (Xiao et al. 1998). However, average interception on land with tree canopy cover ranged from 6-13% (150 gal [20 m³] 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 m³) (\$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 ft³ (1.5 million m³), valued at \$3.2 million annually (American Forests 2001a).

In the Willamette/Lower Columbia region, existing canopy (24%) reduced runoff by 8.5 billion ft³ (240.7 million m³). 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). Skin cancer is especially hazardous in the sunny Southwest. 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 binder (Muchnick 2003). 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).

Figure 4. Although shade trees can be expensive to maintain, their shade can reduce the cost for resurfacing streets, promote pedestrian travel, and improve air quality directly through pollutant uptake and reduced emissions of VOCs from parked cars.



COSTS

Planting and Maintaining Trees

Cities spend about \$4.62 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 Desert Southwest region spent an average of about \$4.62 per tree, annually, for street and park tree management (Tschantz and Sacamano 1994). This amount was intermediate, with five regions spending more than this and five 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, street and front yard 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.

Residents spend about \$5-\$10 per tree

Annual expenditures for tree management on private property have not been well-documented. Costs vary considerably, ranging from some commercial/residential properties that receive regular professional landscape service to others that are virtually “wild” and without maintenance. An 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 arid climate, newly planted trees require irrigation for three to five years, and very few will thrive without irrigation after establishment. Installation of drip or bubbler irrigation can increase planting costs by \$100 or more per tree. Once planted, trees typically require about 1,000 gal (3.8 m³) per year during the establishment period and 4,000 gal (15.1 m³) per year as they mature. Assuming a water price of \$1.81/1000 gals (\$0.48/m³) in Glendale, annual irrigation water costs are initially less than \$4/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.



Conflicts with Urban Infrastructure

Tree roots and sidewalks can conflict

Unlike many other cities across the U.S., our data suggest that communities in the Desert Southwest region are spending relatively less to manage conflicts between trees and power lines, sidewalks, sewers, and other elements of the urban infrastructure. Many street trees are planted in wide areas along boulevards where they do not conflict with sidewalks or power lines. Also, tree populations in Desert Southwest cities contain small-stature trees than in other regions of the country. 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). 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 rootsidewalk conflicts was well over \$100 million per year in California alone. Our findings indicate that most communities in the Desert Southwest region are spending a fraction of this amount because fewer conflicts are present.

Cost of conflicts

However, conflicts are most apparent in older areas, where trees are larger and the infrastructure is deteriorating due to age. In these areas, the consequences of efforts to control these costs can have alarming effects on urban forests (Bernhardt and Swiecki 1993, Thompson and Ahern 2000):

- Cities continue to “downsize” their urban forests by planting smaller-stature trees. Although small trees are appropriate under power lines and in small planting sites, they are less effective than large trees at providing shade, absorbing air pollutants, and intercepting rainfall.
- Sidewalk damage is 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 are removing more trees than they are planting. Residents forced to pay for sidewalk repairs may not want replacement trees.

Use the right tree to fix conflicts

Collectively, this is a loselose situation. Cost-effective strategies to retain benefits from large street trees while reducing costs associated with infrastructure conflicts are described in *Reducing Infrastructure Damage by Tree Roots: A Compendium of Strategies* (Costello and Jones 2003). Matching the growth characteristics of trees to conditions at the planting site is one strategy. The recommended tree selection list in Chapter 5 contains information on planting suitability by location and size.

Roots can damage sewer lines

Tree roots can damage old sewer lines that are cracked or otherwise susceptible to invasion. Sewer repair companies estimate that sewer damage is minor until trees and sewers are over 30 years old, and roots from trees in yards are usually more of a problem than roots from trees in planter strips along streets. The 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 power lines are reflected in electric rates. Large trees under power lines require more frequent pruning than better-suited trees. Frequent *crowns* 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

Some Desert Southwest cities are recycling green waste from urban trees as mulch, compost, and firewood. Frequently, 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 \$

There are innovative ways to recycle green waste. For example, 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.



CHAPTER 4. BENEFITS AND COSTS OF COMMUNITY FORESTS IN DESERT SOUTHWEST 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

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 uhdei*, Evergreen ash), medium, (*Prosopis chilensis*, Chilean mesquite), small (*Acacia farnesiana*, Sweet acacia) deciduous trees, as well as a coniferous (*Pinus halapensis*, Aleppo pine) tree. Growth curves were developed from street trees sampled in Glendale, AZ (Figure 5).



Tree care costs based on survey findings

Frequency and costs of tree management were estimated based on surveys with *municipal foresters* in Glendale and Phoenix. In addition, commercial arborists were contacted from Tucson, Phoenix, and Glendale for information on tree management costs on residential properties.

Tree benefits based on numerical models

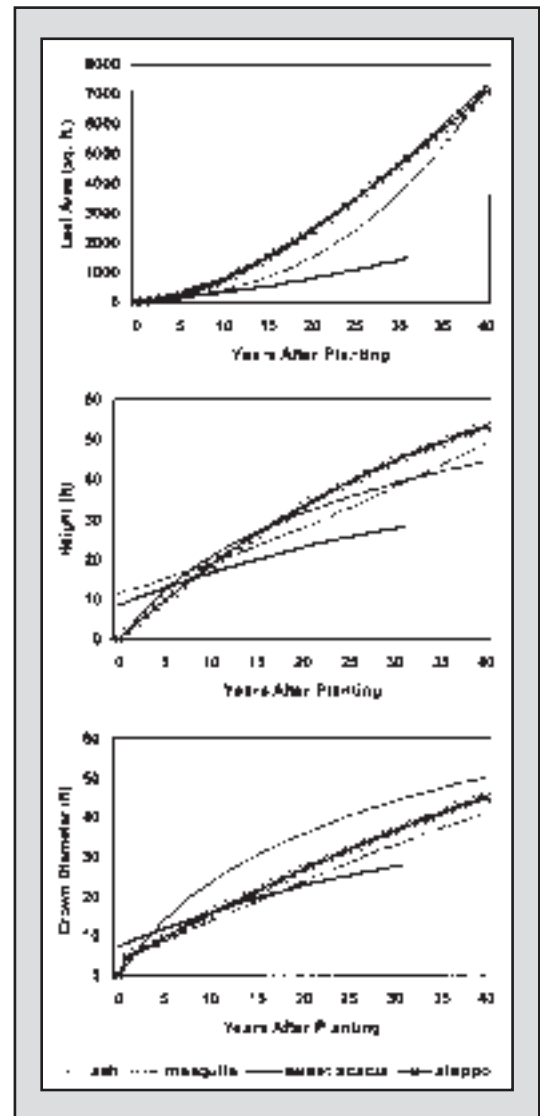
Benefits were calculated with numerical models and input data from both regional (e.g., pollutant emission factors for avoided emissions due to energy savings) and local sources (e.g., Phoenix climate data for energy effects). Regional electricity and natural gas prices were used in this study to quantify 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, this analysis assumed that

Figure 5. Tree dimensions are based on data collected from street and park trees in Glendale, AZ. Data for the “typical” large, medium, small, and coniferous tree are from the Evergreen ash, Chilean mesquite, Sweet acacia, and Aleppo pine, respectively. Differences in leaf surface area among species are most important for this analysis because functional benefits such as summer shade, rainfall interception, and pollutant uptake are related to leaf surface area.



40% of the hypothetical planted trees died over the 40-year period. Annual mortality rates were 2.5% for the first five years and 0.8% 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 5-year intervals for 40 years.

FINDINGS OF THIS STUDY

Average Annual Net Benefits

Average annual net benefits increase with size of tree

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

- \$3 to \$16 for a small tree
- \$21 to \$43 for larger shade trees and a conifer

Large trees provide the most benefits

This finding suggests that average annual net benefits from large-growing trees, like the Mesquite and Evergreen ash, can be substantially greater than those from small trees like Sweet acacia. Average annual net benefits for the small, medium, coniferous, and large public (street/park) trees were \$3, \$21, \$22, and \$23, respectively. The largest average annual net benefits, however, stemmed from residential yard trees opposite the west-facing wall of a house: \$16, \$43, \$41, and \$38 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 \$70 at year 40. Planting the Evergreen ash in a public site produced a reduced annual net benefit—\$43 at year 40. Forty years after planting medium, coniferous, and small trees, they produced annual net benefits of \$71, \$88, and \$30 for west-side residential trees, respectively. The small Sweet acacia in a typical public space netted \$12 at year 40, while a medium Mesquite and Aleppo pine in the same locations produced \$40 and \$55 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:

- \$360 (yard) and \$0 (public) for small trees
- \$640 (yard) and \$120 (public) for medium trees
- \$1,520 (yard) and \$920 (public) for large trees
- \$1,720 (yard) and \$840 (public) for conifers

Net annual benefits at year 20 for yard 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 \$42 for a large tree, \$53 for a medium tree, \$41 for a conifer, and \$23 for a small tree (Table 1). For a large Evergreen ash at 20 years after planting, the total value of environmental benefits alone (\$31), was four times greater than annual costs (\$7). Similarly, environmental benefits totaled \$52 and \$43 for the Mesquite and Aleppo pine, while tree care costs totaled substantially less (\$9 and \$14). Annual environmental benefits were \$23 for a 20-year old Sweet acacia yard tree, while management costs were \$7.

Net annual benefits at year 20 for street/park trees

Twenty years after planting the annual net benefit from a large public tree was \$24 (Table 2). At that time, net annual benefits from the medium, conifer, and small public trees were \$24, \$20, and \$6, respectively.

Average Annual Costs

Costs of tree care

Average annual costs 20 years after planting for tree planting and care ranged from \$7 to \$20 per tree (see Table 3, for detailed results see Appendix A):

- \$7-\$17 for a small tree
- \$9-\$20 for a medium shade tree and conifer
- \$7-\$17 for a large tree

Public trees are more expensive to maintain yard 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 \$6-14, while public tree care costs were \$17-\$20. In general, public trees are more intensively maintained than yard trees because of their prominence and greater need for public safety.

Greatest costs for pruning, planting and removal

Tree pruning was the single greatest cost for public trees, averaging approximately \$12-\$14/year/tree. Pruning expenditures are greater in the Desert Southwest region than in most other regions because the long growing season and frequent irrigation promotes rapid growth. As a result, more frequent pruning is required. Annualized expenditures for tree planting were an important cost, especially for trees planted in private yards (\$330 for 24 inch boxed tree or \$8.25/tree/yr). The third greatest annual cost for yard trees was for removal and disposal (\$2-\$3/tree/yr).

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

Benefit Category	Sweet acacia Small Tree 23 ft tall 22 ft spread LSA= 251 ft2	Chilean mesquite Medium Tree 31 ft tall 36 ft spread LSA= 768 ft2	Evergreen ash Large Tree 28 ft tall 23 ft spread LSA= 473 ft2	Aleppo pine Conifer Tree 33 ft tall 27 ft spread LSA= 744 ft2				
Electricity savings (\$0.09/kWh)	167 kWh	\$15.79	388 kWh	\$36.75	200 kWh	\$18.97	80.4 kWh	\$26.58
Natural gas savings (\$0.97/therm)	2 kBtu	\$0.02	-116 kBtu	-\$1.13	24 kBtu	\$0.23	-79.1 kBtu	-\$0.77
Carbon dioxide (\$0.008/lb)	198 lb	\$1.48	342 lb	\$2.56	239 lb	\$1.80	299.9 lb	\$2.25
Ozone (\$4.00/lb)	0.17 lb	\$0.68	0.31 lb	\$1.23	0.08 lb	\$0.31	0.06 lb	\$0.22
NO2 (\$4.00/lb)	0.31 lb	\$1.23	0.69 lb	\$2.75	0.32 lb	\$1.28	0.44 lb	\$1.77
SO2 (\$15.70/lb)	0.20 lb	\$3.09	0.46 lb	\$7.23	0.23 lb	\$3.63	0.34 lb	\$5.28
PM10 (\$6.00/lb)	0.36 lb	\$2.15	0.42 lb	\$2.54	0.28 lb	\$1.65	0.16 lb	\$0.95
VOC's (\$4.00/lb)	0.03 lb	\$0.14	0.08 lb	\$0.33	0.04 lb	\$0.17	0.06 lb	\$0.25
BVOC's (\$4.00/lb)	-1.00 lb	-\$3.99	-1.88 lb	-\$7.53	0.00 lb	\$0.00	-0.33 lb	-\$1.33
Rainfall Interception (\$0.005/gal)	493 gal	\$2.37	1,604 gal	\$7.70	670 gal	\$3.22	1,649 gal	\$7.91
Environmental Subtotal		\$22.96		\$52.43		\$31.26		\$43.13
Other Benefits		\$ 6.59		\$ 9.37		\$18.09		\$11.86
Total Benefits		\$29.55		\$61.80		\$49.35		\$54.98
Total Costs		\$ 6.70		\$ 8.76		\$ 7.13		\$13.94
Net Benefits		\$22.85		\$53.04		\$42.23		\$41.05

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

Benefit Category	Sweet acacia Small Tree 23 ft tall 22 ft spread LSA= 251 ft2	Chilean mesquite Medium Tree 31 ft tall 36 ft spread LSA= 768 ft2	Evergreen ash Large Tree 28 ft tall 23 ft spread LSA= 473 ft2	Aleppo pine Conifer Tree 33 ft tall 27 ft spread LSA= 744 ft2				
Electricity savings (\$0.09/kWh)	77 kWh	\$7.31	180 kWh	\$17.10	81 kWh	\$7.65	101.3 kWh	\$9.61
Natural gas savings (\$0.97/therm)	229 kBtu	\$0.31	229 kBtu	-\$0.43	229 kBtu	\$0.50	229 kBtu	-\$0.18
Carbon dioxide (\$0.008/lb)	187 lb	\$1.40	306 lb	\$2.29	192 lb	\$1.44	191.4 lb	\$1.44
Ozone (\$4.00/lb)	0.17 lb	\$0.68	0.31 lb	\$1.23	0.08 lb	\$0.31	0.06 lb	\$0.22
NO2 (\$4.00/lb)	0.31 lb	\$1.23	0.69 lb	\$2.75	0.32 lb	\$1.28	0.44 lb	\$1.77
SO2 (\$15.70/lb)	0.20 lb	\$3.09	0.46 lb	\$7.23	0.23 lb	\$3.63	0.34 lb	\$5.28
PM10 (\$6.00/lb)	0.36 lb	\$2.15	0.42 lb	\$2.54	0.28 lb	\$1.65	0.16 lb	\$0.95
VOC's (\$4.00/lb)	0.03 lb	\$0.14	0.08 lb	\$0.33	0.04 lb	\$0.17	0.06 lb	\$0.25
BVOC's (\$4.00/lb)	-1.00 lb	-\$3.99	-1.88 lb	-\$7.53	0.00 lb	\$0.00	-0.33 lb	-\$1.33
Rainfall Interception (\$0.005/gal)	493 gal	\$2.37	1,604 gal	\$7.70	670 gal	\$3.22	1,649 gal	\$7.91
Environmental Subtotal		\$14.69		\$33.20		\$19.86		\$25.93
Other Benefits		\$7.79		\$11.07		\$21.38		\$14.01
Total Benefits		\$22.48		\$44.26		\$41.24		\$39.93
Total Costs		\$16.96		\$19.95		\$17.28		\$20.23
Net Benefits		\$5.52		\$24.31		\$23.96		\$19.70

For public trees in Desert Southwest communities, average annual expenditures for planting (\$190 for 24 inch boxed tree or \$5/tree/yr) and program administration were significant (\$2-\$3/tree/yr). Strategies to reduce these costs may help municipalities use their limited funds to plant and care for more trees.

Average Annual Benefits

Average benefits increase with size of tree

Average annual benefits also increased with mature tree size (for detailed results see last two columns in Appendix A):

- \$23 to \$29 for a small tree
- \$44 to \$60 for a conifer and medium shade tree
- \$45 to \$54 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 \$7-\$8, \$9-\$11, and \$16-\$19 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.

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

	Sweet acacia Small Tree 28 ft tall 27 ft spread LSA= 435 ft2		Chilean mesquite Medium Tree 44 ft tall 50 ft spread LSA= 2250 ft2		Evergreen ash Large Tree 49 ft tall 41 ft spread LSA=2248 ft2		Aleppo pine Conifer Tree 53 ft tall 45 ft spread LSA= 2176 ft2	
Costs (\$/yr/tree)	Private: West	Public tree	Private: West	Public tree	Private: West	Public tree	Private: West	Public tree
Tree&Planting	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pruning	3.96	11.80	3.96	11.80	3.96	11.80	9.66	13.89
Remove&Dispose	2.09	1.81	2.88	2.50	1.99	1.72	2.42	2.09
Pest&Disease	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01
Infrastructure	0.02	0.03	0.03	0.05	0.02	0.03	0.03	0.04
Irrigation	0.60	0.60	1.85	1.85	1.13	1.13	1.80	1.80
Clean-Up	0.02	0.11	0.03	0.16	0.02	0.11	0.02	0.13
Liability&Legal	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Admin&Other	0.00	2.60	0.00	3.59	0.00	2.48	0.00	2.26
TotalCosts	6.70	16.96	8.76	19.95	7.13	17.28	13.94	20.23



Figure 6. Although park trees seldom provide energy benefits from direct shading of buildings, they provide other benefits as settings for recreation and relaxation.

Figure 7. Estimated annual benefits and costs for a large (Evergreen ash), medium (Chilean mesquite), small (Sweet acacia) and coniferous (Aleppo pine) tree located west of a residence. Costs are greatest during the initial establishment period while benefits increase with tree size.

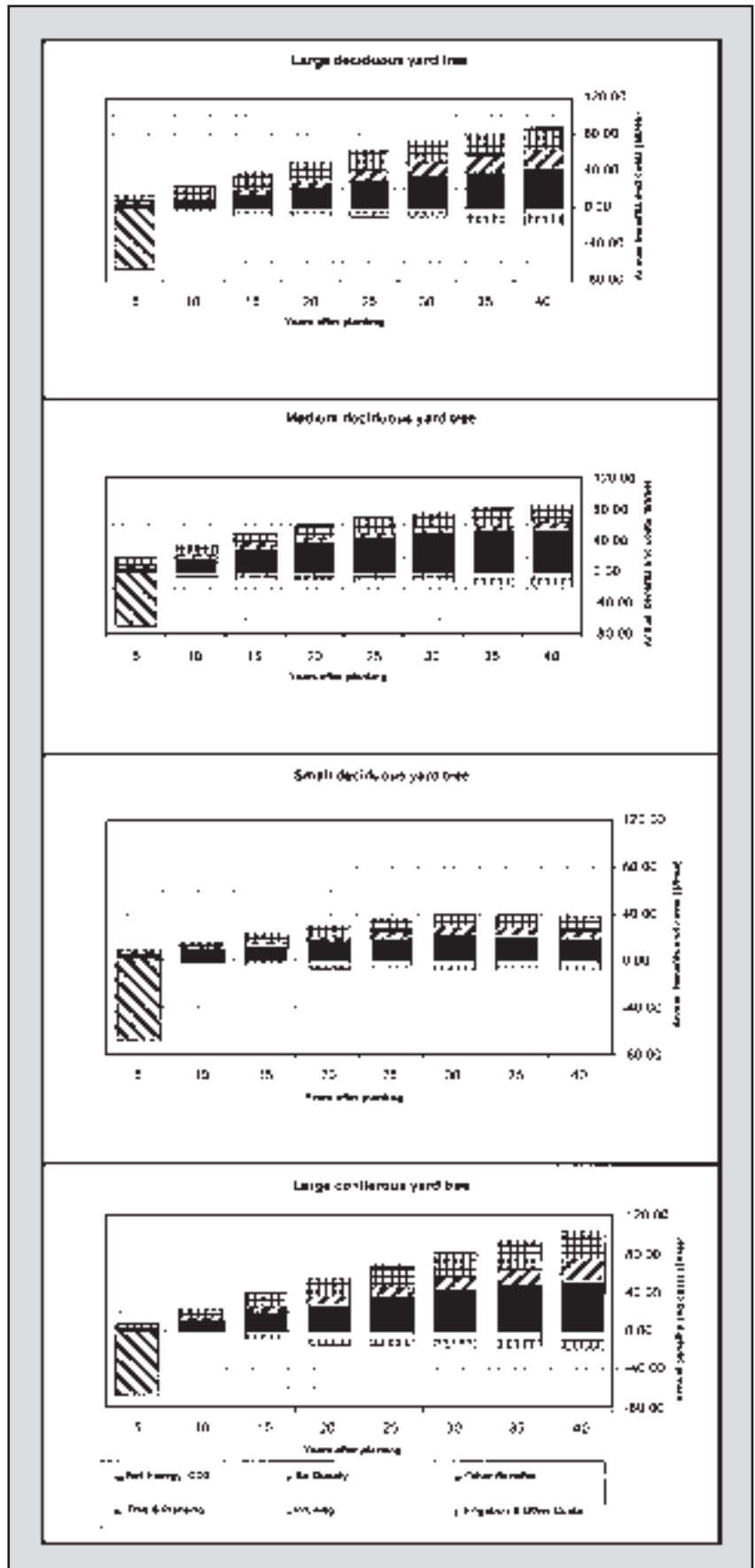
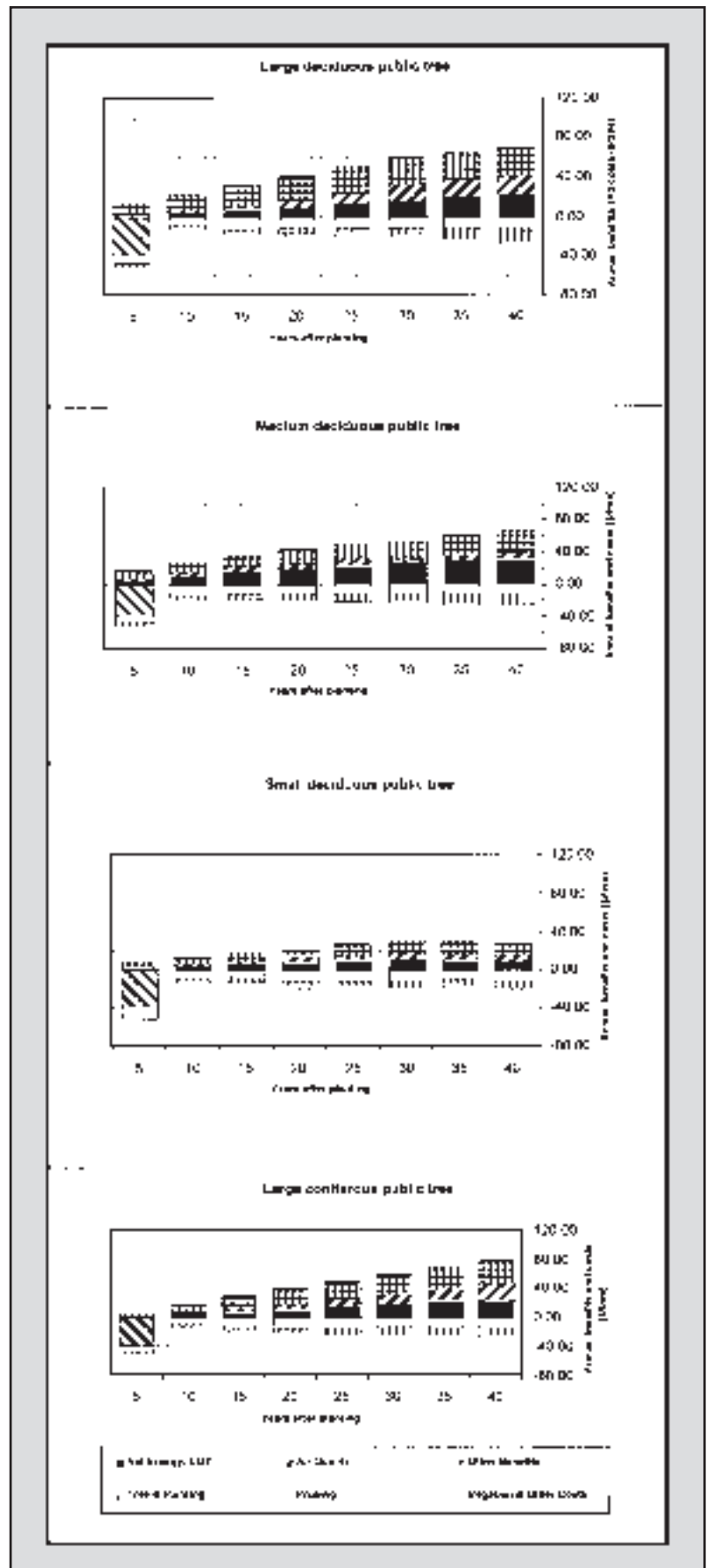


Figure 8. Estimated annual benefits and costs for a large (Evergreen ash), medium (Chilean mesquite), small (Sweet acacia) and coniferous (Aleppo pine) public tree.



Public vs. yard trees & property values

Aesthetic and other benefits were slightly greater for the public street/park tree than the residential yard tree because of the assumption that most yard trees are located in backyards, 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.

Energy

After aesthetics, values were largest for energy benefits. Energy benefits tended to increase with tree size. For example, average annual net benefits were only \$7 for the small, Sweet acacia and \$18 for the larger Mesquite in a street or park location. Also, energy savings increased as trees matured and their *leaf surface area* increased, regardless of their mature size (Figures 7 and 8).

As expected, cooling savings accounted for most of the total energy benefit. Average annual cooling savings for the Sweet acacia and Mesquite ranged from \$7-15 and \$17-35, respectively. Average annual heating savings for the same species ranged from -\$1.41 to \$0.02 and -\$2.70 to \$0.57. In certain locations, winter shade increased heating costs more than reduced wind speeds lowered heating costs, resulting in a net increase in heating.

West is best

Average annual net energy benefits for residential trees were greatest for a tree located west of a building because the shading effect on cooling costs was maximized. A yard tree located south of a building produced the least net energy benefit because it had the least benefit during summer, and the greatest adverse effect from shade on heating costs. Trees located east of a building provided intermediate net benefits. Net energy benefits, however, were a function of species-related traits such as size, form, branch pattern and density, and foliage period. Species like the Mesquite performed best because its broad, dense, low branching crown cast ample shade on building walls and windows. The Evergreen ash and Aleppo pine provided less cooling benefit than the Mesquite, largely because their crowns were narrower and higher above the building.

The Aleppo pine and large Evergreen ash provided net energy benefits at all locations. Their annual average cooling savings during the summer months (\$9-28) more than offset heating costs associated with winter shade (\$1-3). Average annual net benefits were ranged from \$12-28 for the Aleppo pine and \$10-\$22 for the Evergreen ash.

Carbon Dioxide

CO₂ reduction accrues for large and medium trees

Net atmospheric CO₂ reductions accrued for all four tree-types. Average annual net reductions ranged from 202-308 lbs (92-140 kg) (\$2) for the large tree to 94-169 lbs (43-77 kg) (\$1) for the small tree. Trees opposite west-facing house walls produced the greatest CO₂ reduction due to avoided power plant emissions associated with energy savings. Releases of CO₂ associated with tree care activities accounted for only 1% of net CO₂ sequestration.

Stormwater Runoff

Stormwater runoff benefits are crucial to environmental integrity

Avoided stormwater runoff benefits associated with rainfall interception were substantial for all four trees. The Evergreen ash intercepted 930 gal/yr (3.5 m³/yr) on average with an implied value of \$5. A large, Evergreen ash at 40 years after planting had an interception rate of over 2,040 gal/yr (7.7 m³/yr)—valued at \$10.

Bark and foliage of the Mesquite and Aleppo pine intercepted 1,818 gal/yr (6.9 m³/yr) and 2,195 gal/yr (8.3 m³/yr) on average, with a value of \$9 and \$11, respectively. By intercepting 570 gallons (2.2 m³/yr) of rainfall annually, a typical Sweet acacia provided \$3 in stormwater management savings.

Given our assumptions, these results indicate that the amount of rainfall trees intercept is approximately one-half the amount they consume through irrigation. Because the price of irrigation water is considerably less than the cost of treating stormwater per gallon, water quality benefits associated with rainfall interception are 3-5 times greater than irrigation costs.

Air Quality

Large trees and remove more air pollutants

Air quality benefits were defined as the sum of pollutant uptake by trees and avoided power plant emissions due to energy savings, minus *biogenic volatile organic compounds (BVOCs)* released by trees. The total average annual air quality benefits were a relatively low \$4-5 for the Mesquite and Sweet acacia because they are moderate emitters of BVOCs (monoterpenes). Larger benefits were estimated for the Aleppo pine and Evergreen ash (\$9-10) in Desert Southwest communities, largely because they emitted fewer BVOCs and had high pollutant uptake rates due to their size. Benefit values were greatest for SO₂, followed by PM₁₀, NO₂, and O₃. Though positive, trees had minimal effect on VOCs avoided at the power plant.

Low-emitters increase air quality benefits

The cost of BVOCs released by the low-emitting Evergreen ash was negligible. However, on average a single Mesquite emitted about 2.8 lb (1.3 kg) of BVOCs per year. These releases offset annual benefits of \$16 due to pollutant uptake and avoided emissions by \$11. As a result, the net air quality benefit was only \$5.

Benefit Summary

Environmental benefits alone exceed costs for many trees

Average annual benefits for all trees, except the small public tree, exceeded costs of tree planting and management. Surprisingly, in most situations, annual *environmental* benefits, alone, exceeded total costs. Only small, public trees did not meet this standard. Adding the value of aesthetics and other benefits to these environmental benefits resulted in substantial net benefits.



A Sweet acacia, representative of small trees in this report.



A mature Chilean mesquite, representative of medium trees in this report



A mature Evergreen ash, used in this report as representative of a large tree.



A mature Aleppo pine, representative of coniferous trees in this report.

CHAPTER 5. HOW TO ESTIMATE BENEFITS AND COSTS FOR TREE PLANTING PROJECTS IN YOUR COMMUNITY

In this chapter we show two ways that benefit-cost information presented in this Guide can be used. The first hypothetical example demonstrates how to adjust values from the Guide for local conditions when the goal is to estimate benefits and costs for a proposed tree planting project. The second example explains how to compare net benefits derived from planting different types of trees. The 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: MINERAL CITY EXAMPLE

The city of Mineral City is located in the Desert Southwest region and has a population of 24,000. Most of the street trees were planted in the 1930s, with mulberry (*Morus alba*) and Arizona ash (*Fraxinus velutina*) 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 Mineral City over a five-year period. It is anticipated that trained volunteers will plant 15 gal trees and the total cost for planting will be \$75/tree. Trees will be planted along Main Street, other downtown streets, and in parks. One hundred Mesquites will be planted in parks, and the remaining 900 trees will be planted to shade streets. The mature tree sizes are assumed to be 65% large, 20% medium, 5% small, and 10% conifer.

The Mineral 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, CO₂, 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 Mineral City forester and Green Team decide to use tables in the Guide's 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 Mineral City's urban and community forestry project that may differ from the region-wide values used in this Tree Guide (values assumed for Appendix A are described in Appendix B):

- 1) The price of electricity and natural gas in Mineral City are \$0.12/kWh and \$0.0085/kBtu, not \$0.095/kWh and \$0.0097/kBtu assumed in the Guide. It is assumed that nearby buildings have air conditioning and natural gas heating.
- 2) 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 the Guide assume an average annual cost of \$3.87/tree for public trees. Thus, an adjustment is necessary.
- 3) Planting will total \$75/tree due to labor provided by trained volunteers. The Guide assumes planting costs total \$190/tree for 24" boxed trees.
- 4) 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., 40% 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 Mineral City price. This value was then multiplied by the number of trees planted and 40 years ($96 \text{ kWh} \times \$0.12 \times 650 \text{ trees} \times 40 \text{ years} = \$299,520$) 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 (\$6.98 for large, public tree), the 40-year average value of pollutant uptake was divided by the 40-year average amount of pollutant uptake ($\$9.91/1.42 \text{ lb}$). This *adjusted* price accounts for differences in uptake amounts and values among the different pollutants in Mineral City. For aesthetic and other benefits, the dollar values for public trees are placed in the resource unit columns.

The third step: adjust for local costs

To adjust cost figures, the city forester changed the planting cost from \$190 assumed in the Guide to \$75 (Table 4). This planting cost was annualized by dividing the cost/tree by 40 years ($\$75/40 = \$1.88/\text{tree}/\text{yr}$). Total planting costs were calculated by multiplying this value by 650 large trees and 40 years (\$48,750).

The 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 (\$7,339,800, \$28.23/tree/yr), medium (\$1,698,950, \$21.24/tree/yr), small (\$-26,252, \$-1.31/tree/yr), and coniferous (\$525,732, \$13.14/tree/yr) trees. Benefits total \$17.27 million (\$43/tree/yr) and costs total \$7.73 million (\$19/tree/year). The total net benefit for all 1,000 trees over the 40-year period is \$9.54 million, or \$24/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 ($\$9,538,230/1,000 \text{ trees}/40 \text{ yrs.} = \23.85). Dividing total benefits by total costs yielded the benefit-cost ratios (BCRs) that ranged from 0.92 for small trees—where costs slightly exceed benefits—to 2.48 for large, public trees. The BCR for all public trees is 2.23, indicating that \$2.23 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 \$7.73 million, and the average annual cost will be \$193,245 (\$7.73 million/ 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 = 33% (cooling = 32%, heating = 1%)
- Carbon dioxide reduction = 5%
- Air pollution reduction = 12%
- Stormwater runoff reduction = 13%
- Aesthetics/property value increase = 37%

**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 (\$7.73 million), fees could be distributed in the following manner:

- \$2.5 million from electric and natural gas utilities for energy savings (33%)
- \$382,461 from local business and industry for atmospheric carbon dioxide reductions (5%)
- \$915,331 from the air quality management district for net reduction of air pollutants (12%)
- \$1.05 million from the stormwater management district for water quality improvement associated with reduced runoff (13%)
- \$2.85 million from property owners for increased property values (37%).

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: CITY OF MESQUITE EXAMPLE

As a municipal cost-cutting measure, the city of Mesquite 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, Mesquite’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 Mesquite.

The first step: calculate benefits and cost over 40 yrs

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 Mesquite. 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 Mesquite’s urban and community forestry program are different than assumed in this tree guide:

- 1) The price of electricity is \$0.11/kWh, not the \$0.095/kWh assumed in the Guide
- 2) No funds are spent on pest and disease control
- 3) Planting costs are \$225/tree for city trees instead of the \$190/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 Mesquite price (96 kWh x \$0.11= \$10.56). This value was multiplied by 40 years and 500 trees (\$10.56 x 40 x 500 = \$211,200) to obtain cumulative air conditioning savings for the project (Table 5). The same steps were followed for medium and small trees.

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

Benefits	Adjusted Price (\$)	650 RU/tree/yr	Large Total \$	200 RU/tree/yr	Medium Total \$	50 RU/tree/yr	Small Total \$	100 RU/tree/yr	Conifer Total \$	1,000 Total \$	\$/tree/yr	% benefits
Electricity (kWh)	0.12	96	299,520	180	172,800	74	17,760	118	56,640	546,720	13.67	31.7%
NaturalGas(kBtu)	0.0097	50	12,610	58	4,501	2	39	49	1,901	19,051	0.48	1.1%
NetEnergy (kBtu)			312,130		177,301		17,799		58,541	565,771	14.14	32.8%
NetCO2(lb)	0.008	267	55,536	318	20,352	159	2,544	219	7,008	85,440	2.14	4.9%
AirPollution (lb)	6.98	1.42	257,660	-0.42	(23,449)	-0.71	(9,910)	-0.71	(19,820)	204,481	5.11	11.8%
Hydrology (gal)	0.0048	930	116,064	1,818	69,811	570	5,472	2,195	42,144	233,491	5.84	13.5%
Aesthetics & Other		18.77	488,020	11.12	88,960	7.84	15,680	11.24	44,960	637,620	15.94	36.9%
TotalBenefits	Adjusted Price (\$)		1,229,410		332,975		31,585		132,833	1,726,803	43.17	100%
Costs	Adjusted Price (\$)	Cost/tree/yr/yr	Total \$	Cost/tree/yr	Total \$	Cost/tree/yr	Total \$	Cost/tree/yr	Total \$	Total \$	\$/tree/yr	% costs
Tree & Planting	75.00	1.88	48,750	1.88	15,000	1.88	3,750	1.88	7,500	75,000	1.88	9.7%
Pruning		10.86	282,360	11.06	88,480	10.01	20,020	11.27	45,080	435,940	10.90	56.4%
Remove & Dispose		2.11	54,860	2.73	21,840	1.98	3,960	2.28	9,120	89,780	2.24	11.6%
Pest & Disease		0.01	260	0.01	80	0.01	20	0.01	40	400	0.01	0.1%
Infrastructure Repair		0.03	780	0.04	320	0.03	60	0.04	160	1,320	0.03	0.2%
Irrigation (5yrs)		1.55	40,300	2.01	16,080	0.59	1,180	1.96	7,840	65,400	1.64	8.5%
Clean-Up		0.11	2,860	0.15	1,200	0.1	200	0.12	480	4,740	0.12	0.6%
Liability & Legal		0.01	260	0.01	80	0.01	20	0.01	40	400	0.01	0.1%
Admin & Other	100.00	2.50	65,000	2.50	20,000	2.50	5,000	2.50	10,000	100,000	2.50	12.9%
TotalCosts			495,430		163,080		34,210		80,260	772,980	19.32	100.0%
NetBenefit			733,980		169,895		(2,625)		52,573	953,823	23.85	
Benefit/CostRatio			2.48		2.04		0.92		1.66	2.23		

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 (\$225) to obtain the adjusted cost for Mesquite (500 x \$225 = \$112,500). 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 (\$475,100), medium (\$620,800), and small (\$153,600) trees. The total net benefit for the 40-year period was \$1.25 million (total benefits - total costs), or \$833/tree (\$1.25 million/1500 trees) on average (Table 5).

By not investing in street tree planting, the city would save \$337,700 in initial planting costs. If the developer planted 1,500 small-stature trees, benefits total \$460,800 (3 x \$153,600 for 500 small trees). If 1,500 large-stature trees were planted, benefits total \$1.45 million. Planting of small-stature trees causes the city to forego benefits valued at nearly \$1 million. This amount exceeds the savings of \$337,700 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:

- \$950 for a large tree
- \$1,242 for a medium tree
- \$307 for a small tree

Based on this analysis, the City of Mesquite decides to retain their policy of promoting planting of larger-stature trees where space permits. They now require tree shade plans that show how developers will achieve 50% shade over streets, sidewalks, and parking lots within 15 years of development.

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.

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

Benefits	500 Large RUs		500 Medium RUs		500 Small RUs		1,500Tree Total RUs		Average	
	Total \$	Total \$	Total \$	Total \$	Total \$	Total \$	Total \$	\$/tree	% benefits	
Electricity (kWh)	1,920,000	211,200	3,600,000	396,000	1,480,000	162,800	7,000,000	770,000	513	25.4%
Natural Gas (kBtu)	1,000,000	9,600	1,160,000	11,400	40,000	400	2,200,000	21,400	14	0.7%
Net Energy (kBtu)	20,140,000	191,000	37,200,000	352,800	14,860,000	140,800	72,200,000	684,600	456	22.6%
Net CO2 (lb)	5,340,000	40,000	6,360,000	47,800	3,180,000	23,800	14,880,000	111,600	74	3.7%
Air Pollution (lb)	20,000	196,200	0	98,600	0	78,200	20,000	373,000	249	12.3%
Hydrology (gal)	18,600,000	89,200	36,360,000	174,600	11,400,000	54,600	66,360,000	318,400	212	10.5%
Aesthetics and Other Benefits	375,400		222,400		156,800		754,600	503		24.9%
Total Benefits		1,112,600		1,303,600		617,400		3,033,600	2,022	100.0%
Costs		Total\$		Total\$		Total\$		Total\$		
Tree & Planting		112,500		112,600		112,600		337,700	225	32.4%
Pruning		182,800		169,200		135,400		487,400	325	46.7%
Remove & Dispose		43,800		40,600		38,800		123,200	82	11.8%
Pest and Disease		0		0		0		0	0	0.0%
Infrastructure		4,000		3,600		3,400		11,000	7	1.1%
Irrigation		9,800		9,000		8,600		27,400	18	2.6%
Clean-Up		15,400		14,400		13,000		42,800	29	4.1%
Liability & Legal		3,600		3,400		3,200		10,200	7	1.0%
Admin & Other		1,600		1,400		800		3,800	3	0.4%
Total Costs		373,500		354,200		315,800		1,043,500	696	100.0%
Net Benefits		739,100		949,400		301,600		1,990,100	1,327	
Benefit/Cost ratio		2.98		3.68		1.96		2.91		

INCREASING PROGRAM COST-EFFECTIVENESS

What if the costs are too high?	What if the program you have designed is promising in terms of stormwater runoff reduction, energy savings, volunteer participation, and ancillary benefits, but the costs are too high? This section describes some steps to consider that may increase benefits and reduce costs, thereby increasing cost-effectiveness.
	Increase Benefits
Work to increase survival rates	Improved stewardship to increase the health and survival of recently planted trees is one strategy for increasing cost-effectiveness. An evaluation of the Sacramento Shade program found that tree survival rates had a substantial impact on projected benefits (Hildebrandt et al. 1996). Higher survival rates increased energy savings and reduced tree removal costs.
Target tree plantings with highest pay back	Conifers and broadleaf evergreens intercept rainfall and particulates year-round as well as reduce wind speeds, which lowers summer cooling and winter heating costs. Locating these types of trees in yards, parks, school grounds, and other open space areas can increase benefits.
Customize planting locations	You can further increase energy benefits by targeting a higher percentage of trees for locations that produce the greatest energy savings, such as opposite west-facing walls and close to buildings with air conditioning. By customizing tree locations to increase numbers in high-yield sites, energy savings can be boosted.
	Reduce Program Costs
Reduce up-front and establishment costs	Cost-effectiveness is influenced by program costs as well as benefits: $\text{Cost-effectiveness} = \text{Total Net Benefit} / \text{Total Program Cost}$ <p>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:</p> <ul style="list-style-type: none">• 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 power lines, sidewalks, and underground utilities. Time spent planning the planting will result in long-term savings. Also consider soil type and irrigation, microclimate, and the type of activities occurring around the tree that will influence its growth and management.

It all adds up – trees pay us back

When evaluating the bottom line—trees pay us back—do not forget to consider benefits other than the stormwater runoff reductions, energy savings, atmospheric CO₂ 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:

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

Morgan, R. Undated. **An Introductory Guide to Community and Urban Forestry in Washington, Oregon, and California**. Portland, OR: World Forestry Center.

Morgan, R. 1993. **A Technical Guide to Urban and Community Forestry**. Portland, OR: World Forestry Center.

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



CHAPTER 6. GENERAL GUIDELINES FOR SELECTING AND PLACING TREES

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

RESIDENTIAL YARD TREES

Maximizing Energy Savings from Shading

Where should shade trees be planted?

The right tree in the right place can save energy and reduce tree care costs. In midsummer, the sun shines on the east side of a building in the morning, passes over the roof near midday, and then shines on the west side in the afternoon (Figure 3). Electricity use is highest during the afternoon when temperatures are warmest and incoming sunshine is greatest. Therefore, the west side of a home is the most important side to shade.

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



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

Use solar friendly trees

Trees located to shade south walls can block winter sunshine and increase heating costs, because during winter the sun is lower in the sky and shines on the south side of homes (Figure 10). The warmth the sun provides is an asset, so do not plant evergreen trees that will block southern exposures and solar collectors. Use *solar friendly* trees 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 Honey locust (*Gleditsia triacanthos*) and ash (*Fraxinus spp.*).

To maximize summer shade and minimize winter shade, locate shade 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).



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

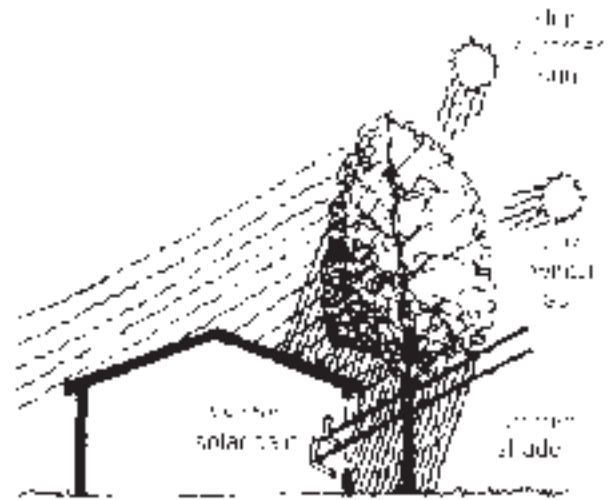


Figure 11. Trees south of a home before and after pruning. Lower branches are pruned up to increase heat gain from winter sun (from Sand 1993).

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 power lines and avoid planting directly above underground water and sewer lines if possible. Contact your local utility company before planting to determine where underground lines are located and which tree species should not be planted under power lines.

Planting Windbreaks for Heating Savings

Locating 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. Locate rows of trees perpendicular to the prevailing wind (Figure 12), usually the north and west side of homes in this region.

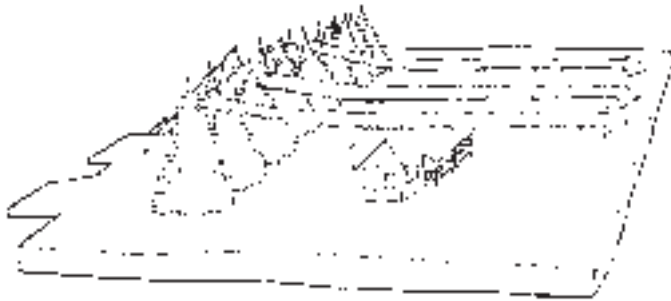


Figure 12. Evergreens protect a building from dust and cold by reducing wind speeds (from Sand 1993).

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.

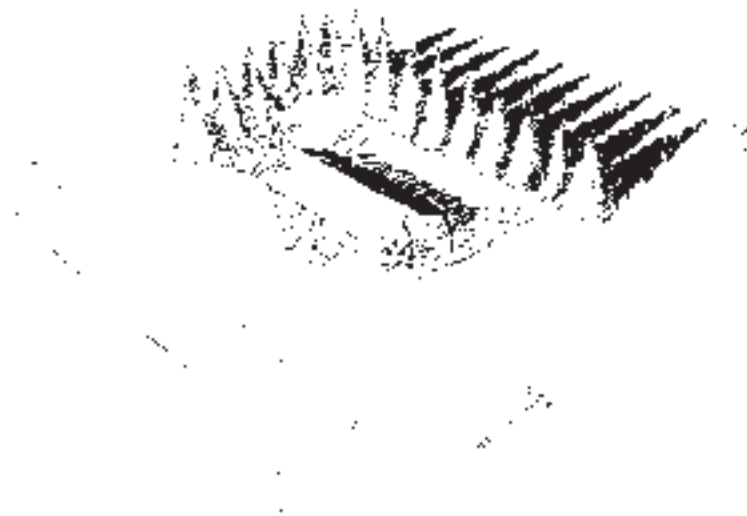


Figure 13. Mid-winter shadows from a well-located windbreak and shade trees do not block solar radiation on the south-facing wall (from Sand 1993).

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 Desert Southwest include Afghan and Aleppo pine (*Pinus eldarica* and *P. halapensis*). Good windbreak species for smaller sites include Arizona and Rocky Mountain juniper (*Juniperus osteosperma* and *J. scopulorum*).

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.

Selecting Yard Trees to Maximize Benefits

There are lots of choices

The ideal shade tree has a fairly dense, round crown with limbs broad enough to partially shade the roof. Given the same placement, a large tree will provide more building shade than a small tree. Deciduous trees allow sun to shine through leafless branches in winter. Plant small trees where nearby buildings or power lines limit aboveground space. Columnar 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.

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.

The green infrastructure is a significant component of communities in the Desert Southwest.



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. 1999). 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 CO₂ 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, CO₂ reductions are primarily due to sequestration. Fast-growing trees sequester more CO₂ 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 CO₂ than smaller growing trees. To maximize CO₂ 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 7), 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 CO₂, and can be unsightly liabilities in the landscape.

How to maximize trees as CO₂ sinks

Parks and other public landscapes serve multiple purposes. Some of the guidelines listed below may help you maximize their ability to serve as CO₂ sinks:

- Provide as much pervious surface as possible (including use of porous concrete near trees) so that trees grow vigorously and store more CO₂.
- Maximize use of woody plants, especially trees, since they store more CO₂ than do herbaceous plants and grass.
- Increase tree-stocking levels where feasible, and immediately replace dead trees to compensate for CO₂ 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 CO₂ emissions stemming from high maintenance needs.
- Group species with similar landscape maintenance and water requirements together and consider how irrigation, pruning, fertilization, weed, pest, and disease control can be done most efficiently.
- Where feasible, reduce CO₂ released through landscape management by using push mowers (not gas or electric), hand saws (not chain saws), pruners (not gas/electric shears), rakes and brooms (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 CO₂ 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 CO₂ 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.

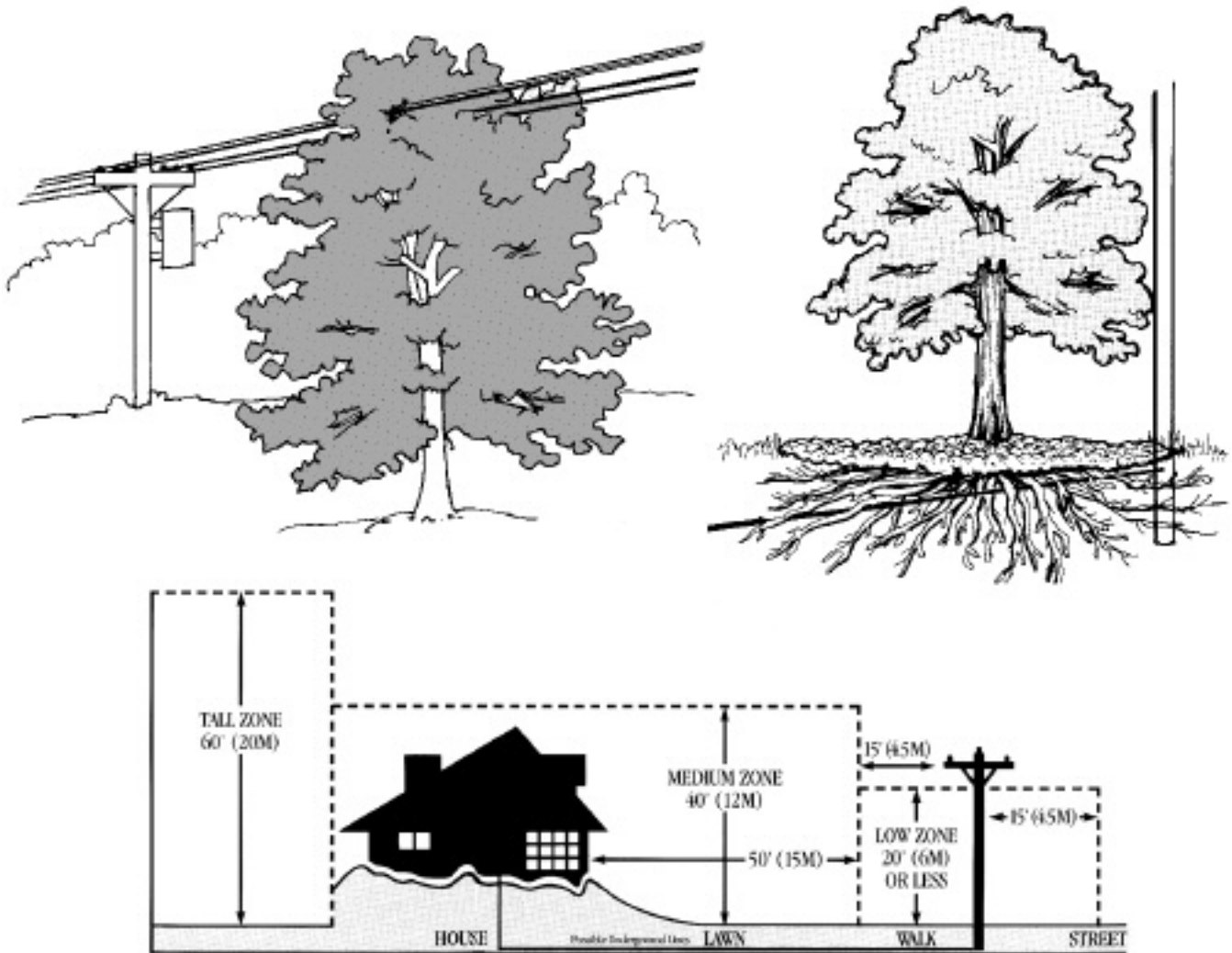


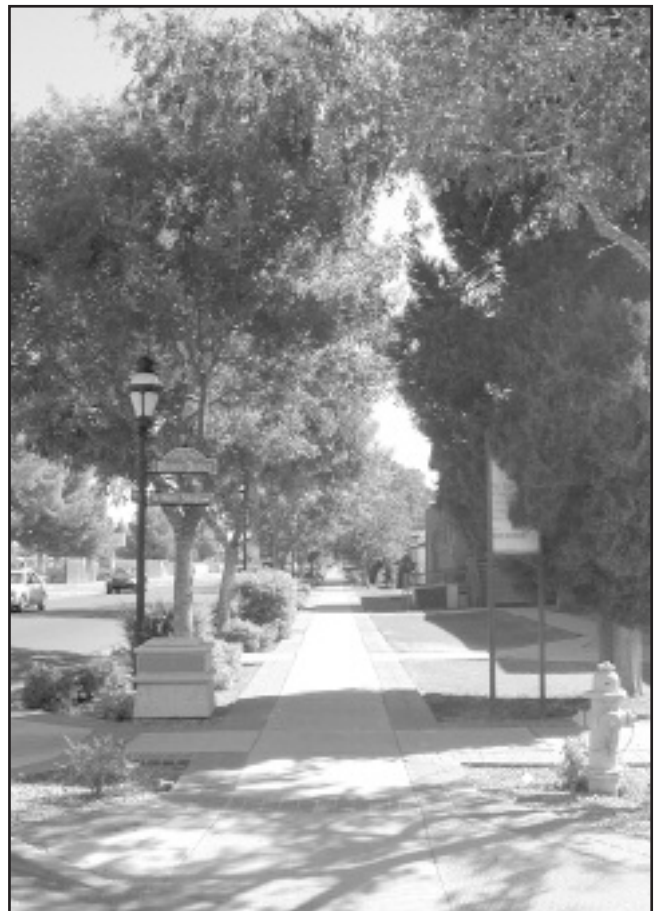
Figure 14. (a, b) Know where power lines and other utility lines are before planting. (c) Under power lines use only small-growing trees (“Low Zone”), and avoid planting directly above underground utilities. Larger trees may be planted where space permits (“Medium” and “Tall” zones) (from ISA 1992)

Pay attention to infrastructure

Before planting contact your local utility company, such as Bluestake, to locate underground water, sewer, gas, and telecommunication lines. Note the location of power lines, streetlights, and traffic signs, and select tree species that will not conflict with these aspects of the city’s infrastructure. Check with local transportation officials for sight visibility requirements. Keep trees at least 30 ft (10 m) away from street intersections to ensure visibility. Avoid planting shallow rooting species near sidewalks, curbs, and paving. Tree roots can heave pavement if planted too close to sidewalks and patios. Generally, avoid planting within 3 ft (1 m) of pavement, and remember that trunk flare at the base of large trees can displace soil and paving for a considerable distance. Select only small-growing trees (<25 ft tall [8 m]) for locations under overhead power lines, 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 7 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 tell-tale sign indicating a poorly anchored tree.

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 rocky or 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 three times a week and thereafter increase the amount of water as the tree grows larger.

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. Leave lower side branches on young trees for the first year and prune back to 4-6 inches (10-15 cm) to accelerate tree caliper development. Remove these laterals after the first full year. 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 CO₂, and provide other benefits. 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). Contact your local urban forestry coordinator or Cooperative Extension agent for research-based information and workshops.

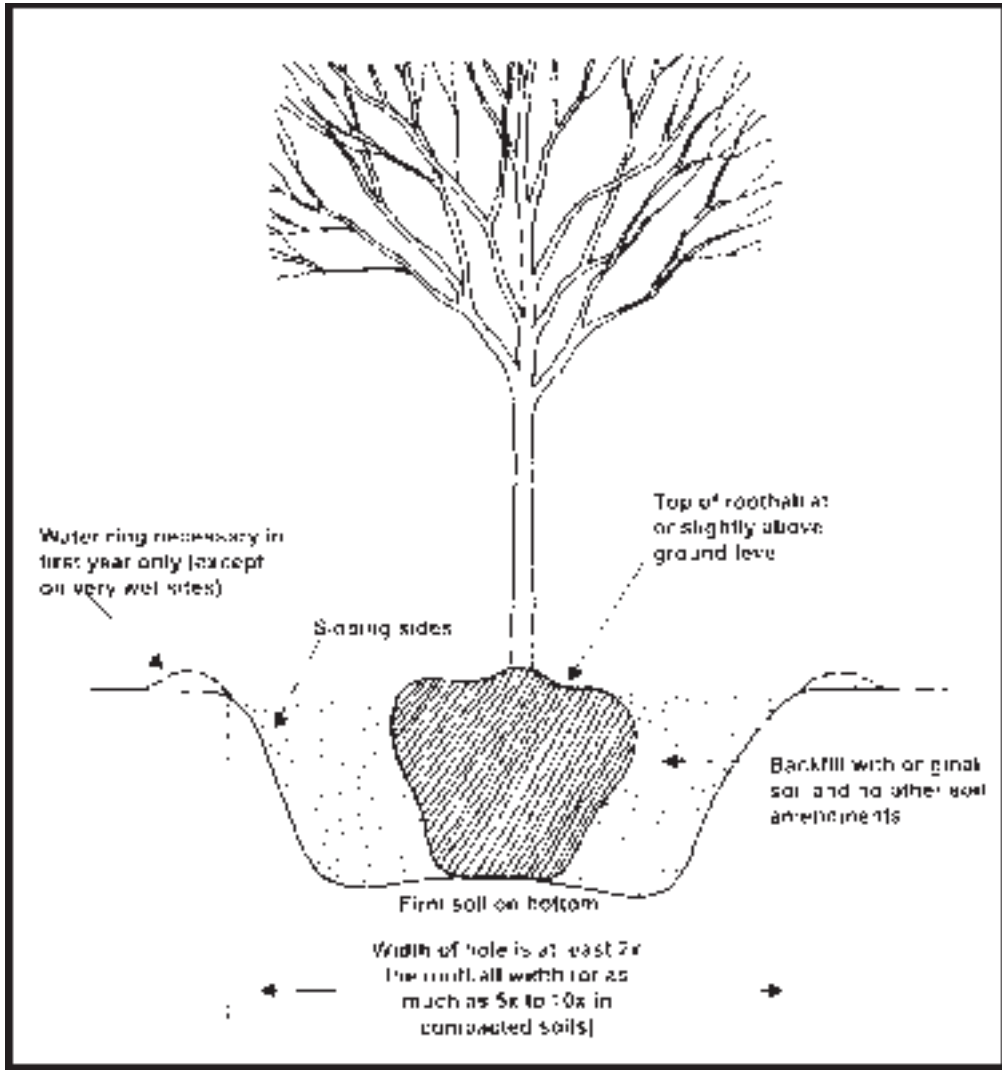


Figure 15. Prepare a broad planting area, plant tree with root ball at ground level, and provide a watering ring to retain water (from Head et al. 2001).



CHAPTER 7. TREE SELECTION LIST FOR DESERT SOUTHWEST COMMUNITIES

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

Desert Southwest landscapes

For the purpose of this chapter, desert southwestern communities include the lower desert regions of southern California, central and southern Arizona, southern Nevada, southern New Mexico and the deserts of southwestern Utah. We have selected these areas as they share many similarities in climate, rainfall, soil conditions, water quality, horticultural practices and have within their borders some of the fastest growing cities in the nation.

Reliable information on the selection, growth and care of landscape trees in the desert southwest comes from scientific research and field experience gathered in a relatively small number of cities and institutions. Within this region the major metropolitan areas include the Coachella Valley, California (Palm Springs/Palm Desert), Phoenix and Tucson, Arizona and Clark County, Nevada (Las Vegas, Henderson, Boulder City). Institutions like the University of Arizona, Tucson, Arizona, Desert Botanical Garden, Phoenix, Arizona, College of the Desert, Palm Desert, California, University of Nevada, Las Vegas, Nevada, the various municipal water conservation authorities and professional and trade organizations have been instrumental in the development and dissemination of information on desert landscape horticulture.

Historically the population growth of this region was significantly driven by immigration of people from other, less arid parts of the country. Landscape designs at all levels, residential, commercial and municipal, attempted to deny the presence of the desert in favor of a more lush and non-indigenous landscape palette. In the last two decades a desert landscape aesthetic has emerged. Driven in part by the need to conserve scarce water, these designs are ultimately inspired by a desire to create a unique and inviting sense of place and to help build communities that embrace rather than mask the beauty of the surrounding deserts.

What is the geographic scope?

The Desert Southwest is a large and enormously diverse region with elevations ranging from near or below sea level (Coachella Valley) to 3,000 feet (914 m) and temperature extremes from single digit winter lows and occasional snow to summer highs of 110 to 115 degrees °F (43-46 °C). The harshness of these conditions is often amplified by low relative humidity coupled with high winds. Additionally, dramatic temperature swings of 30 to 40 degree °F (-1-4 °C) can occur within a single day in the transitions from spring to summer and fall to winter.

Soils can be generally characterized as alkaline and containing little (typically less than 1%) organic matter. Water penetration and water holding capacity of soils varies widely, sometime within very small areas. Blow or dune sands commonly found in California's Coachella Valley afford rapid water penetration with limited water retention. By contrast some southern Nevada soils have a calcareous cap



layer that almost precludes water penetration and must be fractured or removed prior to tree planting. In alluvial areas, like central Arizona's Salt River Valley, loam and sandy clay loam soils can be found but these are not typical of the region as a whole.

Annual rainfall ranges from 2 to 3 inches (51-76 mm) in the Lower California desert and southern Nevada to 8 to 12 inches (203-305 mm) in parts of southern Arizona. Water conservation efforts through out the region are focused on landscape water use, as the overwhelming majority of landscape trees, shrubs and turf are irrigated. The demand to use water efficiently in the landscape has encouraged the introduction, and in many instances re-introduction, of increasing numbers of desert native and desert adapted trees, the use of state-of-the-art irrigation technologies and the application of organic and inorganic surface mulches.

What are the selection criteria?

The trees described below are a reasonably complete, but not an exhaustive listing, of trees adapted to the Desert Southwest. Species listed are well-documented, widely used, and generally available for purchase by the public. Given the region-wide issues associated with water conservation in the landscape, particular emphasis was given to desert native and desert adapted species but other "traditional" landscape trees are also included.

HOW TO MATCH THE TREE TO THE SITE

Selection and placement of landscape trees

Proper placement of trees in the landscape is key to vigorous growth, reduced maintenance and long-term survival. Environmental and physical factors surrounding landscape trees can have dramatic effects on tree health, and appearance. These factors may include reflected heat and light, wind, shade, availability of water, presence or absence of hardscape elements, and the horticultural requirements of the surrounding landscape.

In desert climates, the potential detrimental effects of reflected sunlight and heat on trees cannot be exaggerated. Mirrored or tinted glass used on many mid-rise and high-rise commercial building, large masonry and stucco framed walls and asphalt, paved surfaces reflect and "re-radiate" tremendous amounts of heat. These physical elements in the landscape can, in the protracted heat of a long summer day, add stress and increase transpiration of trees.

Another common problem is mixing trees and shrubs that have widely differing water requirements. This typically involves trees with low water requirements planted either in turf or with high water demanding under-story shrubs. Dense shade generated by mature specimens may adversely affect the growth of surrounding turf and reduce growth and flowering of under-story shrubs and ground covers.

Consider the mature height and width of trees when placing them in the landscape and allow sufficient space between trees to optimize long-term growth without the risk of tangled branches or overlapping canopies. Tree placement should also take into account all the uses of the landscape by pedestrian, bicyclists, motorized vehicles and children.

The presence or absence of thorns is obviously a consideration in the placement of some desert species. The nature, amount and seasonal distribution of leaf, flower and seed pod litter will determine the appropriateness of tree placement near patios, pools, playground equipment, and pedestrian areas.

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.

- Pyramidal – common in excurrent type trees with a main, central stem.
- Oval- elliptical in a vertical fashion.
- Round – self-explanatory.
- Vase – multi-stemmed, decurrent, wider at top than at the base.
- Irregular – no fundamental shape
- Columnar – very upright in its growth.
- Shrub Like – small tree, often multi-stemmed.

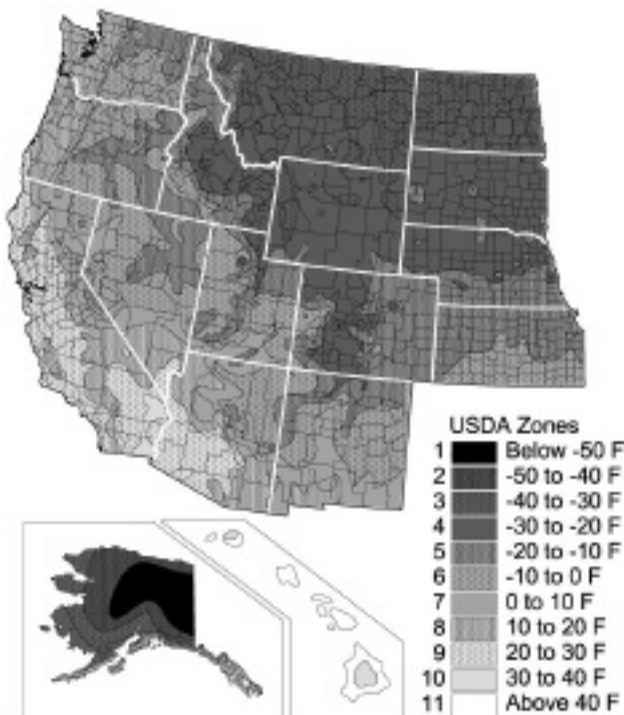


Figure 16. Recommended trees for the Desert Southwest region grow well in USDA Hardiness Zones 8-10 and are acceptable for use by municipalities in the region.

Hardiness Zone: The United States Department of Agriculture’s hardiness zone map was used. Range of zones in the Desert Southwest Region is 8 to 10. Except where noted trees listed are generally cold hardy across these regions. Given the lack of genetic uniformity within some desert adapted species grown from seed, and the existence of some uncharacteristically cold micro-climates within some desert communities, contact local horticulture professionals about conditions in your area.

The symbol ^a indicates that the species may be cold tender in some desert locations, consult local horticulture professionals before planting.

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.

- Fast – more than 2 feet (> 0.6 m) per year
- Medium – 1 foot to 2 feet (0.3-0.6 m) per year
- Slow – less than 1 foot (< 0.3 m) per year.

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

Small – less than 25 feet (7.6 m) tall and wide. Trunk diameters are probably less than 20 inches (51 cm).

Medium – 25-40 feet (7.6-12.2 m) tall and wide. Trunk diameters can be 20 – 30 inches (51-76 cm).

Large – greater than 40 feet (. 12.2 m) tall and wide. Trunk diameters are commonly over 30 inches (> 76 cm).

Exposure: Indicates sun exposure tolerated by the tree.

- FS Full Sun
- PS Partial Shade
- ST Shade Tolerant

BVOC: Biogenic Volatile Organic Compounds are hydrocarbon compounds from vegetation (e.g., isoprene, monoterpene) that exist in the ambient air and contribute to the formation of smog. We identify their potential to adversely affect air quality in ozone non-attainment areas if large numbers are planted:

L = low, < 1;

M = moderate, 1-10;

H = High, > 10 µg/g dry leaf wt/hr

(Benjamin et al. 1996; Karlik and Winer 2002).

NA means no emission rate data are available for members of this family.

TREE LIST REFERENCES

References used to compile the tree list include:

For more information

Arizona Municipal Water Users Association. 2004. **Landscape Plants for the Arizona Desert**. Arizona Municipal Water Users Association, Phoenix, AZ.

Brenzel, Kathleen Norris, 2001. **Western Garden Book**. Sunset Publishing Corporation. Menlo Park, CA.

Irish, Mary. 2003. **Arizona Garden's Guide**. Cool Springs Press. Nashville, TN.

Perry, Bob. 1992. **Landscape Plants for Western Regions**. Land Design Publishing, Claremont, CA.

Walters, James E.; Bachhaus, Balbir. 1992. **Shade and Color with Water Conserving Plants**. Timber Press, Portland, OR.

BOTANICAL NAME	COMMON NAME	FORM	GROWTH RATE	SIZE	EXPOSURE	BVOC
<i>Conifers</i>						
<i>Cedrus atlantica</i>	Blue Atlas Cedar	C	S/M	L	FS	L
<i>Cupressus arizonica</i>	Arizona Cypress	C	M	M	FS, PS	L
<i>Cupressus sempervirens</i>	Italian Cypress	C	M	L	FS	L
<i>Pinus canariensis</i>	Canary Island Pine	O	M	L	FS	M
<i>Pinus eldarica</i>	Afghan Pine	P	F	L	FS	M
<i>Pinus halepensis</i>	Aleppo Pine	I	F	L	FS	L
<i>Pinus pinea</i>	Italian Stone Pine	P	M	L	FS, PS	L
<i>Pinus roxburghii</i>	Chir Pine	O	M	M	FS	M
<i>Pinus thunbergiana</i>	Japanese Black Pine	O	M	L	FS	M
<i>Palms</i>						
<i>Chamaerops humilis</i>	Mediterranean Fan Palm	R	S	S	FS, PS, ST	M
<i>Brahea armata</i>	Mexican Blue Palm	R	S	S	FS	M
<i>Butia capitata</i>	Jelly Palm	R	S	M	FS	M
<i>Phoenix canariensis</i>	Canary Island Date Palm	R	S	L	FS	M
<i>Phoenix dactylifera</i>	Date palm	R	S	L	FS	M
<i>Syagrus romanzoffianum</i>	Queen Palm	R	M	M	FS, PS	M
<i>Washingtonia filifera</i>	California Fan Palm	R	S	L	FS	M
<i>Washingtonia robusta</i>	Mexican Fan Palm	R	F	L	FS	H
<i>Other Trees</i>						
<i>Acacia aneura</i>	Mulga	O	M	S	FS	M
<i>Acacia farnesiana</i> a	Sweet Acacia	O	F	M	FS	M
<i>Acacia pendula</i>	Weeping Myall	V	M	M	FS	M
<i>Acacia rigidula</i>	Black Bush Acacia	O	S	S	FS	M
<i>Acacia salicina</i>	Willow Acacia	O	F	S	FS, PS	M
<i>Acacia schaffneri</i>	Twisted Acacia	I	F	S	FS	M
<i>Acacia stenophylla</i> a	Shoestring Acacia	C	M	L	FS, PS	M
<i>Acacia willardiana</i>	Palo Blanco	C	S	S	FS, PS	M
<i>Albizia julibrissin</i>	Silk Mimosa Tree	O	M	M	FS, PS	H
<i>Bauhinia lunarioides</i>	Anacacho Orchid Tree	O	S/M	S	FS	NA
<i>Brachychiton populneus</i>	Bottle Tree	O	M	M	FS, PB	NA
<i>Caesalpinia cacalaco</i>	Cascalote	V	M	M	FS, PS	M
<i>Caesalpinia mexicana</i>	Mexican Bird of Paradise	V	F	S	FS, PS	M
<i>Callistemon citrinus</i>	Lemon Bottlebrush	C	M	S	FS, PS	H
<i>Callistemon viminalis</i>	Weeping Bottlebrush	C	F	M	FS, PS	H
<i>Casuarina</i> spp.	Beefwood, She Oak	C	M	L	FS	NA
<i>Celtis reticulata</i>	Western or Canyon Hackberry	I	M	M	FS, PS	L
<i>Ceratonia siliqua</i> a	Carob Tree	O	S	L	FS	M
<i>Cercidium floridum</i> (<i>Parkinsonia florida</i>)	Blue Palo Verde	O	F	M	FS	M
<i>Cercidium</i> Hybrid	Thornless Hybrid Palo Verde	V	F	M	FS	M
<i>Cercidium microphyllum</i> (<i>Parkinsonia microphylla</i>) ^a	Foothill or Little Leaf Palo Verde	V	S	M	FS	M
<i>Cercidium praecox</i> (<i>Parkinsonia praecox</i>)	Palo Brea	I	F	M	FS	M
<i>Cercis canadensis</i> v. <i>mexicana</i>	Mexican Redbud	O	M	M	FS, PS	L
<i>Cercis canadensis</i> v. <i>texensis</i>	Texas Redbud	O	M	M	FS, PS	L
<i>Cercis occidentalis</i>	Western Redbud	O	M	M	FS, PS	L

BOTANICAL NAME	COMMON NAME	FORM	GROWTH RATE	SIZE	EXPOSURE	BVOC
<i>Chilopsis linearis</i>	Desert Willow	O	S	M	FS, PS	M
<i>XChitalpa tashkentensis</i>	Chitalpa	O	F	M	FS	M
<i>Chorisia speciosa</i>	Floss Silk Tree	C	M	M	FS, PS	NA
<i>Citrus</i> spp. ^a	Citrus	O	M	S	FS	M
<i>Cotinus coggygria</i>	Smoke Tree	I	M	S	FS	M
<i>Dalbergia sissoo</i> ^a	Indian Rosewood Tree	I	F	M	FS	NA
<i>Elaeagnus angustifolia</i>	Russian Olive	S	M/F	M	FS	NA
<i>Eriobotrya japonica</i>	Loquat	I	M	M	FS, PS	L
<i>Eucalyptus camaldulensis</i>	Red Flowered Mallee	O	F	L	FS	H
<i>Eucalyptus erythrocorys</i>	Red Cap Gum	O	F	M	FS, PS	H
<i>Eucalyptus erythronema</i>	Red flower Mallee	O	F	M	FS, PS	H
<i>Eucalyptus formanii</i>	Feather Gum	O	F	M	FS, PS	H
<i>Eucalyptus leucoxylon</i>	White Ironbark	O	F	M	FS, PS	H
<i>Eucalyptus coolibah</i>	Coolibah	O	F	L	FS	H
<i>Eucalyptus pauciflora</i>	Ghost Gum	O	F	L	FS, PS	H
<i>Eucalyptus polyanthemos</i>	Silver Dollar Gum	O	F	M	FS	H
<i>Eucalyptus rudis</i>	Flooded Gum	O	F	L	FS	H
<i>Eucalyptus sideroxylon</i>	Pink or Red Ironbark	O	F	M	FS, PS	H
<i>Eucalyptus spathulata</i>	Swamp Mallee	I	F	M	FS, PS	H
<i>Eucalyptus torquata</i>	Coral Gum	O	F	M	FS, PS	H
<i>Eysenhardtia orthocarpa</i>	Kidneywood	I	M	M	FS	NA
<i>Ficus carica</i>	Fig Tree	O	M	M	FS, PS	H
<i>Ficus nitida</i> ^a	Indian Laurel Fig	O	M	L	FS, PS	H
<i>Fraxinus greggii</i>	Littleleaf Ash	O	M	S	FS	L
<i>Fraxinus raywoodii</i>	Raywood Ash	O	F	M	FS	L
<i>Fraxinus uhdei</i>	Shamel or Mesquite Ash	O	F	M	FS	L
<i>Fraxinus velutina</i>	Arizona Ash	O	F	M	FS	L
<i>Fraxinus v. fantex</i>	Fantex Ash	O	F	M	FS	L
<i>Fraxinus v. modesto</i>	Modesto Ash	O	F	M	FS	L
<i>Geijera parviflora</i>	Wilga or Australian Willow	SL	M	S	FS, PS	M
<i>Ginkgo biloba</i>	Maidenhair Tree	I	S	L	FS	M
<i>Gleditsia triacanthos inermis</i>	Honey Locust	O	M	M	FS	M
<i>Grevillea robusta</i>	Silk Oak	C	M	L	FS, PS	NA
<i>Jacaranda mimosifolia</i>	Jacaranda	O	M	L	FS, PS	L
<i>Koelreuteria paniculata</i>	Goldenrain Tree	O	M	M	FS	H
<i>Laurus nobilis</i>	Bay Laurel	I	M	S	FS, PS	L
<i>Leucaena retusa</i>	Golden Ball Lead Tree	I	M	S	FS, PS	M
<i>Lysiloma microphylla v. thornberi</i> ^a	Fern of the Desert, Feather Bush	I	S	M	FS, PS	M
<i>Malus</i> spp.	Apple Tree	O	M	S	FS	L
<i>Melia azedarach</i>	Texas Umbrella Tree, Chinaberry	O	M	L	FS	NA
<i>Olea europaea</i>	Olive	O	S	M	FS	L
<i>Olneya tesota</i> ^a	Desert Ironwood	V	S	M	FS	NA
<i>Parkinsonia aculeata</i>	Mexican Palo Verde	V	F	M	FS	M
<i>Paulownia tomentosa</i>	Sapphire Dragon, Empress Tree	O	F	M	FS	M
<i>Pistacia chinensis</i>	Chinese Pistache	O	S	L	FS	M
<i>Pithecellobium flexicaule</i> (<i>Ebenopsis ebanum</i>)	Texas Ebony	O	S	M	FS, PS	NA

BOTANICAL NAME	COMMON NAME	FORM	GROWTH RATE	SIZE	EXPOSURE	BVOC
<i>Pithecellobium mexicanum</i> (<i>Harvardia mexicana</i>)	Mexican Ebony	V	M	M	FS, PS	NA
<i>Pithecellobium pallens</i> (<i>Harvardia pallens</i>)	Tenaza	I	M	M	FS, PS	NA
<i>Pittosporum phillyraeoides</i>	Willow Pittosporum	C	S	S	FS, PS	L
<i>Platanus racemosa</i>	California Sycamore	O	M	L	FS	H
<i>Platanus wrightii</i>	Arizona Sycamore	O	M	L	FS	H
<i>Populus fremontii</i>	Fremont or Western Cottonwood	O	M	L	FS	H
<i>Prosopis</i> spp.	Thornless Hybrid Mesquite	O	F	M	FS	M
<i>Prosopis glandulosa</i>	Honey Mesquite	O	F	M	FS, PS	M
<i>Prosopis pubescens</i>	Screwbean Mesquite	O	M	M	FS	M
<i>Prosopis velutina</i>	Velvet Mesquite	O	M	M	FS	M
<i>Prunus dwarf</i>	Dwarf Fruit Tree	R	M	M	FS, PS	L
<i>Prunus mume</i>	Japanese Flowering Apricot	R	M	M	FS	L
<i>Prunus triloba</i>	Almond	O	M	M	FS	L
<i>Pyrus calleryana</i>	Bradford Pear	O	M	M	FS, PS	L
<i>Pyrus kawakamii</i>	Mesquite Pear	O	M	M/S	FS	L
<i>Quercus buckleyi</i>	Texas, Spanish	O	S	M	FS	H
<i>Quercus fusiformis</i>	Escarpment Live Oak	O	S/M	L	FS	H
<i>Quercus ilex</i>	Holm, Holly Oak	O	S	M	FS	H
<i>Quercus lobata</i>	Valley Oak	O	S	L	FS	M
<i>Quercus muhlenbergia</i>	Chinquapin Oak	O	S	M	FS	H
<i>Quercus suber</i>	Cork Oak	O	S	M	FS	M
<i>Quercus virginiana</i>	Southern Live Oak	O	S	M	FS	H
<i>Rhus lancea</i>	African Sumac	I	M	M	FS, PS	L
<i>Rhus lanceolata</i>	Prairie Flameleaf Sumac	I	M	M	FS	L
<i>Robinia pseudoacacia</i>	Black Locust	O	M	L	FS	H
<i>Salix babylonica</i>	Weeping Willow	O	M	M	FS, PS	H
<i>Salix matsudana</i>	Hankow or Navajo Globe Willow	O	M	M	FS, PS	H
<i>Sambucus mexicana</i>	Mexican Elderberry	S	M	S	FS, PS	L
<i>Schinus molle</i>	California Pepper Tree	I	M	M	FS	M
<i>Schinus terebinthifolius</i>	Brazilian Pepper Tree	I	S	M	FS	M
<i>Tipuana tipu</i>	Tipu Tree	O	M	L	FS, PS	NA
<i>Ulmus parvifolia</i>	Chinese Elm	R	F	L	FS	L
<i>Ungnadia speciosa</i>	Mexican Buckeye	S	S	S	FS, PS	H
<i>Quercus buckleyi</i>	Texas, Spanish	O	S	M	FS	H
<i>Quercus fusiformis</i>	Escarpment Live Oak	O	S/M	L	FS	H
<i>Quercus ilex</i>	Holm, Holly Oak	O	S	M	FS	H
<i>Quercus lobata</i>	Valley Oak	O	S	L	FS	M
<i>Vitex agnus-castus</i>	Chaste Tree or Monk's Pepper	I	S	M	FS, PS	NA
<i>Zelkova serrata</i>	Sawleaf Zelkova	O	F	L	FS	L
<i>Zizyphus jujuba</i>	Chinese Jujube	O	M	M	FS	H

^a May be cold tender in some desert locations, consult local horticulture professionals before planting.



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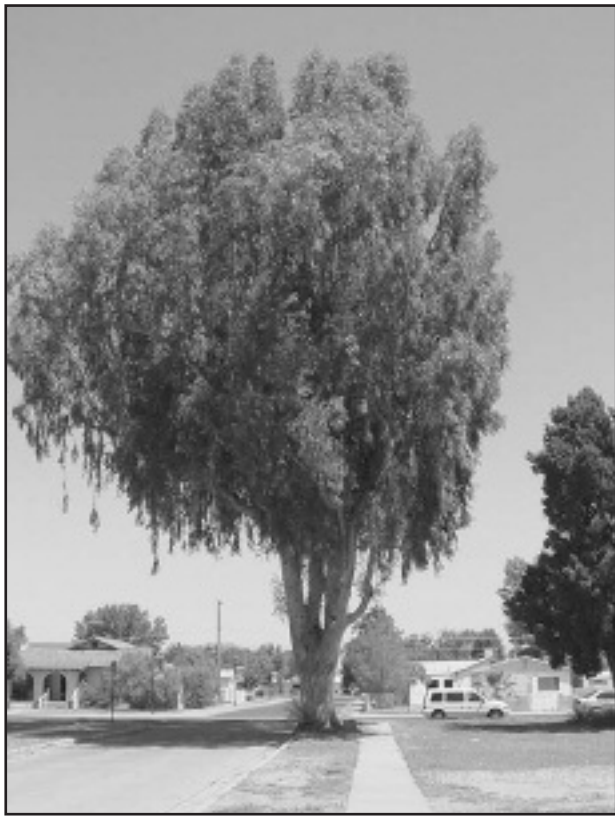


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CHAPTER 9. GLOSSARY OF TERMS

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 CO₂ 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 report follow Benjamin and Winer (1998):

- *Fraxinus uhdei* - 0.0 (Isoprene); 0.0 (Monoterpene)
- *Prosopis chilensis* - 0.0 (Isoprene); 0.47 (Monoterpene)
- *Acacia farnesiana* - 0.0 (Isoprene); 0.47 (Monoterpene)
- *Pinus halapensis* - 0.0 (Isoprene); 0.30 (Monoterpene)

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

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 CO₂/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 "cultivated variety"): Denotes certain cultivated plants that are clearly distinguishable from others by any characteristic and that when reproduced (sexually or asexually) retain their distinguishing 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 CO₂, NO₂, SO₂, and PM₁₀ 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.

Evergreens: Trees or shrubs that are never entirely leafless. Mesquite 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, NO_x): A general term pertaining to compounds of nitric acid (NO), nitrogen dioxide (NO₂), and other oxides of nitrogen. Nitrogen oxides are typically created during combustion processes, and are major contributors to smog formation and acid deposition. NO₂ may result in numerous adverse human 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.

PM₁₀ (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. PM₁₀ also causes visibility reduction.

Resource Unit (RU): The value used to determine and calculate benefits and costs of individual trees. For example, the amount of air conditioning energy saved in kWh/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 CO₂ from the atmosphere through the processes of photosynthesis and respiration (kg CO₂/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 CO₂/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).

SO₂ (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 SO₂. 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 treetop.

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 for roofs and asphalt that absorb solar energy, and 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 and services provided by environmental amenities such as trees and forests.



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 large (Evergreen ash, *Fraxinus uhdei*), medium (Chilean mesquite, *Prosopis chilensis*), small (Sweet acacia, *Acacia farnesiana*), and conifer (Aleppo pine, *Pinus halapensis*) trees. Data are presented as annual values for each five-year interval after planting.

There are two columns in 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 CO₂ 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 in each five-year interval contains dollar values obtained by multiplying RUs by local prices (e.g., kWh saved [RU] × \$/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 (Evergreen ash)

Large Tree Benefits	Year 5		Year 10		Year 15		Year 20		Year 25		Year 30		Year 35		Year 40		41 year average	
	RU	\$	RU	\$	RU	\$	RU	\$	RU	\$	RU	\$	RU	\$	RU	\$	RU	\$
Benefitfree																		
Cooling (WWh)																		
Yard West	36	3.37	76	7.21	143	13.27	268	25.43	328	31.06	372	35.06	388	37.12	398	37.72	228	\$21.66
Yard South	20	1.89	43	4.12	90	8.54	154	14.63	216	20.41	276	26.34	307	29.04	317	29.94	197	\$19.37
Yard East	24	2.29	50	4.71	107	10.07	189	17.93	282	26.85	322	30.48	343	33.00	348	33.00	194	\$18.98
Public	15	1.32	30	2.82	58	5.54	81	7.69	111	10.50	137	12.82	162	15.74	176	16.68	96	\$9.07
Heating (kBtu)																		
Yard West	4	0.04	10	0.10	20	0.18	24	0.22	2	0.01	0.01	0.01	58	0.52	52	0.51	19	\$0.18
Yard South	-2	-0.08	-19	-0.18	-42	-0.48	-40	-0.37	-129	-1.26	-154	-1.42	-144	-1.40	-129	-1.25	-92	(\$0.88)
Yard East	3	0.02	7	0.07	17	0.17	22	0.21	7	0.07	2	0.02	36	0.33	37	0.36	19	\$0.19
Public	11	0.11	27	0.27	41	0.39	52	0.50	45	0.44	44	0.43	65	0.78	103	1.02	50	\$0.48
Net Energy (kBtu)																		
Yard West	309	3.41	750	7.11	1420	13.48	2025	19.20	2757	26.07	3257	30.87	3737	35.87	4032	38.22	2283	\$21.60
Yard South	162	1.61	412	3.92	844	8.02	1256	11.88	1799	16.96	2498	23.68	2820	26.98	2940	27.94	1531	\$14.48
Yard East	284	2.83	666	6.62	1175	11.14	1791	16.72	2784	26.63	3251	30.83	3538	33.55	3555	33.55	1958	\$18.54
Public	158	1.52	327	3.10	604	5.74	869	8.15	1193	10.92	1428	13.32	1681	15.85	1863	17.68	1007	\$9.92
Net CO2 (lb)																		
Yard West	20	0.22	68	0.51	147	1.06	238	1.40	307	2.70	368	3.08	448	4.08	508	4.28	308	\$2.31
Yard South	6	0.05	22	0.15	60	0.41	124	0.79	204	1.44	306	2.16	390	2.83	428	3.04	202	\$1.51
Yard East	19	0.15	46	0.34	105	0.79	192	1.44	303	2.32	440	3.37	474	3.58	497	3.67	241	\$1.90
Public	24	0.18	53	0.40	105	0.81	192	1.44	303	2.32	440	3.37	457	3.65	515	3.88	241	\$2.00
Air Pollution (lb)																		
CO uptake	0.00789	0.01	0.02679	0.02	0.05757	0.15	0.07845	0.21	0.11260	0.68	0.21730	1.11	0.46250	1.88	0.62810	2.64	0.21	\$0.85
NO2 uptake + avoided	0.00253	0.00	0.00806	0.02	0.01707	0.05	0.02907	0.08	0.04670	0.08	0.07493	0.28	0.11850	0.42	0.17493	0.54	0.02	\$1.08
SO2 uptake + avoided	0.00394	0.00	0.01205	0.03	0.02550	0.07	0.04201	0.09	0.06240	0.09	0.09094	0.26	0.14082	0.42	0.21092	0.61	0.28	\$4.35
PM10 uptake + avoided	0.00832	0.00	0.02809	0.08	0.05970	0.17	0.09470	0.28	0.15070	0.34	0.23068	0.70	0.40844	1.20	0.60577	1.87	0.46	\$7.75
VOC's avoided	0.00844	0.00	0.02481	0.07	0.05297	0.15	0.09292	0.27	0.15008	0.23	0.21177	0.25	0.30854	0.33	0.40854	0.38	0.26	\$2.20
NOx's released	0.00060	0.00	0.00200	0.00	0.00300	0.00	0.00400	0.00	0.00500	0.00	0.00600	0.00	0.00700	0.00	0.00800	0.00	0.00	\$0.00
avoided + net uptake	0.10	0.00	0.250	1.00	0.207	0.81	0.047	0.24	1.575	11.17	2.223	15.57	2.859	17.47	3.025	20.05	1.47	\$2.81
Hydrology (gal)																		
Annual Infiltrator	32	0.44	716	2.10	437	1.04	870	3.22	902	4.78	1311	8.29	1744	8.08	2040	9.28	830	\$4.40
Aesthetics and Other Benefits	39.77	\$11.55	\$19.88	\$18.40	\$16.81	\$18.71	\$10.98	\$21.28	\$19.42	\$21.77	\$17.34	\$21.20	\$18.58	\$19.94	\$15.42	\$18.22	\$15.20	\$18.77
Total Benefits																		
Yard West	\$1.09	\$28.42	\$28.42	\$28.42	\$37.47	\$37.47	\$49.35	\$49.35	\$62.81	\$62.81	\$74.34	\$74.34	\$87.74	\$87.74	\$94.17	\$94.17	\$34.12	\$34.12
Yard South	\$1.02	\$20.86	\$20.86	\$20.86	\$31.42	\$31.42	\$41.21	\$41.21	\$52.78	\$52.78	\$63.10	\$63.10	\$70.78	\$70.78	\$78.20	\$78.20	\$48.16	\$48.16
Yard East	\$1.09	\$22.83	\$22.83	\$22.83	\$34.88	\$34.88	\$46.41	\$46.41	\$58.42	\$58.42	\$69.90	\$69.90	\$77.26	\$77.26	\$82.52	\$82.52	\$50.86	\$50.86
Public																		
Year 5		\$14.51				\$52.53		\$4.124		\$28.83		\$18.92		\$63.54		\$59.63		\$48.82
Year 10																		
Year 15																		
Year 20																		
Year 25																		
Year 30																		
Year 35																		
Year 40																		
42 year average																		
Yard West	\$8.25	\$4.75	\$7.42	\$4.75	\$6.04	\$4.75	\$4.56	\$4.75	\$3.25	\$4.75	\$2.42	\$4.75	\$1.60	\$4.75	\$0.87	\$4.75	\$0.25	\$4.75
Yard South	\$2.44	\$10.66	\$2.44	\$10.66	\$2.44	\$10.66	\$2.44	\$10.66	\$2.44	\$10.66	\$2.44	\$10.66	\$2.44	\$10.66	\$2.44	\$10.66	\$2.44	\$10.66
Yard East	\$0.02	\$0.03	\$0.02	\$0.03	\$0.02	\$0.03	\$0.02	\$0.03	\$0.02	\$0.03	\$0.02	\$0.03	\$0.02	\$0.03	\$0.02	\$0.03	\$0.02	\$0.03
Public	\$0.55	\$0.45	\$0.55	\$0.45	\$0.55	\$0.45	\$0.55	\$0.45	\$0.55	\$0.45	\$0.55	\$0.45	\$0.55	\$0.45	\$0.55	\$0.45	\$0.55	\$0.45
Total Net Benefits	\$10.26	\$16.74	\$10.26	\$16.74	\$10.26	\$16.74	\$10.26	\$16.74	\$10.26	\$16.74	\$10.26	\$16.74	\$10.26	\$16.74	\$10.26	\$16.74	\$10.26	\$16.74
Yard West	\$0.25	\$2.08	\$0.25	\$2.08	\$0.25	\$2.08	\$0.25	\$2.08	\$0.25	\$2.08	\$0.25	\$2.08	\$0.25	\$2.08	\$0.25	\$2.08	\$0.25	\$2.08
Yard South	\$0.52	\$1.02	\$0.52	\$1.02	\$0.52	\$1.02	\$0.52	\$1.02	\$0.52	\$1.02	\$0.52	\$1.02	\$0.52	\$1.02	\$0.52	\$1.02	\$0.52	\$1.02
Yard East	\$0.44	\$0.44	\$0.44	\$0.44	\$0.44	\$0.44	\$0.44	\$0.44	\$0.44	\$0.44	\$0.44	\$0.44	\$0.44	\$0.44	\$0.44	\$0.44	\$0.44	\$0.44
Public	\$0.05	\$0.05	\$0.05	\$0.05	\$0.05	\$0.05	\$0.05	\$0.05	\$0.05	\$0.05	\$0.05	\$0.05	\$0.05	\$0.05	\$0.05	\$0.05	\$0.05	\$0.05

Data table for Small tree (Sweet acacia)

Benefit/Tree	Year 0	Year 5		Year 10		Year 15		Year 20		Year 25		Year 30		Year 35		Year 40		40 year average				
		RU	\$	RU	\$	RU	\$	RU	\$	RU	\$	RU	\$	RU	\$	RU	\$	RU	\$	RU	\$	
		Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	Yard	Public	
Benefit/Tree	66.00	\$8.00	66.00	\$8.00	66.00	\$8.00	66.00	\$8.00	66.00	\$8.00	66.00	\$8.00	66.00	\$8.00	66.00	\$8.00	66.00	\$8.00	66.00	\$8.00	66.00	\$8.00
Planting	2.11	\$1.87	2.11	\$1.87	2.11	\$1.87	2.11	\$1.87	2.11	\$1.87	2.11	\$1.87	2.11	\$1.87	2.11	\$1.87	2.11	\$1.87	2.11	\$1.87	2.11	\$1.87
Water & Insect	3.00	\$0.01	3.00	\$0.01	3.00	\$0.01	3.00	\$0.01	3.00	\$0.01	3.00	\$0.01	3.00	\$0.01	3.00	\$0.01	3.00	\$0.01	3.00	\$0.01	3.00	\$0.01
Prune & Disease	3.15	\$0.15	3.15	\$0.15	3.15	\$0.15	3.15	\$0.15	3.15	\$0.15	3.15	\$0.15	3.15	\$0.15	3.15	\$0.15	3.15	\$0.15	3.15	\$0.15	3.15	\$0.15
Improve/View Recor	3.01	\$0.01	3.01	\$0.01	3.01	\$0.01	3.01	\$0.01	3.01	\$0.01	3.01	\$0.01	3.01	\$0.01	3.01	\$0.01	3.01	\$0.01	3.01	\$0.01	3.01	\$0.01
Improve	3.15	\$0.15	3.15	\$0.15	3.15	\$0.15	3.15	\$0.15	3.15	\$0.15	3.15	\$0.15	3.15	\$0.15	3.15	\$0.15	3.15	\$0.15	3.15	\$0.15	3.15	\$0.15
Clean-Up	3.01	\$0.01	3.01	\$0.01	3.01	\$0.01	3.01	\$0.01	3.01	\$0.01	3.01	\$0.01	3.01	\$0.01	3.01	\$0.01	3.01	\$0.01	3.01	\$0.01	3.01	\$0.01
Legal by Legal	3.00	\$0.00	3.00	\$0.00	3.00	\$0.00	3.00	\$0.00	3.00	\$0.00	3.00	\$0.00	3.00	\$0.00	3.00	\$0.00	3.00	\$0.00	3.00	\$0.00	3.00	\$0.00
Adman & Drive	3.00	\$0.00	3.00	\$0.00	3.00	\$0.00	3.00	\$0.00	3.00	\$0.00	3.00	\$0.00	3.00	\$0.00	3.00	\$0.00	3.00	\$0.00	3.00	\$0.00	3.00	\$0.00
Total Costs	\$90.33	\$49.77	\$90.33	\$49.77	\$90.33	\$49.77	\$90.33	\$49.77	\$90.33	\$49.77	\$90.33	\$49.77	\$90.33	\$49.77	\$90.33	\$49.77	\$90.33	\$49.77	\$90.33	\$49.77	\$90.33	\$49.77
Total Net Benefits	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19
Yard: West	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19
Yard: South	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19
Yard: East	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19
Public	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19	\$68	\$19

Cost table for Conifer Irons (Aleppo pine)

	Year 5	Year 10	Year 15	Year 20	Year 25	Year 30	Year 35	Year 40	40 year average
Conifer Type	RU	RU	RU	RU	RU	RU	RU	RU	RU
Conifer Type									
Beneathline									
Cooling (kWht)									
Year: West	20	103	191	286	398	525	672	838	297
Year: South	10	52	100	150	203	264	332	408	215
Year: East	20	103	191	286	398	525	672	838	297
Public	47	458	710	1052	1558	2168	2900	3772	170
Net Energy (MWh)									
Year: West	5	0.05	0.1	0.15	0.22	0.31	0.41	0.52	0.16
Year: South	-1	-0.01	-0.02	-0.03	-0.05	-0.07	-0.09	-0.11	-0.03
Year: East	1	0.01	0.02	0.03	0.05	0.07	0.09	0.11	0.03
Public	13	0.13	0.25	0.40	0.60	0.91	1.34	1.98	0.40
Net CO2 (t/c)									
Year: West	283	7.65	14.87	22.65	34.12	49.58	70.04	97.51	2.85
Year: South	160	4.53	8.71	13.07	19.55	28.11	39.76	54.59	1.67
Year: East	228	6.42	12.22	18.64	28.11	40.58	56.04	76.87	2.42
Public	-80	-2.11	-4.08	-6.20	-9.25	-13.28	-19.05	-26.12	-0.85
Air Pollution (lb)									
Year: West	15	0.11	0.22	0.33	0.46	0.62	0.81	1.04	0.28
Year: South	1	0.01	0.02	0.03	0.05	0.07	0.09	0.11	0.03
Year: East	8	0.06	0.12	0.18	0.27	0.37	0.49	0.64	0.18
Public	20	0.14	0.29	0.44	0.65	0.91	1.22	1.60	0.49
Acoustic (dB)									
Year: West	0.00109	0.00162	0.00249	0.00381	0.00569	0.00861	0.01299	0.01924	0.00561
Year: South	0.00090	0.00136	0.00204	0.00306	0.00459	0.00681	0.00993	0.01416	0.00427
Year: East	0.00260	0.00395	0.00594	0.00889	0.01334	0.01977	0.02883	0.04195	0.01244
Public	0.00449	0.00681	0.01023	0.01554	0.02334	0.03431	0.05081	0.07408	0.02176
Psychology (M)									
Year: West	0.053	0.270	0.512	0.784	1.189	1.734	2.462	3.406	1.03
Year: South	0.036	0.183	0.366	0.549	0.824	1.206	1.734	2.462	0.68
Year: East	0.081	0.405	0.810	1.215	1.823	2.734	4.001	5.734	1.74
Public	0.160	0.810	1.620	2.430	3.640	5.460	8.100	12.150	3.45
Health & Safety									
Year: West	56.00	38.00	26.00	18.00	12.00	8.00	5.00	3.00	15.00
Year: South	25.00	15.00	10.00	7.00	5.00	3.00	2.00	1.00	8.00
Year: East	58.00	35.00	24.00	17.00	12.00	8.00	5.00	3.00	16.00
Public	39.00	24.00	17.00	12.00	8.00	5.00	3.00	2.00	11.00
Costs (Millions)									
Year: West	66.00	38.00	26.00	18.00	12.00	8.00	5.00	3.00	15.00
Year: South	25.00	15.00	10.00	7.00	5.00	3.00	2.00	1.00	8.00
Year: East	58.00	35.00	24.00	17.00	12.00	8.00	5.00	3.00	16.00
Public	39.00	24.00	17.00	12.00	8.00	5.00	3.00	2.00	11.00
Net Benefits									
Year: West	-160	-92	-58	-38	-25	-16	-10	-6	-31
Year: South	-85	-47	-31	-20	-13	-8	-5	-3	-15
Year: East	-160	-92	-58	-38	-25	-16	-10	-6	-31
Public	-100	-54	-35	-23	-15	-9	-5	-3	-17
Total Costs	\$57.49	\$48.21	\$33.14	\$22.23	\$14.67	\$9.34	\$5.86	\$3.40	\$18.92
Total Net Benefits									
Year: West	\$41	\$23	\$15	\$10	\$7	\$4	\$3	\$1	\$11
Year: South	\$21	\$12	\$8	\$5	\$3	\$2	\$1	\$0	\$5
Year: East	\$41	\$23	\$15	\$10	\$7	\$4	\$3	\$1	\$11
Public	\$26	\$15	\$10	\$7	\$4	\$3	\$2	\$1	\$7





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 a large (*Fraxinus uhdei*, Evergreen ash), medium, (*Prosopis chilensis*, Chilean mesquite), small (*Acacia farnesiana*, Sweet acacia) deciduous trees, as well as a coniferous (*Pinus halapensis*, Aleppo pine) tree. Results are reported at 5-year intervals for 40 years.

Leaf surface area and crown volume are useful indicators

Mature tree height is frequently used to distinguish between large, medium, and small species because matching tree height to available overhead space is an important design consideration. However, in this analysis, *leaf surface area (LSA)* and crown 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 Glendale, AZ.

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 2.5% for the first five years and 0.8% 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 size of tree

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 consulting arborists were source of cost estimates

Frequency and costs of tree management were estimated based on surveys with municipal foresters from Glendale and Phoenix. In addition, commercial arborists in Tucson, Glendale, and Phoenix were contacted for information on tree management costs on residential properties.

Pricing benefits

Electricity and natural gas prices for utilities serving Phoenix, Tucson, Las Vegas, and the California desert were used to quantify energy savings for the region. 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 Desert Southwest region. This house was a one story, wood frame, slab-on-grade building with a conditioned floor area of 1,660 ft² (154 m²), window area (double-glazing) of 179 ft² (16.6 m²), and wall, ceiling and floor insulation of R13, R27, and R0, 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 Phoenix (Marion and Urban 1995).

Calculating energy savings

The dollar value of energy savings was based on regional average residential electricity and natural gas prices of \$0.095 per kWh and \$0.097 per *therm*, respectively. Electricity and natural gas prices were year 2003 population-weighted averages for the major energy providers in the region- Arizona Public Service Company, Salt River Project, Nevada Power Company, Tucson Electric Power and Southern California Edison for electricity, Southwest Gas Corporation and Southern California Gas Company for natural gas. 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 (Aleppo pine) had a visual density of 80% during summer and winter. The large tree (evergreen ash) had a visual density of 79% during summer and 37% during winter. The medium tree (Chilean mesquite) and small tree (sweet acacia) had densities of 77% during summer and 67% during winter. Large and medium trees were leafless December 7-February 7, small trees from December 31-February 7. 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. For example, in Modesto, CA 15% of total annual dollar energy savings from street trees was due to shade and 85% due to *climate effects* (McPherson et al. 1999a). In Glendale, about 35% 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 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 30% based on estimates for 6 cities in the region (McPherson and Simpson 1999). Canopy cover was calculated to increase by 1.3%, 3.1%, 1.2%, and 1.7% for 20-year-old large, medium, small, and coniferous trees, respectively, based on an effective lot size (actual lot size plus a portion of adjacent streets and other rights-of-way) of 10,000 ft² (929 m²), 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.

Calculating windbreak effects

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 Desert Southwest 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

Calculating the value of reduced CO₂ emissions

Conserving energy in buildings can reduce CO₂ emissions from power plants. These avoided emissions were calculated as the product of energy savings for heating and cooling based on the respective CO₂ *emission factors* for cooling and heating (Table B1). Pollutant emission factors were based on data for the Western Electricity Coordinating Council Southwest Region where the average fuel mix is 7% hydro, 20% natural gas, 50% coal, 21% nuclear and 2% other (U.S. EPA 2003) (Table B1).

The value of \$15/ton CO₂ reduction (Table B1) was based on the average of high and low estimates by CO₂e.com (2002).

Table B1. Emissions factors and implied values for CO ₂ and criteria air pollutants.			
	Emission Factor Electricity (lb/MWh) ^a	Natural gas (lb/MBtu) ^b	Implied value (\$/lb) ^c
CO ₂	999	118	0.008
NO ₂	3.395	0.1020	4.00
SO ₂	2.046	0.0006	15.70
PM ₁₀	0.120	0.0075	6.00
VOC's	0.020	0.0054	4.00

^aUSEPA, eGRID 2003, except Ottinger et al. 1990 for VOC's, ozone
^bU. S. Environmental Protection Agency 1998.
^cCO₂ from CO₂e.com (2002). Value for SO₂ based on the methods of Wang and Santini (1995) using emissions concentrations from US EPA (2002) and population estimates from the US Census Bureau (2002). All other pollutants from Crumbaker (2004),

Calculating carbon storage

Sequestration, the net rate of CO₂ 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 CO₂. The amount of CO₂ sequestered each year is the annual increment of CO₂ stored as trees add biomass each year.

Power equipment releases CO₂

A value of 0.08 CO₂/inch DBH (0.014 kg CO₂/cm DBH) for *tree-related emissions* was utilized for yard and public trees based on gasoline and diesel fuel consumption for street and park tree care in Glendale (Rodriguez and Van Meeteren 2004), recognizing that it may overestimate CO₂ release associated with less intensively maintained residential yard trees.

Decomposition releases CO₂

To calculate CO₂ 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 CO₂ in the same year (McPherson and Simpson 1999).

Air Quality Improvement

Value of emission reductions

Reductions in building-energy use also result in reduced emissions of air pollutants from power plants and space heating equipment. Volatile organic hydrocarbons (VOCs) and nitrogen dioxide (NO₂)—both precursors of ozone formation—as well as sulfur dioxide (SO₂) and particulate matter of <10 micron diameter (PM₁₀) were considered. Changes in average annual emissions and their offset values were calculated in the same way as for CO₂, using utility-specific emission factors for electricity and heating fuels (Ottinger et al. 1990; US EPA 1998). The price of emissions savings were either based on local estimates (Crumbaker 2004) or derived from models that calculate the marginal cost of controlling different pollutants to meet air quality standards (Wang and Santini 1995). Emissions concentrations for the latter (SO₂) were obtained from U.S. EPA (2002), and population estimates from the U.S. Census Bureau (2002) (Table B1).

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, and R_c) for each hour throughout the year. Hourly concentrations for NO₂, SO₂, O₃, and PM₁₀ and hourly meteorological data (i.e., air temperature, wind speed, solar radiation) for Glendale and environs for 2001 were obtained from the Maricopa county Environmental Service Department (Davis 2004) and the Arizona Meteorological Network (AZMET 2004), respectively. To price pollutant uptake by trees we used stationary source *control and offset* costs reported by the Maricopa Environmental Services Department (Crumbaker 2004) and the work of Wang and Santini (1995) for SO₂ (Table B1). The implied value of NO₂ was used for ozone.

Estimating BVOC emissions from trees

Annual emissions of biogenic volatile organic compounds (BVOCs) were estimated for the four tree species 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 Glendale, AZ during summer 2003. The amount of foliar biomass present for each year of the simulated tree's life was unique for each species. Hourly air temperature and solar radiation data for 2001 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), foliage periods, and tree dimensions (e.g., tree height, crown height, crown diameter, and DBH). 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 inches for all four trees) values influence the amount of projected throughfall. Hourly meteorological and rainfall data for 2001 from the Arizona Meteorological Network (AZMET) (Station name: Phoenix Greenway, Latitude: 33° 37' 17" N, Longitude: 112° 06' 30" W) were used for this simulation. Annual precipitation during 2001 was 6.86 inches (174 mm), close to the recent 10-year average annual precipitation of 7.87 inches (200 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 Glendale's cost for several detention/retention basins. These basins are in parks and developers of adjacent land pay the city for use of the retention facility. The Tarrington Place Park retention facility is 0.67 acres (0.27 ha) and 3-ft deep (0.9 m). The basin holds 2 acre feet (2,468 m³) of runoff and the developer paid \$43,550 for use of the facility (Cardin 2004). With operating and maintenance costs of \$80/month for 20 years, the total project costs were \$62,750. Assuming that the basin filled once annually for 20 years, the control cost was \$0.0048/gal (\$1.27/m³).

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 Desert Southwest 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 to home value

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 Desert Southwest 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 2003 median home prices ranged from \$72,000 in Yuma, AZ to \$223,420 in Palm Springs, CA. By averaging the values for these cities, along with Tucson, Phoenix, Glendale, and Las Vegas, we calculated an average home price for Desert Southwest communities of \$154,403. Therefore, the value of a large tree that added 0.88% to the sales price of such a home was \$1,362. Based on growth data for a 40-year old Evergreen ash, such a tree was 49-ft tall (15 m), had a 41-ft (12.5 m) crown diameter, a 22-inch DBH (56 cm), and 7,303 ft² (679 m²) 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 Evergreen ash in the front yard increased the property's sales price by \$1,362. 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, \$0.15/ft² (\$1.63/m²) 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; Tyrvaiven 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 \$0.18 and \$0.19/ft² (\$1.91 and \$2.01/m²) LSA, respectively. Assuming that 80% of all municipal trees were on streets and 20% in parks, a weighted average benefit of \$0.18/ft² (\$1.93/m²) 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 Desert Southwest municipal and commercial arborists, planting costs depend on tree size. Costs ranged from \$130-\$150 for a 15-gal tree to \$950 for a 36" boxed tree. In this analysis we assumed that a 24" boxed tree was planted. The costs for planting a yard and public tree of this size were \$330 and \$190, respectively. These prices include the tree, as well as planting, staking, and mulching by a professional.

Pruning Costs

Calculating pruning costs

After studying data from municipal forestry programs and their contractors we assumed that young public trees were pruned annually during the first five years after planting, at a cost of \$10/tree. Thereafter, pruning occurred once every other year for small trees (< 20 ft tall), every 4-years for medium trees (20-40-ft tall), and every 6-years for large trees (>40-ft tall). Pruning of small public trees cost \$20/tree. More expensive equipment and more time was required to prune medium-sized (\$62.50/tree) and large trees (\$115/tree). After factoring in pruning frequency, annualized costs were \$10, \$10, \$15.63, and \$18.40 for public young, small, medium, and large trees, respectively.

Pruning residential trees

Based on findings from our survey of commercial arborists in the Desert Southwest region, pruning cycles for yard trees were similar to public trees, but only 20% of all residential trees are professionally pruned. Also, the percentage of homeowners that prune trees themselves decreases, as trees grow larger. We assumed that professionals are paid to prune all large trees, 60% of the medium trees, and only 6% of the small and young trees (Summit and McPherson 1998). Using these *contract rates*, along with average pruning prices (\$25, \$80, \$175, and \$400 for young, small, medium, and large trees, respectively), the average annual cost for pruning a residential yard tree was \$0.30, \$0.48, \$5.25, and \$12.80 for young, small, medium, and large trees.

Tree and Stump Removal

The costs for removing public and yard trees were \$14 and \$20 per inch (\$5.51 and \$7.87/cm) DBH, respectively. Stump removal costs were \$8.50/in (\$3.35/cm) and \$6/in (\$2.36/cm) DBH for public and yard trees, respectively. The total cost for public and yard trees was \$22.50/in and \$26/in (\$8.86/cm and \$10.24/cm) DBH.

Pest and Disease Control

The Southwest Desert regions arid climate reduces the frequency of severe pest and disease outbreaks. As a result, control costs are low and treatments occur on an as needed basis. In Desert Southwest communities this expenditure averaged about \$0.02/tree/yr or approximately \$0.001 per inch (\$0.0004/cm) DBH for public trees. Results of our survey indicated that a negligible amount of money is spent for treating pests and diseases on yard trees.

Irrigation Costs

We assumed that all public and yard trees were irrigated for the 40-year period. Based on landscape irrigation guidelines (AMWUA 2001) the *evapotranspiration (ET)* demand for a mature desert tree can be 4,000 gallons per year in Phoenix. Assuming that water was purchased at a price of \$1.81/ 1000 gals (2004 price for Glendale), and the mature tree had 7,303 ft² (679 m²) of LSA, the annual price of water for an irrigated large tree was \$7.24 or \$0.001/ft² LSA. Hence, annual irrigation water costs were assumed to increase with tree leaf area as the tree matured.

Other Costs for Public and Yard 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. Cost data were obtained from the municipal arborist



survey and assume that 50% of the public trees are street trees and 50% are park trees. Costs for park trees tend to be less than for street trees because there are fewer conflicts with infrastructure such as power lines and sidewalks.

Infrastructure conflict costs

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 Desert Southwest 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 \$0.14/tree (\$0.007/in [\$0.003/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 Desert Southwest communities spend only \$0.01/tree per year on average (\$0.0001/inch 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 costs

The average annual per tree cost for litter clean-up (i.e., street sweeping, storm damage clean-up) was \$0.45 (\$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 high in our survey of Desert Southwest communities. The average annual municipal expenditure was \$1.27/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 \$3.87/tree (\$0.26/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.”

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

Neighborhood attractiveness and property values can be influenced by the extent of tree canopy cover on individual properties. On the community scale, benefits are realized through cleaner air and water, as well as social, educational, and employment and job training benefits that can reduce costs for health care, welfare, crime prevention, and other social service programs. Reductions in atmospheric CO₂ concentrations due to trees are an example of benefits that are realized at the global scale.

The sum of all benefits (B) was:

The sum of all benefits is...

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

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)
- CO₂ = 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 is... 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 pruning 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 were 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 Desert Southwest 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 power lines. 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.

This Isn't the Only Place Where Trees Are Growing!

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