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Midwest Community Tree Guide

Benefits, Costs, and Strategic Planting

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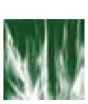
Areas of Research:


Investment Value


Energy Conservation


Air Quality


Water Quality


Firewise Landscapes

Mission Statement

We conduct **research** that demonstrates new ways in which **trees add value** to your community, converting results into **financial** terms to assist you in stimulating more **investment in trees.**

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.

Midwest Community Tree Guide

Benefits, Costs, and Strategic Planting

Authors

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What's in This Tree Guide?

Executive Summary: Presents key findings.

Chapter 1: Describes the guide's purpose, audience, and geographic scope.

Chapter 2: Provides background information on the potential of trees in Midwest communities to provide benefits, as well as management costs that are typically incurred.

Chapter 3: Provides calculations of tree benefits and costs.

Chapter 4: Illustrates how to estimate urban forest benefits and costs for tree-planting projects in your community and tips to increase cost-effectiveness.

Chapter 5: Presents guidelines for selecting and placing trees in residential yards and public open spaces.

References: Lists references cited in the guide.

Glossary of Terms: Provides a glossary of definitions for technical terms that appear in bold text.

Appendix A: Describes the methods, assumptions, and limitations associated with estimating tree benefits.

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

This guide will help users quantify the long-term benefits and costs associated with proposed tree-planting projects. The guide is also available online at http://www.fs.fed.us/psw/publications and also at http://www.fs.fed.us/psw/programs/cufr/. The Center for Urban Forest Research (CUFR) has developed a computer program called STRATUM to estimate the benefits and costs for existing street and park trees. STRATUM is part of the i-Tree software suite. More information on i-Tree and STRATUM is available at www.itreetools.org and the CUFR Web site.

Executive Summary

Benefits and costs quantified

This report quantifies benefits and costs for typical small, medium, and large deciduous (losing their leaves every autumn) trees: crabapple, red oak, and hackberry (see "Common and Scientific Names" section). The analysis assumed that trees were planted in a residential yard or public site (streetside or park) with a 60 percent survival rate over a 40-year timeframe. Tree care costs were based on results from a survey of municipal and commercial arborists. Benefits were calculated by using tree growth curves and numerical models that consider regional climate, building characteristics, air-pollutant concentrations, and prices.

Given the Midwest region's large geographical area, this approach provides first-order approximations. It is a general accounting that can be easily adapted and adjusted for local planting projects. Two examples are provided that illustrate how to adjust benefits and costs to reflect different aspects of local planting projects.

Average annual net benefits

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

- $3 to $15 for a small tree
- $4 to $34 for a medium tree
- $58 to $76 for a large tree

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

Net benefits summed for 40 years

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

- $600 (yard) and $160 (public) for a small tree
- $1,360 (yard) and $640 (public) for a medium tree
- $3,040 (yard) and $2,320 (public) for a large tree

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

Costs

The average annual cost for tree care 20 years after planting ranged from $8 per yard tree to $36 per public tree.

- Small tree: $8 (yard) and $27 (public)
- Medium tree: $13 (yard) and $33 (public)
- Large tree: $15 (yard) and $36 (public)

Tree pruning was the single greatest cost for trees ($5–$20/year per tree); annualized planting ($5–$10/year per tree) and removal ($4–$7/year per tree) costs were also important.

Average annual net benefits at age 40

Large trees provide the most benefits. Average annual benefits increased with mature tree size (approximate size 40 years after planting), and at age 40 the annual benefits were:

- $20–$32 for a small tree
- $25–$54 for a medium tree
- $81–$99 for a large tree

Benefits associated with energy savings and property value accounted for the largest proportion of total benefits. Rainfall interception (water held on tree leaves and the trunk surface, reducing stormwater runoff), atmospheric carbon dioxide (CO_2) reduction, and improved air quality were the next most important benefits.

Energy conservation benefits varied with tree location as well as size. Trees located opposite west-facing walls provided the greatest net heating and cooling energy savings. In addition, trees reduce stormwater runoff. A typical 20-year-old hackberry intercepts 1,394 gal of rainfall per year. After 40 years, this figure increases to 5,387 gal/year—valued at $25.

Reducing heating and cooling energy needs reduced CO_2 emissions and thereby reduced atmospheric CO_2. Similarly, cooling savings that reduced pollutant emissions at power plants accounted for important reductions in gases that produce ozone, a major component of smog. The magnitude of air quality benefits reported here reflects the relatively clean air in the Minneapolis region. Higher benefits are expected in regions with higher pollutant concentrations, such as Chicago, Detroit, and Cleveland. Net air-quality benefits were influenced to a small extent by tree emissions of biogenic volatile organic compounds (hydrocarbons produced by vegetation).

Adjusting for local planting projects

To demonstrate ways that communities can adapt the information in this report to their needs, two fictional cities interested in improving their urban forest have been created. The benefits and costs of different planting projects are determined. In the hypothetical city of Wabena Falls, net benefits and benefit–cost ratios (BCRs) were calculated for a hypothetical planting of 1,000 trees (1-in) assuming a cost of $100/tree, 60 percent survival rate, and 40-year analysis. Total costs were $1.26 million, benefits totaled $3.99 million, and net benefits were $2.73 million ($68/tree per year). The BCR was 3.17:1, indicating that $3.17 was returned for every $1 invested. The net benefits and BCRs by mature tree size were:

- $30,120 (1.62:1) for 50 small crabapple trees
- $252,902 (2.05:1) for 200 medium red oak trees
- $2.45 million (3.52:1) for 750 large hackberry trees

Energy savings (56 percent) and increased property values (24 percent) accounted for 80 percent of the estimated benefits. Storm-water-runoff reduction (9 percent), air quality improvement (7 percent), and atmospheric CO_2 reduction (5 percent) were the remaining benefits.

In the hypothetical city of Lindenville, long-term planting and tree care costs and benefits were compared to determine if a new policy that favors planting small trees will be cost-effective compared with the current policy of planting large trees where space permits. Over a 40-year period, the net benefit for a small crabapple was $659/tree, considerably less than $1,363/tree for the medium red oak, and $3,214/tree for the large hackberry.

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

Table of Contents

Chapter 1. Introduction

This chapter describes the objectives, audience, and scope of the Midwest Community Tree Guide.

The Midwest Region

Midwest communities can derive many benefits from community forests

From small towns surrounded by cropland or forests to the large cities of Chicago, Minneapolis, Kansas City, and Cleveland, the Midwest region contains a diverse assemblage of communities. With manufacturing, information technology, insurance, and financial industries joining the economies of agriculture and livestock, the region is experiencing rapid change. The Midwest region is home to approximately 50 million people. It is characterized by wooded states on the eastern side and former prairie lands mostly converted to corn, soy, and alfalfa fields on the western side. In the glacially sculpted landscape, lakes, streams, and wetlands are abundant. In many areas, forests at the interface of development continue to be an important component of the region's economic, physical, and social fabric. **Community forests*** bring opportunity for economic renewal, combating development woes, and increasing the quality of life for community residents.

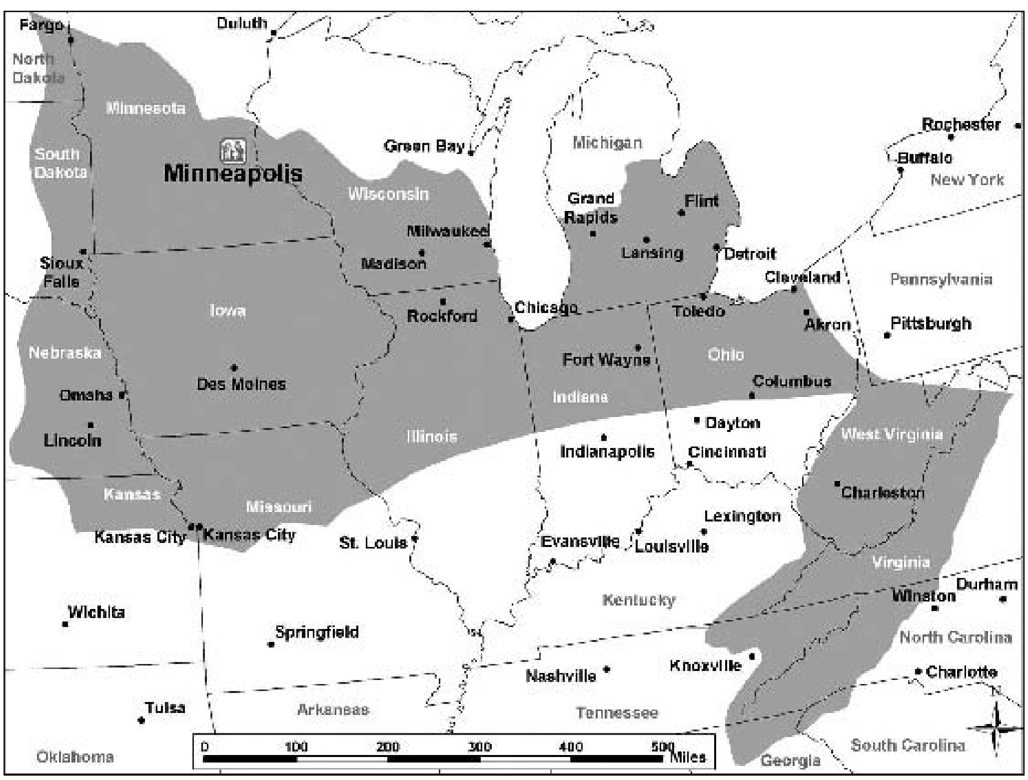


Figure 1—The Midwest region (shaded area) extends from Fargo, North Dakota, to Kansas City, Missouri, and from Cleveland, Ohio, through small communities in the Appalachian Mountains. Minneapolis, the reference city for the Midwest region, is highlighted.

** Words in bold are defined in the glossary.*

In the Midwest region, urban forest canopies form living umbrellas. They remain distinctive features of the landscape that protect residents from the elements, clean the water they drink and the air they breathe, and form a living connection to earlier generations that planted and tended these trees. Lessons learned in the wake of Dutch elm disease (see "Common and Scientific Names" section) that swept through the region and devastated large populations of American elms suggest a diversified urban and community forest with increased citizen participation.

Geographic scope

On its western boundary, the Midwest region extends from North Dakota to northern Kansas (fig. 1). Its northern border crosses central Minnesota, Wisconsin, and Michigan. Its southern border crosses central Missouri, Illinois, Indiana, and Ohio. The Midwest region stretches to the southeast into the Appalachian Mountains of West Virginia, Virginia, Kentucky, Tennessee, Georgia, and the Carolinas. The only state that falls completely within the Midwest region is Iowa. Boundaries correspond with Sunset Climate Zones 36 (Brenzel 2001) and USDA Hardiness Zones 4–7. The **climate** in this region is notoriously cold in the winter, limiting the number of tree species that will grow. Summers are warm but pleasant. Annual precipitation ranges from 20 to 50 in (508–1270 mm). These guidelines are specific to the Midwest region, and are based on measurements and calculations from open-growing urban trees.

Quality of life improves with trees

As many Midwest 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 in enhancing the environment, increasing community attractiveness and livability, and fostering 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, businesses, and government for the betterment of their communities (fig. 2).

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

Midwest communities can promote energy efficiency through tree planting and stewardship programs that strategically locate trees to save energy and minimize conflicts with

Trees provide environmental benefits

urban infrastructure. The same trees can provide additional benefits by reducing stormwater runoff; improving local air, soil, and water quality; reducing atmospheric carbon dioxide; providing wildlife habitat; increasing property values; slowing traffic; enhancing community attractiveness and investment; and promoting human well-being.

Scope defined

This guide builds upon previous studies by the USDA Forest Service (McPherson and others 1994, 1997) in Chicago, American Forests (1996) in Milwaukee, and others to extend existing knowledge of urban forest benefits in the Midwest. This guide:

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

Audience and objective

Street, park, and shade trees are components of all Midwest communities, and they impact every resident. Their benefits are myriad (fig. 3). With municipal tree programs dependent on taxpayer-supported general funds, however, 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 Midwest communities—providing a tool for municipal tree managers, arborists, and tree enthusiasts to increase public awareness and support for trees (Dwyer and Miller 1999).

Figure 3—Trees in Midwest communities enhance quality of life.

What will this tree guide do?

This tree guide addresses a number of questions about the environmental and esthetic benefits of community tree plantings in Midwest communities:

- What potential do tree planting programs have to improve environmental quality, conserve energy, and add value to communities?
- Where should residential yard and public trees be placed to maximize their benefits and cost-effectiveness?
- How can plantings minimize conflicts with power lines, sidewalks, and buildings?

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

This chapter describes benefits and costs of publicly 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 necessary process for creating cost-effective programs (Hudson 1983, Dwyer and others 1992).

Benefits

Saving Energy

How trees work to save energy

Conserving energy by greening our cities is important because it is often more cost-effective than building new power plants. For example, in Chicago a single tree was found to produce substantial savings ($75 per tree) for three-story brick buildings, as well as for more energy efficient two-story wood-frame houses ($23) (McPherson 1994). A 20-year economic analysis found that the benefit-cost ratio (discounted benefits divided by costs) from planting one tree per new home was 1.90:1, indicating that $1.90 was returned on every $1 expended for tree planting and management. These findings suggest that a utility-sponsored shade tree program could be cost-effective for both existing and new construction in Chicago.

Trees modify climate and conserve building energy use in three principal ways (fig. 4):

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

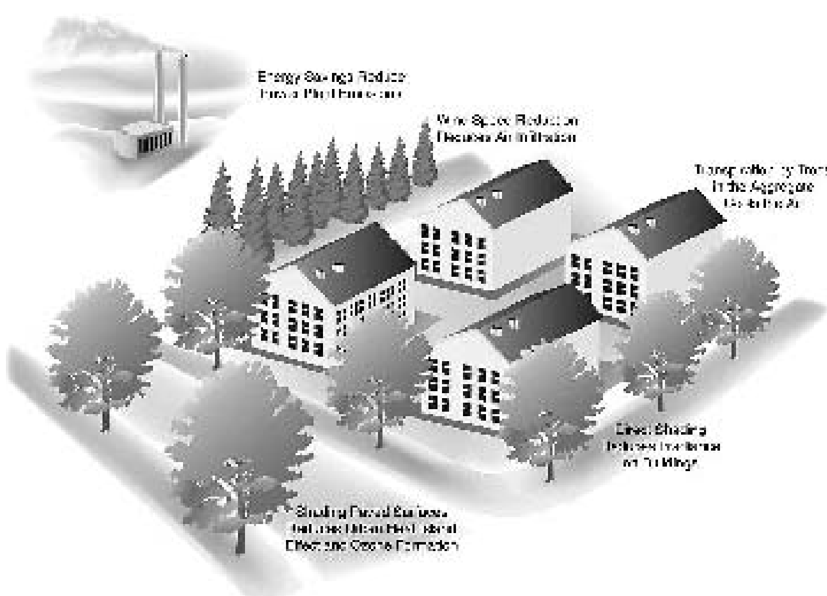


Figure 4—Trees save heating and cooling energy by shading buildings, lowering summertime temperatures, and reducing windspeeds. Secondary benefits from energy conservation are reduced water consumption and reduced pollutant emissions by power plants (drawing by Mike Thomas).

Trees lower temperatures

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

Trees increase home energy efficiency and save money

For individual buildings, strategically placed trees can increase energy efficiency in the summer and winter. Because the summer sun is low in the east and west for several hours each day, solar angles should be considered. Trees that shade east, and especially west, walls help keep buildings cool (fig. 5). In winter, allowing the sun to strike the southern side of a building can warm interior spaces. However, even the trunks and branches of **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 a building can increase substantially with windspeed. In cold, windy weather, the entire volume of air in newer, tightly sealed homes may change every 2 to 3 hours. Windbreaks reduce windspeed and resulting air infiltration by up to 50 percent, translating into potential annual heating savings of 10 to 12 percent (Heisler 1986). Reductions in windspeed reduce heat transfer through conductive materials as well. Cool winter winds blowing against windows can contribute significantly to the heating load of buildings by increasing the gradient between inside and outside temperatures. Windbreaks reduce air infiltration and conductive heat loss from buildings.

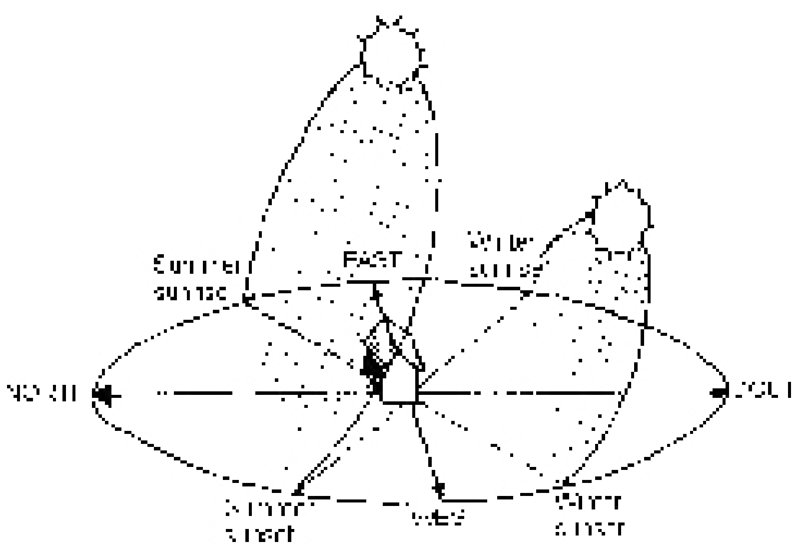


Figure 5—Paths of the sun on winter and summer solstices (from Sand 1991). Summer heat gain is primarily through east- and west-facing windows and walls. The roof receives most irradiance, but insulated attics reduce heat gain to living areas. Lower angle winter sun strikes the south-facing surfaces.

Trees provide greater energy savings in the Midwest region than in milder climate regions because they can have greater effects during the cold winters and warm summers. An average energy-efficient home with an air conditioner in Minneapolis, Minnesota, spends about $750 each year for heating and $72 for cooling. A computer simulation demonstrated that wind protection from three 25-ft-tall (7.5 m) trees—two on the west side and one on the east side of the house—would save $25 each year for heating, a 3 percent reduction (5 **MBtu**) (McPherson and others 1993). Shade and lower air temperatures from the same three trees during summer reduced annual cooling costs by $40 (56 percent). The total $65 savings represented an 8 percent reduction in annual heating and cooling costs.

Retrofit for more savings

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

Reducing Atmospheric Carbon Dioxide (CO_2)

Trees reduce CO_2

Human activities, primarily fossil-fuel consumption, are adding greenhouse gases to the atmosphere, resulting in gradual temperature increases. This warming is expected to have a number of adverse effects. Melting polar ice caps are predicted to raise sea level by 6 to 37 in. With 50 to 70 percent of the world's population living in coastal areas, the effects could be disastrous. Increasing frequency and duration of extreme weather events will tax emergency management resources. Some plants and animals may become extinct as habitat becomes restricted.

Urban forests have been recognized as important storage sites for CO_2, the primary greenhouse gas (Nowak and Crane 2002). At the same time, private markets dedicated to economically reducing CO_2 emissions are emerging (McHale 2003, CO2e.com 2002). Carbon credits are selling for $0.11 to $20 per **metric tonne (t)**, while the cost for a tree planting project in Arizona was $19/t of CO_2 (McPherson and Simpson 1999). As carbon reductions become accredited and prices rise, carbon credit markets could become monetary resources for community forestry programs.

Urban forests can reduce atmospheric CO_2 in two ways (fig. 6):

- Trees directly sequester CO2 in their stems and leaves while they grow.

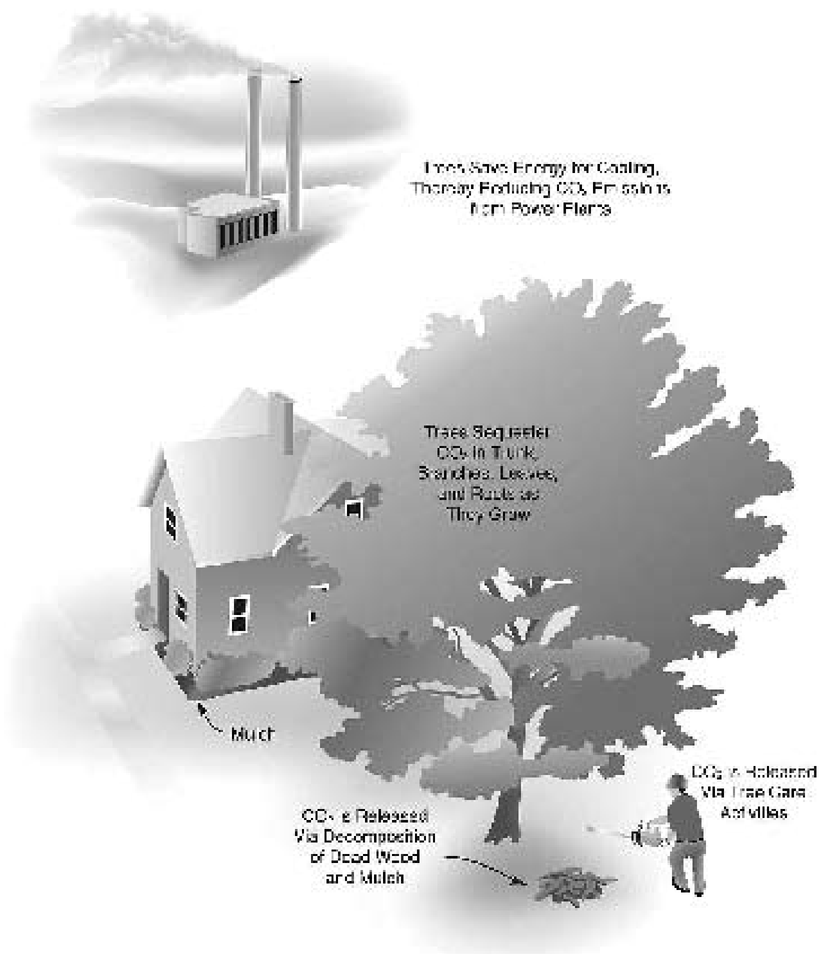


Figure 6—Trees sequester CO_2 (carbon dioxide) as they grow and indirectly reduce CO_2 emissions from power plants through energy conservation. Carbon dioxide is released through decomposition and tree care activities that involve fossil-fuel consumption (Drawing by Mike Thomas).

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

Tree-related activities that release CO_2

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

Avoided CO_2 emissions

Typically, CO_2 released during tree planting, maintenance, and other program-related activities is about 2 to 8 percent of annual CO_2 reductions obtained through **sequestration** and **avoided power plant emissions** (McPherson and Simpson 1999). To provide a complete picture of atmospheric CO_2 reductions from tree plantings, it is important to consider CO_2 released into the atmosphere through tree planting and care activities, as well as decomposition of wood from pruned or dead trees.

Regional variations in climate and the mix of fuels that produce energy to heat and cool buildings influence potential CO_2 emission reductions. Minnesota's average emission rate is 1,640 lb CO_2/**kWh**, close to the Midwest average of 1,720 lb (U.S. Environmental Protection Agency 2003). Because of the large amount of coal in the mix of fuels used to generate power in the Midwest, this emission rate is higher than in some other regions. For example, the two-state average for Oregon and Washington is much lower—308 lb CO_2/kWh—because hydroelectric power predominates. The Midwest region's relatively high CO_2 emission rate means greater benefits from reduced energy demand relative to other regions with lower emissions rates.

Chicago's urban forest

A study of Chicago's urban forest found that the region's trees stored about 7 million tons of atmospheric CO_2 (Nowak 1994a). The 51 million trees sequestered approximately 155,000 tons of atmospheric CO_2 annually.

Another study in Chicago focused on the carbon sequestration benefit of residential tree **canopy cover**. Tree canopy cover in two residential neighborhoods was estimated to sequester on average 0.11 lb/ft^2, and released 0.01 lb/ft^2 through pruning (Jo and McPherson 1995). Net annual carbon uptake was 0.10 lb/ft^2.

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

Since 1990, Trees Forever, an Iowa-based nonprofit organization, has planted trees for energy savings and atmospheric CO_2 reduction with utility sponsorships. Over 1 million trees have been planted in 400 communities with the help of 120,000 volunteers. These trees are estimated to offset CO_2 emissions by 50,000 tons annually. Based on an Iowa State University study, survival rates are an amazing 91 percent, indicating a highly trained and committed volunteer force (Ramsay 2002).

CO_2 reduction through community forestry

Improving Air Quality

Trees improve air quality

Approximately 159 million people live in areas where **ozone (O_3)** concentrations violate federal air quality standards, and 100 million people live in areas where dust and other particulate matter (**PM_{10}**) exceed levels for healthy air. Air pollution is a serious health threat to many city dwellers, causing coughing, headaches, respiratory and heart diseases, and cancer. Impaired health results in increased social costs for medical care, greater absenteeism on the job, and reduced longevity.

Although many communities in the Midwest region do not have 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 Chicago/Milwaukee, Detroit and most of southern Michigan, Toledo/Cleveland/ Columbus, Fort Wayne, Indiana, and Charleston, West Virginia. Tree planting is one practical strategy for communities in these areas to meet and sustain mandated air quality standards.

Recently, the EPA recognized tree planting as a measure for reducing O_3 in state implementation plans. Air-quality-management districts have funded tree planting projects to control particulate matter. These policy decisions are creating new opportunities to plant and care for trees as a method for controlling air pollution (Luley and Bond 2002).

Urban forests provide four main air quality benefits (fig. 7):

- They absorb gaseous pollutants (e.g., ozone, **nitrogen oxides**, and **sulfur dioxide**) through leaf surfaces.
- They intercept particulate matter (e.g., dust, ash, pollen, smoke).

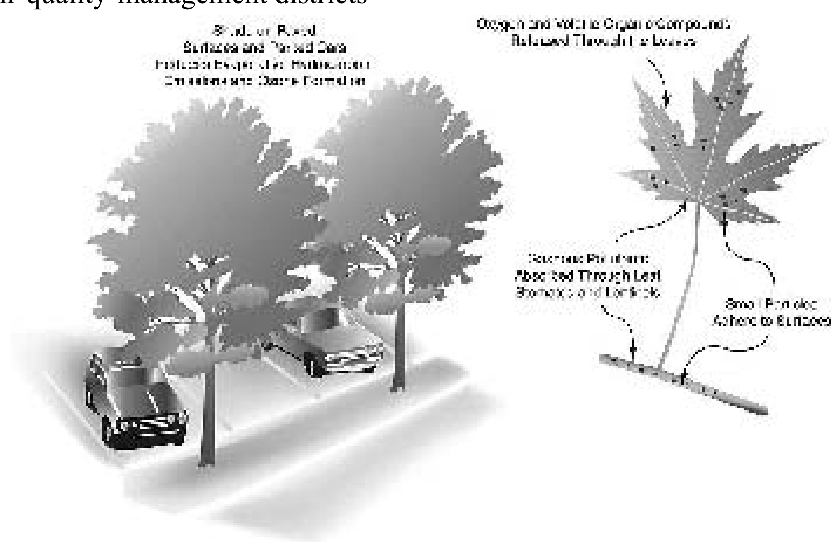


Figure 7—Trees absorb gaseous pollutants, retain particles on their surfaces, and release oxygen and volatile organic compounds. By cooling urban heat islands and shading parked cars trees can reduce ozone formation (Drawing by Mike Thomas).

- They release oxygen through **photosynthesis**.
- They transpire water and shade surfaces, which lowers air temperatures, thereby reducing ozone levels.

Trees affect ozone formation

Trees can adversely affect air quality. Most trees emit **biogenic volatile organic compounds (BVOCs)** such as isoprenes and monoterpenes that can contribute to O_3 formation. The ozone-forming potential of different tree species differs considerably (Benjamin and Winer 1998). Genera having the greatest relative effect on increasing O_3 are sweetgum (see "Common and Scientific Names" section), black gum, sycamore, poplar, and oak (Nowak 2000). A computer simulation study for the Los Angeles basin found that increased tree planting of low-BVOC-emitting tree species would reduce O_3 concentrations, whereas planting of medium and high emitters would increase overall O_3 concentrations (Taha 1996). A study in the Northeastern United States, however, found that species mix had no detectable effects on O_3 concentrations (Nowak and others 2000). The contribution of BVOC emissions of city trees to O_3 formation depends on complex geographic and atmospheric interactions that have not been studied in most cities.

Trees absorb gaseous pollutants

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

Trees intercept particulate matter

Trees intercept small airborne particles. Some particles that impact a tree are absorbed, but most adhere to plant surfaces. Species with hairy or rough leaf, twig, and bark surfaces are efficient interceptors. Intercepted particles are often resuspended to the atmosphere when wind blows the branches.

Trees release oxygen

Urban forests freshen the air we breathe by releasing oxygen into the air as a byproduct of photosynthesis. Net annual oxygen production varies depending on tree species, size, health, and location. A healthy tree, such as a 32-ft-tall ash, produces about 260 lb of net oxygen annually. A typical person consumes 386 lb of oxygen per year. Therefore, two medium-sized, healthy trees can supply the oxygen required for a single person over the course of a year.

Trees reduce ozone and particulate matter

The Chicago region's 50.8 million trees were estimated to remove 234 tons of PM_{10}, 210 tons of O_3, 93 tons of sulfur dioxide (SO_2), and 17 tons of carbon monoxide in 1991. This environmental service was valued at $9.2 million (Nowak 1994b).

Tree shade prevents evaporative hydrocarbon emissions

Trees in a Davis, California, parking lot were found to improve air quality by reducing air temperatures 1 to 3 °F (Scott and others 1999). By shading asphalt surfaces and parked vehicles, the trees reduced hydrocarbon emissions from gasoline that evaporates out of leaky fuel tanks and worn hoses. These evaporative emissions are a principal component of smog, and parked vehicles are a primary source. In Chicago, the EPA adapted these research findings to the local climate and developed a method for easily estimating the reductions in evaporative emissions owing to parking-lot trees. This approach could be used to quantify pollutant reductions from proposed parking-lot tree planting projects.

Reducing Stormwater Runoff and Improving Hydrology

Urban stormwater runoff is a major source of pollution entering wetlands, streams, lakes, and oceans. Healthy trees can reduce the amount of runoff and pollutant loading in receiving waters. This is important because federal law requires states and localities to control nonpoint-source pollution, such as from pavements, buildings, and landscapes. Trees are mini-reservoirs, controlling runoff at the source because their leaves and branch surfaces intercept and store rainfall, thereby reducing runoff volumes and erosion of watercourses, as well as delaying the onset of **peak flows**. Trees can reduce runoff in several ways (fig. 8):

- Leaves and branch surfaces intercept and store rainfall, thereby reducing runoff volumes and delaying the onset of peak flows.
- Roots increase the rate at which rainfall infiltrates soil and the capacity of soil to store water, thereby reducing overland flow.
- Tree canopies reduce soil erosion by diminishing the impact of raindrops on barren surfaces.

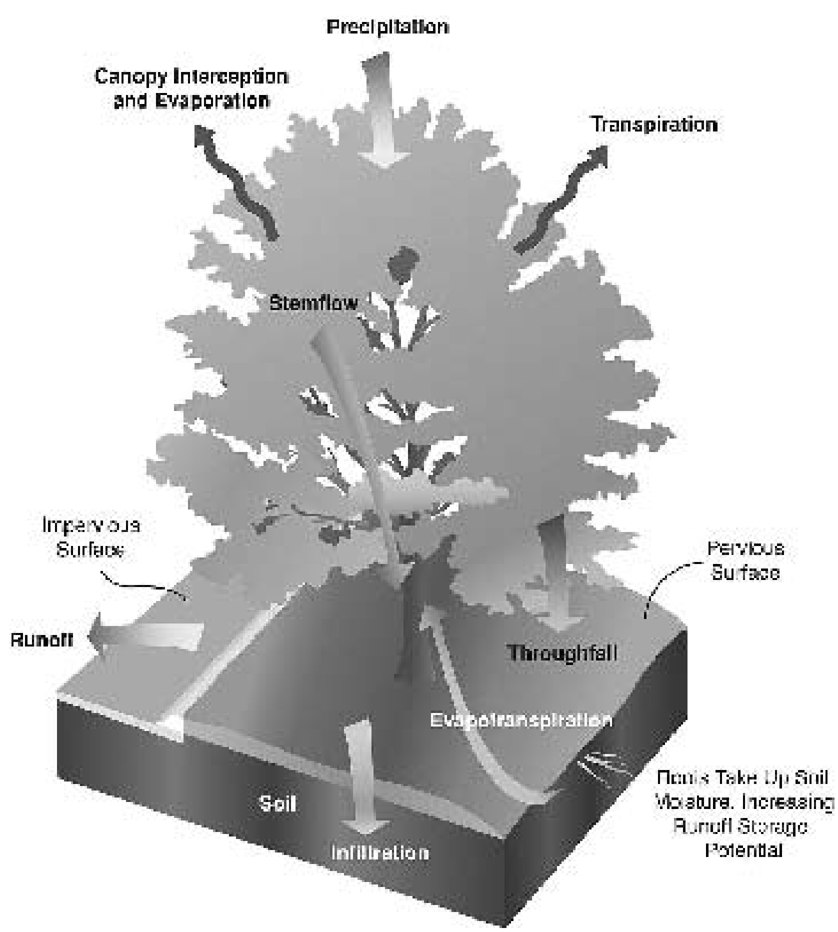


Figure 8—Trees intercept a portion of rainfall that evaporates and never reaches the ground. Some rainfall runs to the ground along branches and stems (stem flow), and some falls through gaps or drips off leaves and branches (throughfall). Transpiration increases soil moisture storage potential (Drawing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

- **Transpiration** through tree leaves reduces soil moisture, increasing the soil's capacity to store rainfall.

Trees reduce runoff

Rainfall that is stored temporarily on **canopy** leaf and bark surfaces is called intercepted rainfall. Intercepted water evaporates, drips from leaf surfaces, and flows down stem surfaces to the ground. **Tree-surface saturation** generally occurs after 1 to 2 in of rainfall has fallen (Xiao and others 2000). During large storm events, rainfall exceeds the amount that the tree **crown** can store, about 50 to 100 gal per tree. The **interception** benefit is limited to this amount of interception, as well as delaying the time of peak flow. Trees protect water quality by substantially reducing runoff during small rainfall events, which are responsible for most pollutant washoff. Therefore, urban forests generally produce more benefits through water quality protection than through flood control (Xiao and others 1998).

The amount of rainfall trees intercept depends on their architecture, rainfall patterns, and the climate. Tree crown characteristics that influence interception are the trunk, stem, and surface areas, textures, area of gaps, period when leaves are present, and dimensions (e.g., tree height and diameter). Trees with coarse surfaces retain more rainfall than trees with smooth surfaces do. Large trees generally intercept more rainfall than small trees do because of greater surface areas and higher evaporation rates. Tree crowns with few gaps reduce **throughfall** to the ground. Species that are in-leaf when rainfall is plentiful are more effective during the rainy season than are deciduous species that have dropped their leaves.

Studies that have simulated urban forest effects on stormwater runoff have reported reductions of 2 to 7 percent. Annual interception of rainfall by Sacramento's urban forest for the total urbanized area was only about 2 percent because of the winter rainfall pattern and lack of **evergreen** species (Xiao and others 1998). However, average interception under the tree canopy ranged from 6 to 13 percent (150 gal per tree), close to values reported for rural forests. A typical medium-size tree in coastal southern California was estimated to intercept 2,380 gal, an annual value of $5 (McPherson and others 2000). Broadleaf evergreens and conifers intercept more rainfall than do deciduous species when rainfall is highest in fall, winter, or spring (Xiao and McPherson 2002).

Urban forests can treat wastewater

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

Tree shade reduces 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 per kWh of electricity provided. Trees that reduce the demand for electricity, therefore, also reduce water consumed at the power plant (McPherson and others 1993). A strategically located shade tree in a Midwest community can reduce annual cooling demand by 200 kWh, thereby reducing power plant water consumption by 200 gal. As a result, precious water resources are conserved, and thermal pollution of rivers is reduced.

Esthetic and Other Benefits

Beautification

Trees provide a host of esthetic, 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 esthetic quality of residential streets has shown that street trees are the single strongest positive influence on scenic quality (Schroeder and Cannon 1983).

Attractiveness of retail settings

Consumer surveys have found that preference ratings increase with the presence of trees in the commercial streetscape. In contrast to areas without trees, shoppers indicated that they shop more often and longer in well-landscaped business districts. They were willing to pay more for parking and up to 11 percent more for goods and services (Wolf 1999).

Public safety benefits

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

Property value benefits

Well-maintained trees increase the “curb appeal” of properties. Research comparing sales prices of residential properties with different tree resources suggests that people are willing to pay 3 to 7 percent more for properties with many trees versus properties with few or no trees. One of the most comprehensive studies of the influence of trees on residential property values was based on actual sales prices and found that each large front-yard tree was associated with about a 1 percent increase in sales price (Anderson and Cordell 1988). A much greater value of 9 percent ($15,000) was determined in a U.S. Tax Court case for the loss of a large black oak on a property valued at $164,500 (Neely 1988). 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 and others 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 and Kaplan 1989). Desk workers with a view of nature report lower rates of sickness and greater satisfaction with their jobs compared with those having no visual connection to nature (Kaplan 1992). Trees provide important settings for recreation and relaxation in and near cities (fig. 9). The act of planting trees can have social value, as bonds between people and local groups often result.

Figure 9—Parks and trees are oases in the city, providing opportunities for residents to relax, recreate, socialize, enjoy wildlife, and restore a sense of well-being.

Human health benefits

Trees in cities provide public health benefits and improve the 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 the stress response of both body and mind (Parsons and others 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 who have views of nature and spend time 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 to 15 decibels. Plants absorb more high frequency noise than low frequency, which is advantageous to humans since higher frequencies are most distressing to people (Cook 1978).

Wildlife habitat

Numerous types of wildlife inhabit cities and are generally highly valued by residents. For example, older parks, cemeteries, and botanical gardens often contain a rich assemblage of wildlife. Remnant woodlands and **riparian habitats** within cities can connect a city to its surrounding bioregion (fig. 10). Wetlands, greenways (linear parks), and other greenspace can provide habitats that conserve **biodiversity** (Platt and others 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 United States. 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 and municipal volunteer programs often provide educational material, work with area schools, and provide hands-on training in the care of trees.

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

Shade can reduce street maintenance

Tree shade on streets can help offset pavement management costs by protecting paving from weathering. The asphalt paving on streets contains stone aggregate in an oil binder. Tree shade lowers the street surface temperature and reduces the heating and volatilization of the binder (Muchnick 2003). As a result, the aggregate remains protected by the oil binder for a longer period. When unprotected, vehicles loosen the aggregate and much like sandpaper, the loose aggregate grinds down the pavement. Because most weathering of asphalt-concrete pavement occurs during the first 5 to 10 years, when new street tree plantings provide little shade, this benefit mainly applies when older streets are resurfaced (fig. 11). In Midwest communities, the benefit from summer shade can be offset by winter shade that prolongs snow and ice accumulation, and may result in greater use of salt and sand. Further study is needed to evaluate the seasonal effects of tree shade on paving condition and safety.

Figure 11—Although shade trees can be expensive to maintain, their shade can reduce the cost for resurfacing streets (Muchnick 2003), promote pedestrian travel, and improve air quality directly through pollutant uptake and reduced emissions of volatile organic compounds from parked cars.

Costs

Planting and Maintaining Trees

The environmental, social, and economic benefits of urban and community forests come with a price. A national survey reported that communities in the Midwest region spent an average of about $3.67 per tree, annually, for street- and park-tree management (Tschantz and Sacamano 1994). This amount is relatively low, with six national regions spending more than this and three regions spending less.

Nationwide, the single largest expenditure was for tree pruning, followed by tree removal and disposal, and tree planting.

High removal costs due to Dutch elm disease

Recently, the Midwest has been plagued by pests (Asian long-horned beetle, emerald ash borer) and diseases (Dutch elm disease) that have required unusually high expenditures for tree removal and disposal. Our survey of **municipal foresters** in Stevens Point and Waukesha, Wisconsin, Lansing, Michigan, Glen Ellyn, Illinois, and Minneapolis, Minnesota, indicates that they are spending about $35 per tree annually. Most of this amount is for removal ($15 per tree), pruning ($12 per tree), and planting ($2 per tree). Other expenditures are for administration ($5 per tree) and other activities such as inspection, pest/disease control, and storm cleanup ($1 per tree). Other municipal departments incur costs for infrastructure repair and trip-and-fall claims that average about $3.50 per tree annually.

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

Residential costs vary

Annual expenditures for tree management on private property have not been well documented. Costs differ considerably, ranging from some commercial and 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 spend about $5 to $10 annually per tree for pruning and pest and disease control (McPherson and others 1993, Summit and McPherson 1998). Our survey of commercial arborists in the Midwest indicated that expenditures typically range from $15 to $25 per tree. On a per-tree basis, expenditures are usually greatest for pruning, planting, and removal.

Irrigation costs

Because of the region's warm summer climate, newly planted trees require irrigation for 3 to 5 years. Once planted, trees typically require about 1 in of irrigation per week during warm periods without rain. Assuming water costs $2.38 per hundred cubic feet in Minneapolis, annual water costs for irrigation are initially less than $2 per tree; however, as trees mature their water use can increase. During drought years, costs for irrigating trees may be higher.

Conflicts With Urban Infrastructure

Tree roots can damage sidewalks

Like other cities across the United States, communities in the Midwest region are spending millions of dollars each year to manage conflicts between trees and powerlines, sidewalks, sewers, and other elements of the urban infrastructure. In our survey of several Midwest municipal foresters, cities spent an average of $220,000 or $3.70 per tree on sidewalk, curb, and gutter repair, and legal costs. This amount is less than the $11.22 per tree reported for 18 California cities (McPherson 2000). These figures apply only to street trees and do not include repair costs for damaged sewer lines, building foundations, parking lots, and various other **hardscape** elements. When these additional expenditures are included, the total cost of root-sidewalk conflicts is well over $50 million per year in the Midwest alone.

In the Midwest region, dwindling budgets are increasing the sidewalk-repair backlog and forcing cities to shift the costs of sidewalk repair to residents. This shift has significant impacts on residents in older areas, where large trees have outgrown small sites and infrastructure has deteriorated.

Cost of conflicts

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

- Cities are downsizing their urban forests by planting smaller trees. Although small trees are appropriate under power lines and in small planting sites, they are less effective than large trees at providing shade, absorbing air pollutants, and intercepting rainfall.
- Sidewalk damage was the second most common reason that street and park trees were removed. Thousands of healthy urban trees are lost each year and their benefits forgone because of this problem.
- Of cities surveyed, 25 percent were removing more trees than they were planting. A resident forced to pay for sidewalk repairs may not want replacement trees.

Collectively, this is a lose-lose situation. Cost-effective strategies to retain benefits from large street trees while reducing costs associated with infrastructure conflicts are described in *Reducing Infrastructure Damage by Tree Roots* (Costello and Jones 2003). Matching the growth characteristics of trees to the conditions at the planting site is one strategy.

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 sewer rodding (inserting a cleaning implement to temporarily remove roots) to $1,000 or more for sewer excavation and replacement.

Cleaning up after trees

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

Large trees under power lines can be 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 and can make trees appear less attractive (fig. 12). Frequent crown reduction reduces the benefits these trees could otherwise provide. Moreover, increased costs for pruning are passed on to customers.

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

Wood Salvage, Recycling, and Disposal

Hauling and recycling waste wood are primary costs

In our survey, most Midwest cities are recycling green waste from urban trees as mulch, compost, and firewood. In Minneapolis, a large tub grinder works year round to reduce large material from elms and other trees. Some power plants will use this wood to generate electricity, thereby helping to defray costs for hauling and grinding. Generally, the net costs of waste wood disposal are less than 1 percent of total tree-care costs as cities and contractors strive to break even. Hauling and recycling costs are nearly offset by revenues from sales of mulch, milled lumber, and firewood. The cost of waste wood disposal may be higher, however, depending on geographic location and the presence of exotic pests that require extensive waste wood disposal.

Chapter 3. Determining Benefits and Costs of Community Forests in Midwest Communities

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

A crabapple, representative of small trees in this report.

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 Midwest region's large geographical area, with many different climates, soils, and types of community forestry programs, this approach provides first-order approximations. It is a general accounting that can be easily adapted and adjusted for local planting projects. It provides a basis for decisions that set priorities and influence management direction (Maco and McPherson 2003).

A mature red oak, representative of medium trees in this report.

Overview of Procedures

Approach

In this study, annual benefits and costs were estimated over a 40-year planning horizon for newly planted trees in three residential yard locations (east, south, and west of the residence) and a public streetside or park location. Henceforth, we refer to trees in these hypothetical locations as "yard" trees and "public" trees. Prices were assigned to each cost (e.g., planting, pruning, removal, irrigation, infrastructure repair, liability) and benefit (e.g., heating/cooling energy savings, air-pollutant mitigation, stormwater-runoff reduction) 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. More information on data collection, modeling procedures, and assumptions can be found in appendix A.

A mature hackberry, representative of large trees in this report.

To account for differences in the mature size and growth of different tree species, we report results for a small tree, the crabapple, a medium tree, the red oak, and a large tree, the hackberry (see "Common and Scientific Names" section). Growth curves were developed from street trees sampled in Minneapolis, Minnesota (fig. 13).

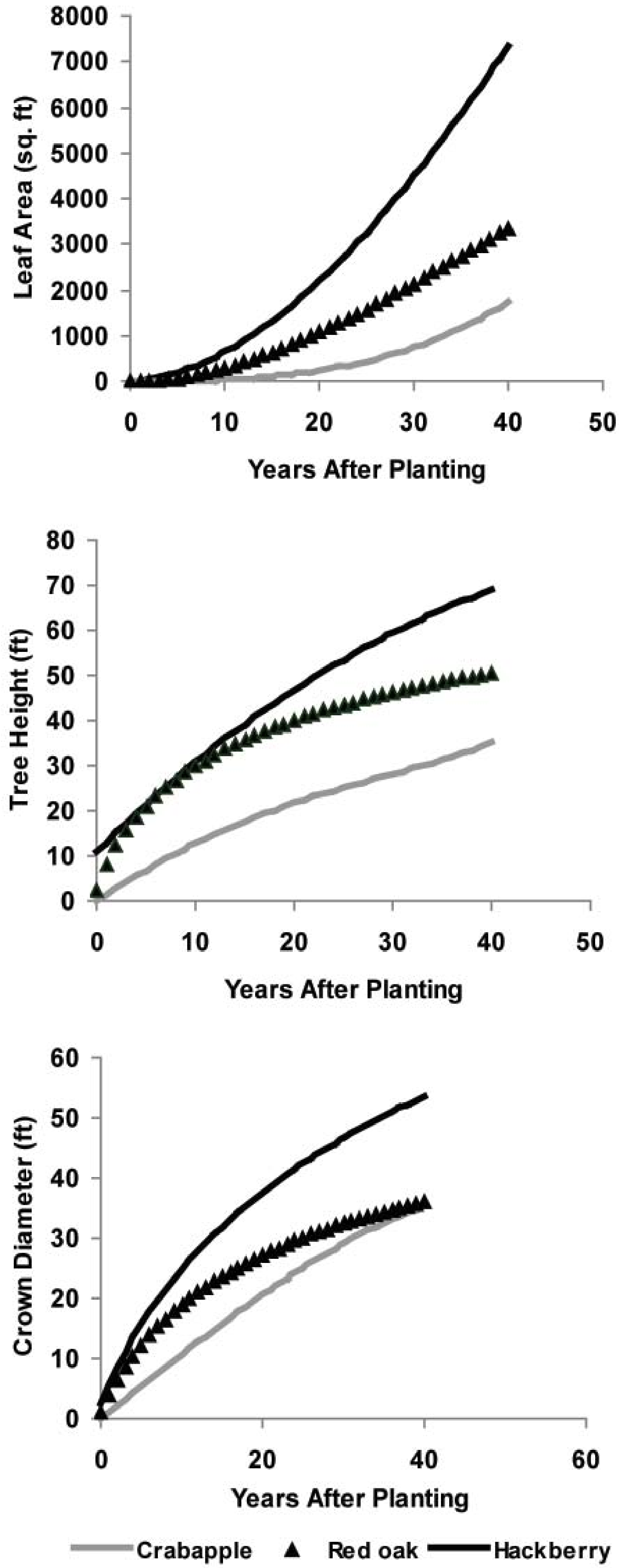


Figure 13—Tree dimensions are based on data collected from street and park trees in Minneapolis, Minnesota. Data for the "typical" small, medium, and large trees are from the crabapple, red oak, and hackberry, respectively. Differences in leaf surface area among species are most important for this analysis because functional benefits such as summer shade, rainfall interception, and pollutant uptake are related to leaf surface area.

Frequency and costs of tree management were estimated based on surveys with municipal foresters in Stevens Point and Waukesha, Wisconsin, Lansing, Michigan, Glen Ellyn, Illinois, and Minneapolis, Minnesota. In addition, commercial arborists from Merton and Appleton, Wisconsin, and Troy, Michigan, provided information on tree-management costs on residential properties.

Tree care costs based on survey findings

Benefits were calculated with numerical models and input data both from regions (e.g., pollutant **emission factors** for avoided emissions from energy savings) and local sources (e.g., Minneapolis 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 **willingness to pay** for air-quality improvements. For example, the prices for air-quality benefits were estimated by using marginal control costs (Wang and Santini 1995). If a developer is willing to pay an average of $1 per pound of treated and controlled pollutant to meet minimum standards, then the air-pollution-mitigation value of a tree that intercepts one pound of pollution, eliminating the need for control, should be $1.

Tree benefits based on numerical models

Reporting results

Results are reported in terms of annual value per tree planted. To make these calculations realistic, however, mortality rates are included. Based on our survey of regional municipal foresters and commercial arborists, this analysis assumed that 40 percent of the planted trees would die over the 40-year period. Annual mortality rates were 1 percent per year for the 40-year period. 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 B, results are reported for 5-year intervals for 40 years.

Tree mortality included

Findings of This Study

Average Annual Net Benefits

Average annual net benefits (benefits minus costs) per tree increased with **mature tree size** (for detailed results, see app. B):

- $3 to $15 for a small tree
- $4 to $34 for a medium tree
- $58 to $76 for a large tree

Average annual net benefits increase with size of tree

Our findings suggest that average annual net benefits from large trees, like the red oak and hackberry, can be substantially greater than those from small trees like crabapple. Average annual net benefits for the small, medium, and large public trees were $4, $16, and

Large trees provide the most benefits

$58, respectively. The largest average annual net benefits, however, stemmed from yard trees opposite the west-facing wall of a house: $15, $34, and $76, for small, medium, and large trees, respectively.

Net annual benefits at year 40

The large residential tree opposite a west house wall produced a net annual benefit of $123 at year 40. In the same location, 40 years after planting, the red oak and crabapple produced annual net benefits of $58 and $45.

Forty years after planting at a typical public site, the small, medium, and large trees provided annual net benefits of $24, $37, and $99, respectively.

Net benefits summed for 40 years

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

- $600 (yard) and $160 (public) for a small tree
- $1,360 (yard) and $640 (public) for a medium tree
- $3,040 and $2,320 (public) for a large tree

Year 20—environmental benefits exceed tree care costs

Twenty years after planting, annual net benefits for a yard tree located west of a home were $20 for a small tree, $45 for a medium tree, and $87 for a large tree (table 1). For a large hackberry 20 years after planting, the total value of environmental benefits alone ($77) was five times the annual costs ($15). Similarly, environmental benefits

Table 1—Estimated annual benefits and costs for a tree in a residential yard opposite a west-facing wall, 20 years after planting

	Crabapple small tree 22 ft tall 21 ft spread			Red oak medium tree 40 ft tall 27 ft spread			Hackberry large tree 47 ft tall 37 ft spread		
Benefit	**RUs**		**Total $**	**RUs**		**Total $**	**RUs**		**Total $**
Electricity savings ($0.00759/kWh)	87.47	kWh	6.64	212.5	kWh	16.13	300.69	kWh	22.82
Natural gas savings ($0.0098/kBtu)	1,243.03	kBtu	12.18	1,816.46	kBtu	17.80	3,400.13	kBtu	33.32
CO_2 ($0.0075/lb)	337.66	lb	2.53	645.36	lb	4.84	979.10	lb	7.34
Ozone ($3.34/lb)	0.05	lb	0.18	0.15	lb	0.51	0.18	lb	0.60
NO_2 ($3.34/lb)	0.33	lb	1.11	0.66	lb	2.22	1.16	lb	3.88
SO_2 ($2.06/lb)	0.20	lb	0.40	0.46	lb	0.94	0.73	lb	1.51
PM_{10} ($2.84/lb)	0.14	lb	0.41	0.21	lb	0.59	0.25	lb	0.71
VOCs ($3.75/lb)	0.04	lb	0.16	0.09	lb	0.35	0.16	lb	0.59
BVOCs ($3.75/lb)	0	lb	0.00	-0.29	lb	-1.08	0	lb	0.00
Rainfall interception ($0.0046/gal)	143.54	gal	0.66	767.19	gal	3.53	1,394.13	gal	6.41
Environmental subtotal			24.27			45.83			77.19
Other benefits			4.07			12.22			24.85
Total benefits			28.34			58.05			102.04
Total costs			8.47			13.11			15.11
Net benefits			19.86			44.93			86.93

RU = resource unit.

totaled $46 and $24 for the red oak and crabapple, while tree care costs were substantially less, $13 and $8, respectively.

Net annual benefits at year 20 for public trees

Twenty years after planting, the annual net benefit from a large public tree was $60 (table 2). At that time, net annual benefits from the medium and small public trees were $20 and $0, respectively. For the small tree, annual benefits and costs were both estimated at $27, whereas annual benefits were $53 and costs were $33 for the medium tree. Net benefits were less for public trees than for yard trees. Public-tree care costs were greater and energy benefits were generally lower than for yard trees because public trees were assumed to not shade buildings (fig. 14).

Table 2—Estimated annual benefits and costs for a public tree on a street or in a park, 20 years after planting

	Crabapple small tree 22 ft tall 21 ft spread			Red oak medium tree 40 ft tall 27 ft spread			Hackberry large tree 47 ft tall 37 ft spread		
Benefit	**RUs**		**Total$**	**RUs**		**Total$**	**RUs**		**Total$**
Electricity savings ($0.0759/kWh)	38.5	kWh	2.92	68.73	kWh	5.22	136.63	kWh	10.37
Natural gas savings ($0.0098/kBtu)	1,432.65	kBtu	14.04	2,275.51	kBtu	22.30	3,756.12	kBtu	36.81
CO_2 ($0.0075/lb)	281.47	lb	2.11	468.7	lb	3.52	757.77	lb	5.68
Ozone ($3.34/lb)	0.05	lb	0.18	0.15	lb	0.51	0.18	lb	0.60
NO_2 ($3.34/lb)	0.33	lb	1.11	0.66	lb	2.22	1.16	lb	3.88
SO_2 ($2.06/lb)	0.2	lb	0.40	0.46	lb	0.94	0.73	lb	1.51
PM_{10} ($2.84/lb)	0.14	lb	0.41	0.21	lb	0.59	0.25	lb	0.71
VOCs ($3.75/lb)	0.04	lb	0.16	0.09	lb	0.35	0.16	lb	0.59
BVOCs ($3.75/lb)	0	lb	0.00	-0.29	lb	-1.08	0	lb	0.00
Rainfall interception ($0.0046/gal)	143.54	gal	0.66	767.19	gal	3.53	1,394.13	gal	6.41
Environmental subtotal			22.00			38.09			66.57
Other benefits			4.80			14.44			29.36
Total benefits			26.80			52.52			95.93
Total costs			26.66			33.01			35.87
Net benefits			0.14			19.52			60.05

RU = resource unit.

Figure 14—Although park trees seldom provide energy benefits from direct shading of buildings, they provide other benefits such as settings for recreation and relaxation and a temperature-lowering effect on the overall urban climate.

Table 3—Estimated annual costs and benefits for a tree in a residential yard opposite a west-facing wall and for a public tree, 20 years after planting

	Crabapple small tree 22 ft tall 21 ft spread leaf surface area: 236 ft^2		Red oak medium tree 40 ft tall 27 ft spread leaf surface area: 1,060 ft^2		Hackberry large tree 47 ft tall 37 ft spread leaf surface area: 2,201 ft^2	
Cost	Yard: west	Public	Yard: west	Public	Yard: west	Public
Pruning	3.84	20	6.86	24	6.86	24
Remove and dispose	3.72	2.79	5.02	3.76	6.62	4.97
Pest and disease	0.72	0.05	0.97	0.07	1.28	0.1
Infrastructure repair	0.18	0.9	0.24	1.21	0.32	1.6
Cleanup	0.01	0.03	0.01	0.04	0.01	0.06
Liability and legal	0.01	0.05	0.02	0.1	0.02	0.11
Administration and other	0	2.83	0	3.82	0	5.04
Total costs	8.47	26.66	13.11	33.01	15.11	35.87
Total benefits	28.34	26.8	58.05	52.52	102.04	95.93
Total net benefits	19.86	0.14	44.93	19.52	86.93	60.05

RU = resource unit.

Average Annual Costs

Costs of tree care

Twenty years after planting, average annual costs for tree care ranged from $8 to $36 per tree (see table 3, for detailed results see app. B):

- $8 and $27 for a small tree
- $13 and $33 for a medium tree
- $15 and $36 for a large tree

Public trees are more expensive to maintain than yard trees

Table 3 shows annual management costs 20 years after planting for yard trees to the west of a house and for public trees. Annual costs for yard trees ranged from $8 to $15, whereas costs for public trees were $27 to $36. In general, public trees are more expensive to maintain than yard trees because of their prominence and because of the greater need for public safety.

Greatest costs for pruning, planting, and removal

Over the 40-year period, tree pruning was the single greatest cost for public trees, averaging approximately $5 to $20 per tree per year. Annualized expenditures for tree planting were important, especially for trees planted in private yards ($10/tree per year). We assumed that a yard tree with a 2.5-in diameter trunk was planted at a cost of $400. The cost for planting a 1.5-in public tree was $200 or $5/tree per year. The third greatest annual cost for yard trees was for removal and disposal ($4 to $7/tree per year).

Average Annual Benefits

Average annual benefits increased with mature tree size (for detailed results see last two columns in app. B):

- $20 and $32 for a small tree
- $25 and $54 for a medium tree
- $81 and $99 for a large tree

Energy savings

Values were largest for energy benefits, which tended to increase with tree size. For example, average annual net energy benefits were only $20 for the small crabapple opposite a west-facing wall, but $51 for the large hackberry. Also, energy savings increased as trees matured and their **leaf surface area (LSA)** increased, regardless of their mature size (figs. 15 and 16).

As expected in a region with long winters, heating savings accounted for most of the total energy benefit. Average annual heating savings for the crabapple ranged from $5 to $15 and for the hackberry ranged from $21 to $34. Average annual cooling savings for the crabapple ranged from $4 to $7, and for the hackberry ranged from $10 to $20.

Average annual net energy benefits for residential trees were greatest for a tree located west of a building because the effect of shade 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 in winter. Trees located east of a building provided intermediate net benefits. Net energy benefits also reflect species-related traits such as size, form, branch pattern and density, and time in leaf.

Average annual net energy benefits for public trees were less than for yard trees, and ranged from $19 for the crabapple to $44 for the hackberry.

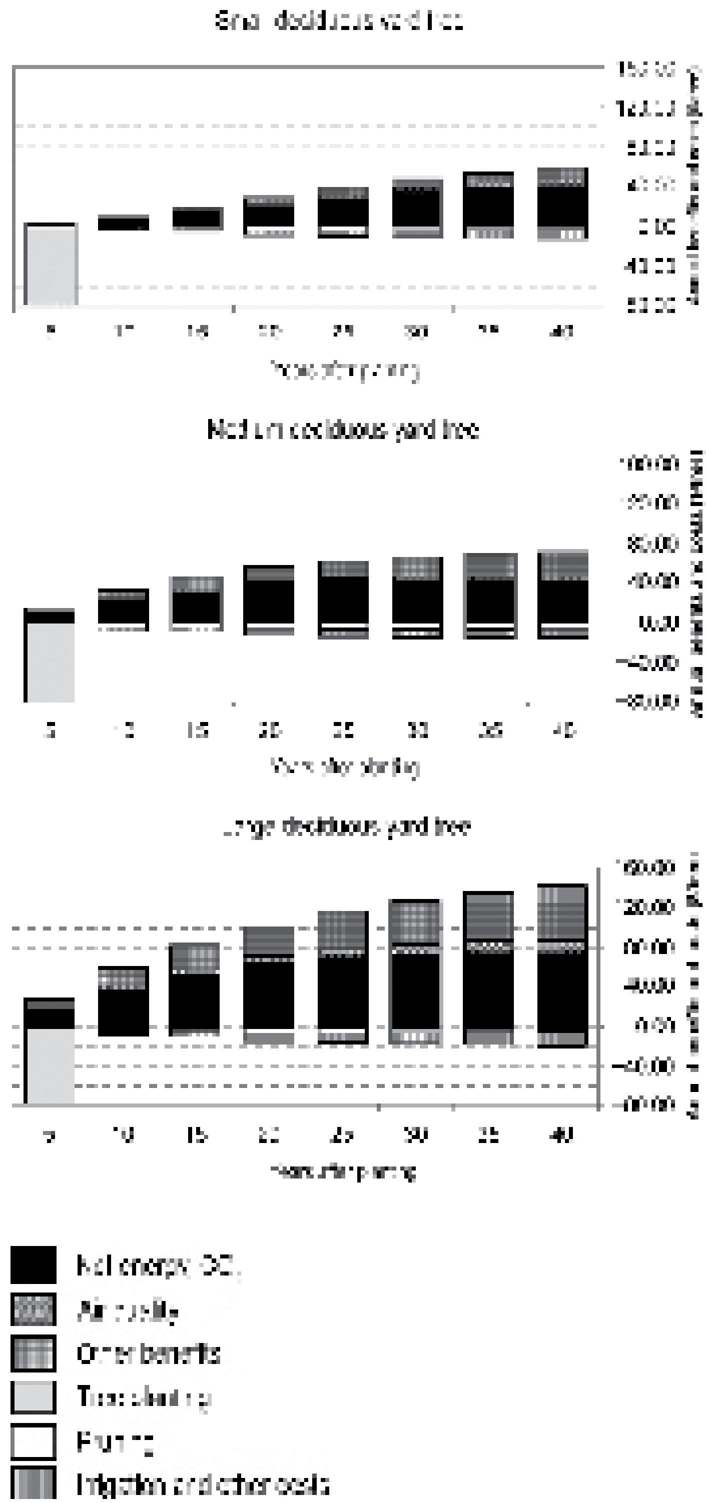


Figure 15—Estimated annual benefits and costs for small (crabapple), medium (red oak), and large (hackberry) yard trees located west of a residence. Costs are greatest during the initial establishment period, whereas benefits increase with tree size.

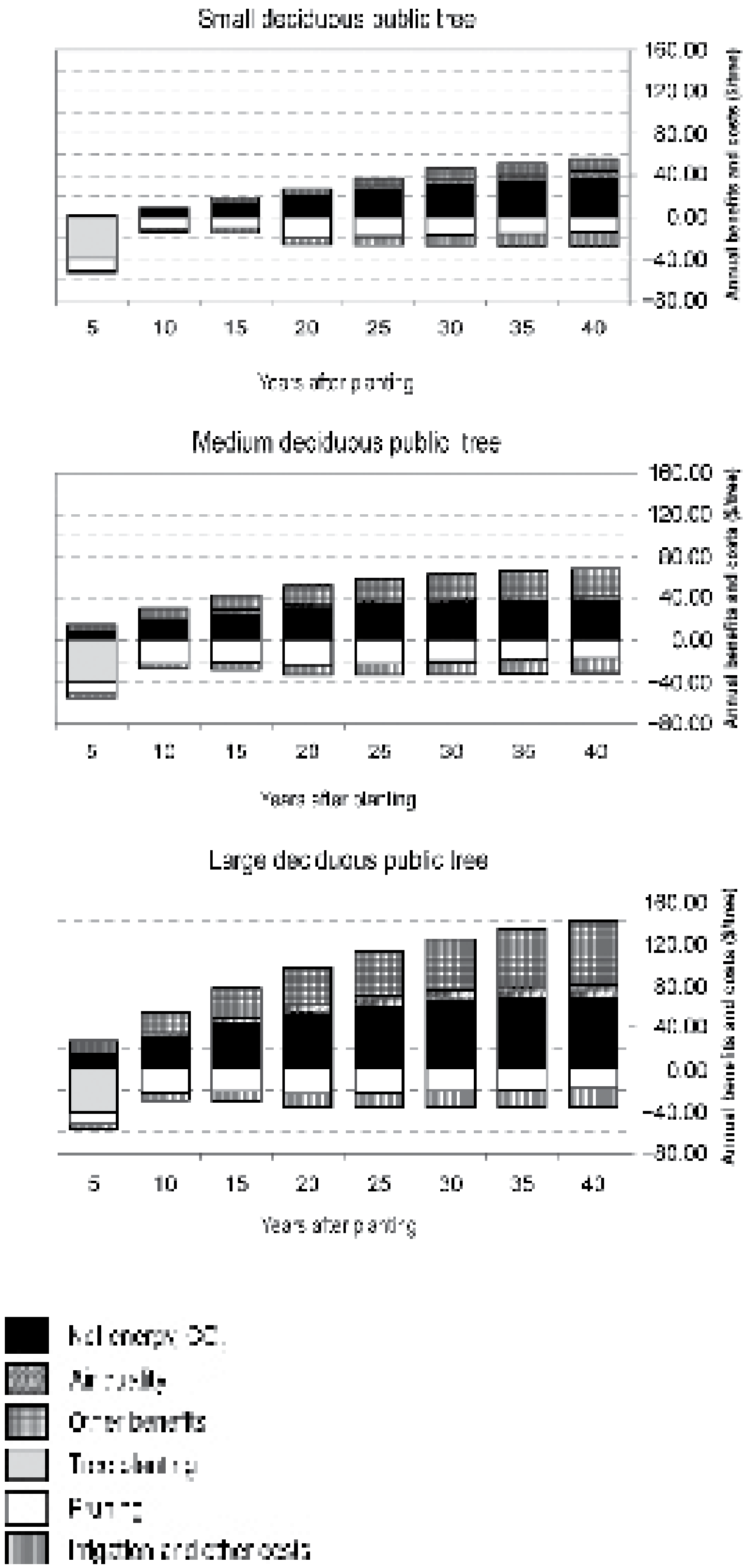


Figure 16—Estimated annual benefits and costs for small (crabapple), medium (red oak), and large (hackberry) public trees.

Esthetic and other benefits

Benefits associated with property value accounted for the second largest portion of total benefits. As trees grow and become more visible, they can increase the property's sales price. Average annual values associated with these esthetic and other benefits for public trees were $5, $13, and $28 for the small, medium, and large trees. The values for residential yard trees were slightly less than for public trees because off-street trees contribute less to a property's curb appeal than more prominent street trees. Because our estimates are based on median home sale prices, the effects of trees on property values and esthetics will differ depending on local economies. This assumption has not been tested, so there is a high level of uncertainty associated with our results.

Carbon dioxide reduction

CO_2 reduction accrues for large and medium trees. Net atmospheric CO_2 reductions accrued for all three tree types. Average annual net reductions ranged from 226 to 390 lbs ($2 to 3) for the small tree and from 665 to 911 lbs ($5 to $7) for the large tree. Trees opposite west-facing house walls produced the greatest CO_2 reduction owing to avoided power plant emissions associated with energy savings. Twenty years after planting, a large yard tree opposite the west wall of a residence resulted in the following average annual reductions in CO_2: 882 lbs of avoided emissions, 109 lbs of sequestered CO_2, and 12 lbs of released CO_2. The net benefit was 979 lb ($7.34) (app. B). Releases of CO_2 associated with tree care activities accounted for only 1 percent of net CO_2 sequestration.

Stormwater runoff reduction

Stormwater runoff benefits are crucial

Benefits associated with rainfall interception, reducing stormwater runoff, were substantial for all three tree types. The hackberry intercepted an average of 2,162 gal/year of rainfall with an implied value of $10. A large hackberry at 40 years after planting intercepted rainfall at a rate of 5,387 gal/year, valued at $25.

Bark and foliage of the crabapple and red oak intercepted 292 and 1,129 gal/year on average, with values of $1 and $5, respectively.

With the exception of crabapple, these results indicate that the amount of rainfall trees intercept is considerably greater than the amount they consume through irrigation during establishment (300 gal). Also, because the price of irrigation water ($0.003) is less than the cost of treating stormwater per gallon ($0.005), water-quality benefits associated with rainfall interception are greater than irrigation costs.

Air-quality improvement

Annual air-quality benefits are $3 to $8 per tree

Air-quality benefits were defined as the sum of pollutant uptake by trees and avoided power plant emissions from energy savings minus biogenic volatile organic compounds (BVOCs) released by trees. Overall, average annual benefits ranged from $3 to $8 per tree. These values are relatively low because air-pollutant concentrations in Minneapolis are low. Higher benefits are associated with higher pollutant concentrations found in areas such as Chicago, Detroit, and Cleveland.

Saving energy reduces NO_2 and SO_2 emissions

The total average annual air-quality benefit was a relatively low $3 for the red oak and crabapple. Red oak is a high emitter of BVOCs. Larger benefits were estimated for the hackberry ($8/year) because they emitted fewer BVOCs and had high avoided emission rates and pollutant-uptake rates because of their size. Benefit values were greatest for **NO_2**, followed by SO_2, PM_{10}, and O_3. Trees had a small positive effect on VOCs avoided at the power plant.

Avoided power plant emissions from cooling savings were especially important for NO_2 and SO_2 benefits. For example, the 20-year-old hackberry opposite a west-facing wall was estimated to reduce the annual home cooling load by 301 kWh, and this savings reduced power plant emissions of NO_2 by 1.15 lb (0.52 kg). Uptake of NO_2 by the same tree was only 0.03 lb (0.01 kg). Hence, planting trees to conserve energy can also be an effective way to reduce emissions of NO_2, an ozone forming pollutant.

Low emitters increase air-quality benefits

The cost of BVOCs released by the low-emitting hackberry was negligible. A single red oak, however, emitted about 0.5 lb (0.23 kg) of BVOCs per year on average. These releases somewhat offset annual benefits of $4.70 owing to pollutant uptake and $1.83 owing to avoided emissions. As a result, the net air-quality benefit was only $2.87.

Summary of benefits

Environmental benefits alone exceed costs for many trees

Average annual benefits for all trees 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 esthetics and other benefits to the environmental benefits resulted in substantial net benefits.

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

This chapter shows two ways that the 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 second example compares large and small trees. The last section discusses actions communities can take to increase the cost-effectiveness of their tree programs.

Applying Benefit–Cost Data

Wabena Falls Example

The hypothetical city of Wabena Falls is located in the Midwest region and has a population of 24,000. Most of its street trees were planted in the 1930s, with silver maple (see "Common and Scientific Names" section) and green ash as the dominant species. Currently, the tree canopy cover is sparse because most of the trees have died and have not been replaced. Many of the remaining street trees are in declining health. The city hired an urban forester 2 years ago, and an active citizens' group, the Green Team, has formed (fig. 17).

Initial discussions among the Green Team, local utilities, the urban forester, and other partners led to a proposed urban forestry program. The program intends to plant 1,000 trees in Wabena Falls over a 5-year period. Trained volunteers will plant ¾- to 1-in trees in the following proportions: 75 percent large trees, 20 percent medium trees, and 5 percent small trees. The total cost for planting will be $100/tree. Trees will be planted along Main Street, other downtown streets, and in parks. One hundred trees will be planted in parks, and the remaining 900 trees will be planted to shade streets.

Figure 17—The Green Team is gung-ho to regreen their community by planting 1,000 trees in 5 years.

The Wabena Falls City Council has agreed to maintain the current funding level for management of existing trees. Also, they will advocate formation of a municipal tree district to raise funds for the proposed tree-planting project. A municipal tree district is similar in concept to a landscape assessment district that receives revenues based on formulas that account for the services different customers receive. For example, the proximity of customers to greenspace in the landscape assessment district may determine how much they pay for upkeep. A municipal tree district might receive funding from air-quality districts, stormwater management agencies, electric utilities, businesses, and residents in proportion to the value of future benefits trees will produce related to air quality, hydrology, energy, carbon dioxide (CO_2), and property value. Such a district would require voter approval of a special assessment that charges recipients for tree planting and maintenance costs in proportion to the tangible benefits they receive from the new trees. The Council needs to know the amount of funding required for tree planting and maintenance, as well as how the benefits will be distributed over the 40-year life of the project.

The first step: Determine tree planting numbers

As a first step, the Wabena Falls city forester and the Green Team decided to use the tables in appendix B to quantify total cumulative benefits and costs over 40 years for the proposed planting of 1,000 public trees—50 small trees, 200 medium trees, and 750 large trees.

Before setting up a spreadsheet to calculate benefits and costs, the team considered aspects of Wabena Falls's urban and community forestry project that may differ from the regionwide values used in this guide (the methods for calculating the values in appendix B are described in appendix A):

1. The prices of electricity and natural gas in Wabena Falls are $0.08/kWh and $0.015/kBtu, not $0.00759/kWh and $0.0098/kBtu assumed in this guide. It is assumed that the buildings the new street trees will eventually shade have air conditioning and natural gas heating.
2. The Green Team projected future annual costs for monitoring tree health and implementing their stewardship program. Administration and other costs are estimated to average $2.50/tree planted each year, or $5,500 annually for the life of the trees. Values in this guide assumed an average annual cost of $4.65/tree for large public trees. Thus, an adjustment is necessary.
3. Planting costs will total $100/tree for ¾- to 1-in trees because labor will be provided by trained volunteers. The guide assumes planting costs total $200/tree for 1.5-in trees.
4. Normally, tree mortality is greatest during the first years after planting; however, in this case a contractor has guaranteed to replace all dead or dying trees after the first season. The replacement guarantee should result in relatively high survival rates for the establishment period. Therefore, the team agreed to apply the survival rate assumed for calculations shown in appendix B of this guide (i.e., 60 percent 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 created a spreadsheet table (table 4). Each benefit and cost category is listed in the first column. Prices, some adjusted and some not, are entered into the second column. The third column contains the **resource units (RU)** per tree per year associated with the benefit or the cost per tree per year. The fourth column lists the 40-year total values, obtained by multiplying the RU values by tree numbers, prices, and 40 years.

To adjust for higher electricity prices, the forester multiplied electricity saved for a large public tree in the RU column (136 kWh) by the Wabena Falls price ($0.08/kWh). This value ($10.88/tree per year) was then multiplied by the number of trees planted and 40 years ($10.88 × 750 trees × 40 years = $326,400) to obtain cumulative air-conditioning energy savings for the large public trees (table 4). The same steps were followed to adjust the natural gas prices for all tree types (small, medium, and large trees). To find the annual value for net air-pollutant uptake ($2.95 for a large public tree), the 40-year average value of pollutant uptake was divided by the 40-year average amount of pollutant uptake ($7.65 ÷ 2.59 lb). This adjusted

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

		50 Small trees		200 Medium trees		750 Large trees		1,000 Total trees		
Benefits	**Price ($)**	**RU/tree/yr**	**Total $**	**RU/tree/yr**	**Total $**	**RU/tree/yr**	**Total $**	**Total $**	**$/tree/yr**	**% benefits**
Electricity (kWh)	0.08	48	7,680	67	42,880	136	326,400	376,960	9.42	9.4
Natural gas (kBtu)	0.015	1,534	46,020	2,099	251,880	3,430	1,543,500	1,841,400	46.04	46.1
Net energy (kBtu)			53,700		294,760		1,869,900	2,218,360	55.46	55.6
Net CO_2 (lb)	0.008	336	5,376	444	28,416	734	176,160	209,952	5.25	5.3
Air pollution (lb)	2.95	0.99	5,848	1.11	26,229	2.59	229,215	261,577	6.54	6.6
Hydrology (gal)	0.0048	292	2,803	1,129	43,354	2,162	311,328	357,485	8.94	9.0
Esthetics and other ($)		5.32	10,640	12.67	101,360	27.69	830,700	942,700	23.57	23.6
Total benefits			78,367		494,119		3,417,303	3,989,789	99.75	100.0
Costs		**$/tree/yr**	**Total $**	**$/tree/yr**	**Total $**	**$/tree/yr**	**Total $**	**Total $**	**$/tree/yr**	**% costs**
Tree and planting ($)		2.5	5,000	2.5	20,000	2.5	75,000	100,000	2.50	7.9
Pruning ($)		15.04	30,080	20.11	160,880	20.61	618,281	809,241	20.23	64.2
Remove and dispose ($)		3.03	6,060	3.71	29,680	4.96	148,800	184,540	4.61	14.6
Pest and disease ($)		0.05	100	0.07	560	0.09	2,700	3,360	0.08	0.3
Infrastructure repair ($)		0.87	1,740	1.1	8,800	1.48	44,400	54,940	1.37	4.4
Irrigation (5 yrs) ($)		0.05	100	0.05	400	0.05	1,500	2,000	0.05	0.2
Cleanup ($)		0.03	60	0.04	320	0.05	1,500	1,880	0.05	0.1
Liability and legal ($)		0.05	100	0.09	720	0.1	3,000	3,820	0.10	0.3
Administration ($)		2.5	5,000	2.5	20,000	2.5	75,000	100,000	2.50	7.9
Total costs			48,240		241,360		970,181	1,259,781	31.49	100.0
Net benefit			30,127		252,759		2,447,122	2,730,008	68.25	
Benefit/cost ratio			1.62		2.05		3.52	3.17		

RU = resource unit.

price accounts for differences in uptake amounts and values for the different pollutants in Wabena Falls. For esthetic 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 $200 assumed in the guide to $100 (table 4). This planting cost was annualized by dividing the cost per tree by 40 years ($100/40 = $2.50/tree per year). Total planting costs were calculated by multiplying this value by 750 large trees and 40 years ($75,000).

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 cost for large public trees is $2.50/tree times 750 large trees and 40 years ($75,000). The same procedure was followed to calculate costs for the medium and small trees.

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

Subtracting total costs from total benefits yielded net benefits for the small ($30,127 or $15.06/tree per year), medium ($252,759 or $31.59/tree per year), and large ($2,447,122 or $81.57/tree per year) trees. Benefits total $3.99 million ($100/tree per year) and costs total $1.26 million ($31/tree per year). The total net benefit for all 1,000 trees over the 40-year period is $2.73 million, or $68/tree per year. 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 ($2,730,008/1,000 trees/40 years = $68.25). Dividing total benefits by total costs yielded benefit-cost ratios (BCRs) that ranged from 1.62 for small trees, to 2.05 and 3.52 for medium and large public trees. The BCR for the entire planting is 3.17, indicating that $3.17 will be returned for every $1 invested.

Remember that this analysis assumes 40 percent 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 about $1.26 million. The average annual cost will be $31,490 ($1.26 million for 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 = 55 percent (cooling = 9 percent, heating = 46 percent)

- Carbon dioxide (CO_2) reduction = 5 percent
- Air-pollution reduction = 7 percent
- Stormwater-runoff reduction = 9 percent
- Esthetics/property value increase = 24 percent

Distributing costs of tree management to multiple parties

With this information the planning team can determine how to distribute the costs for tree planting and maintenance based on who benefits from the services the trees will provide. For example, assuming the goal is to generate enough annual revenue to cover the costs of managing the trees ($1.26 million), fees could be distributed in the following manner:

- $700,307 from electric and natural gas utilities for peak energy savings (55 percent) (It is more cost-effective for utility companies to plant trees to reduce peak energy demand than to meet peak needs through added infrastructure.)
- $66,279 from local businesses and industry for atmospheric carbon dioxide reductions (5 percent)
- $82,576 from the air-quality-management district for net reduction of air pollutants (7 percent)
- $112,853 from the stormwater-management district for water-quality improvement associated with reduced runoff (9 percent)
- $297,598 from property owners for increased property values (24 percent)

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

City of Lindenville Example

As a municipal cost-cutting measure, the hypothetical city of Lindenville plans to stop planting 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 trees than the city would have. Currently, Lindenville's policy is to plant as large a tree as possible given each site's available growing space (fig. 18). Planting more small 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 small, medium, and large trees for a hypothetical street-tree planting project in Lindenville.

Figure 18—Lindenville's policy to plant as large a tree as the site will handle has provided ample benefits in the past. Here, large-stature trees have been planted.

The first step: Calculate benefits and costs over 40 years

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

- The price of electricity is $0.11/kWh, not $0.00759/kWh.
- No funds are spent on pest and disease control.
- Planting costs are $225/tree for city trees instead of $200/tree.

The second step: Adjust for local prices of benefits

To calculate the dollar value of total benefits and costs for the 40-year period, the last column in appendix B (40-year average) was multiplied by 40 years. Because this value is for one tree, it must be multiplied by the total number of trees planted in the respective small-, medium-, or large-tree size classes. To adjust for higher electricity prices we multiplied electricity saved for a large public tree in the resource unit column by the Lindenville price (136 kWh × $0.11 = $14.96). This value was multiplied by 40 years and 500 trees (14.96

× 40 × 500 = $299,200) to obtain cumulative air-conditioning energy savings for the project (table 5). The same steps were followed for medium and small trees.

The third step: Adjust for local costs

To adjust 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 Lindenville (500 × $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.

Subtracting total costs from total benefits yielded net benefits for the small ($329,800), medium ($681,600), and large ($1,606,900) trees. The total net benefit for the 40-year period was $2.62 million (total benefits − total costs), or $1,744/tree ($2.62 million/1,500 trees) on average (table 5).

The fourth step: Calculate cost savings and benefits forgone

By not investing in street-tree planting, the city would save $337,700 in initial costs. There is a risk, however, that developers will not plant the largest trees possible. If the developer planted 1,500 small trees, benefits would total $1.94 million (3 × $645,600 for 500 small trees). If 1,500 large trees were planted, benefits would total $5.94 million. Planting all small trees would cost the city $4 million in forgone benefits. This amount exceeds the savings of $337,700 obtained by

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

	500 Small		500 Medium		500 Large		1,500 Tree Total		Average	
Benefits	**RUs**	**Total $**	**RUs**	**Total $**	**RUs**	**Total $**	**RUs**	**Total $**	**$/tree**	**% benefits**
Electricity (kWh)	960,000	105,600	1,340,000	147,400	2,720,000	299,200	5,020,000	552,200	368	10.2
Natural gas (kBtu)	30,680,000	297,600	41,980,000	407,200	68,600,000	665,400	141,260,000	1,370,200	913	25.3
Net CO_2 (lb)	6,720,000	50,400	8,880,000	66,600	14,680,000	110,000	30,280,000	227,000	151	4.2
Air pollution (lb)	20,000	58,800	20,000	57,400	60,000	153,000	100,000	269,200	179	5.0
Hydrology (gal)	5,840,000	26,800	22,580,000	103,800	43,240,000	199,000	71,660,000	329,600	220	6.1
Esthetics and other ($)		106,400		253,400		553,800		913,600	609	16.8
Total benefits		645,600		1,035,800		1,980,400		3,661,800	2,440	100.0
Costs		**Total $**		**Total $**		**Total $**		**Total $**		
Tree and planting ($)		112,600		112,600		112,500		337,700	225	32.4
Pruning ($)		135,400		169,200		182,800		487,400	325	46.7
Remove and dispose ($)		38,800		40,600		43,800		123,200	82	11.8
Infrastructure ($)		3,400		3,600		4,000		11,000	7	1.1
Irrigation ($)		8,600		9,000		9,800		27,400	18	2.6
Cleanup ($)		13,000		14,400		15,400		42,800	29	4.1
Liability and legal ($)		3,200		3,400		3,600		10,200	7	1.0
Administration ($)		800		1,400		1,600		3,800	3	0.4
Total costs		315,800		354,200		373,500		1,043,500	696	100.0
Net benefits		329,800		681,600		1,606,900		2,618,300	1,744	
Benefit/cost ratio		2.04		2.92		5.30		3.51		

RU = resource unit.

requiring developers to plant new street trees, and suggests that, when turning over the responsibility for tree planting to others, the city should be very careful to develop and enforce a street tree ordinance that requires planting large trees where feasible.

The net benefits per public tree planted were as follows:

- $659 for a small tree
- $1,363 for a medium tree
- $3,214 for a large tree

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

This analysis assumed 40 percent 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 by using the municipal discount rate.

Increasing Program Cost-Effectiveness

What if costs are too high?

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

Increasing Benefits

Work to increase survival rates

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

Target tree plantings with highest return

Conifers and broadleaf evergreens intercept rainfall and particulates year round as well as reduce windspeeds, 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 planting a higher percentage of trees in locations that produce the greatest energy savings, such as opposite west-facing walls and close to buildings with air conditioning. By customizing tree locations to increase numbers in high-yield sites, energy savings can be boosted.

Reducing Program Costs

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

Cost-effectiveness = Total net benefit / total program cost

Reduce up-front and establishment costs

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

- Plant bare-root or smaller tree stock
- Use trained volunteers for planting and pruning of young trees (fig. 19)
- Provide follow-up care to increase tree survival and reduce replacement costs
- Select and locate trees to avoid conflicts with infrastructure.

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. In highly urbanized settings and sites subject to vandalism, however, large stock may survive the initial establishment period better than small stock.

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

Figure 19—Trained volunteers can plant and maintain young trees, allowing the community to get more accomplished at lower cost and providing satisfaction for participants.

Although organizing and training volunteers requires labor and resources, it is usually less costly than contracting the work. A cadre of trained volunteers can easily maintain trees until they reach a height of about 20 ft and limbs are too high to prune from the ground with pole pruners. By the time trees reach this size they are well established. Pruning during this establishment period should result in trees that will require less care in the long term. Training young trees can provide a strong branching structure that requires less frequent thinning and shaping (Costello 2000). Ideally, young trees should be inspected and pruned every other year for the first 5 years after planting.

Prune early

As trees grow larger, pruning costs may increase on a per-tree basis. The frequency of pruning will influence these costs, as it takes longer to prune a tree that has not been pruned in 10 years than one that was pruned a few years ago. Although pruning frequency differs by species and location, a return frequency of about 5 to 8 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 CO_2 reductions, and other tangible benefits. The magnitude of benefits related to employment opportunities, job training, community building, reduced violence, and enhanced human health and well-being can be substantial (fig. 20). 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 sources:

Figure 20—The green infrastructure is a significant component of communities in the Midwest.

Utilizing Municipal Trees: Ideas From Across the Country (Bratkovich 2001)

Urban Forestry: Planning and Managing Urban Greenspaces (Miller 1997)

An Introductory Guide to Community and Urban Forestry in Washington, Oregon, and California (Morgan, not dated)

A Technical Guide to Urban and Community Forestry (Morgan 1993)

Urban Tree Risk Management: A Community Guide to Program Design and Implementation (Pokorny 2003)

Chapter 5. General Guidelines for Selecting and Placing Trees

This chapter gives general guidelines for selecting and locating trees. Both residential trees and trees in public places are considered.

Guidelines for Energy Savings

Maximizing Energy Savings From Shading

Where should shade trees be planted?

The right tree in the right place can save energy and reduce tree care costs. In midsummer, the sun shines on the east side of a building in the morning, passes over the roof near midday, and then shines on the west side in the afternoon (fig. 5). 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 (Sand 1994).

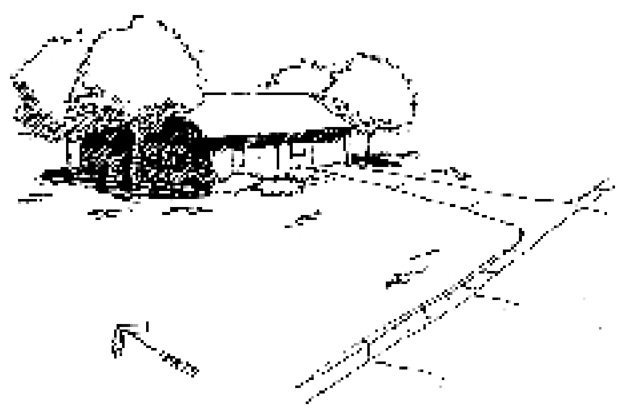


Figure 21—Locate trees to shade west and east windows (from Sand 1993).

Depending on building orientation and window placement, sun shining through windows can heat a home quickly during the morning hours. The east side is the second most important side to shade when considering the net impact of tree shade on cooling and heating costs (fig. 21). Deciduous trees on the east side provide summer shade and more winter solar heat gain than evergreens.

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 (fig. 22). 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 percent) (Ames 1987). Examples of solar-friendly trees include most species and **cultivars** of maples (see “Common and Scientific Names” section), hackberry, honeylocust, Kentucky coffeetree, and Japanese pagodatree.

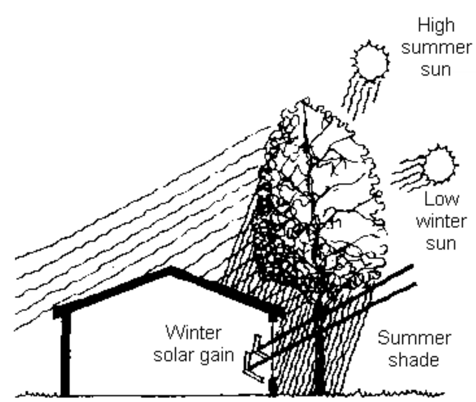


Figure 22—Select solar-friendly trees for southern exposures and locate trees close enough to the house to provide winter sun and summer shade (from Sand 1991).

Figure 23—Trees south of a home before and after pruning. Lower branches are pruned up to increase heat gain from winter sun (from Sand 1993).

Figure 24—Evergreens protect a building from dust and cold by reducing windspeeds (from Sand 1993).

To maximize summer shade and minimize winter shade, locate shade trees about 10 to 20 ft south of the home. As trees grow taller, prune lower branches to allow more sun to reach the building if this will not weaken the tree's structure (fig. 23).

The closer a tree is to a home the more shade it provides, but 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 10 ft or further from the home depending on mature crown spread, to avoid these conflicts. Trees within 30 to 50 ft of the home most effectively shade windows and walls.

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.

Plant only small-stature 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 below power lines.

Planting Windbreaks for Heating Savings

A tree's size and crown density can make it ideal for blocking wind, thereby reducing the impacts of cold winter weather and the drying effects of summer winds. Locate rows of trees perpendicular to the prevailing wind (fig. 24), usually the north and west side of homes in the Midwest region.

Design the windbreak row to be longer than the building being sheltered because windspeed increases at the edge of the windbreak. Ideally, the windbreak should be planted upwind about 25 to 50 ft from the building and should consist

Plant dense evergreens

of dense evergreens that will grow to twice the height of the building they shelter (Heisler 1986, Sand 1991). Avoid planting windbreaks that will block sunlight to south and east walls (fig. 25). 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 on center. If there is room for two or more rows, then space rows 10 to 12 ft apart.

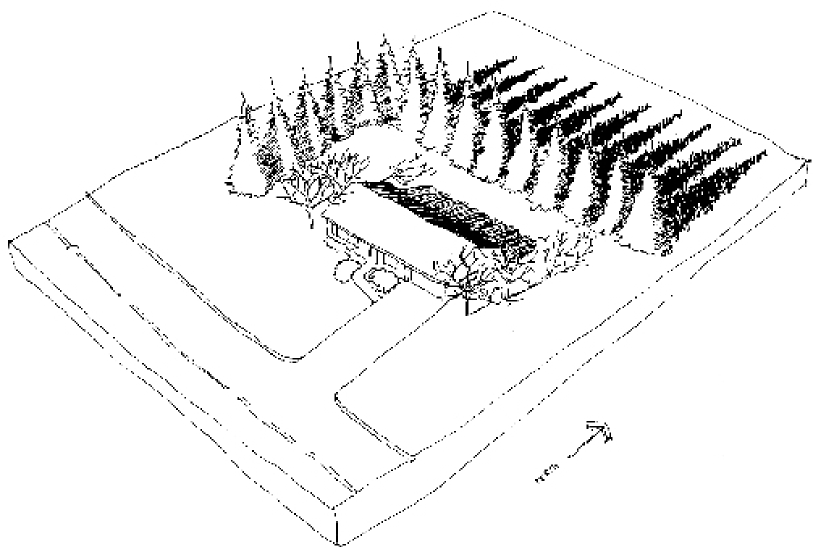


Figure 25—Midwinter shadows from a well-located windbreak and from shade trees do not block solar radiation on the south-facing wall (from Sand 1993).

Evergreens are preferred over deciduous trees for windbreaks because they provide better wind protection. The ideal windbreak tree is fast growing, visually dense, has branches that are firmly attached, and has stiff branches that do not self-prune. Large windbreak trees for communities in the Midwest include white fir, Colorado, and Black Hills spruce. Good windbreak species for smaller sites include eastern redcedar and arborvitae.

In 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 Trees to Maximize Benefits

Choices are many

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

Picking the right tree

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

Maximizing energy savings from trees

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

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

Guidelines for Reducing Carbon Dioxide

Figure 26—Compared with small trees, large trees can store more carbon, filter more air pollutants, intercept more rainfall, and provide greater energy savings.

Because trees in common areas and other public places may not shelter buildings from sun and wind and reduce energy use, carbon dioxide (CO_2) reductions are primarily due to sequestration. Fast-growing trees sequester more CO_2 initially than do slow-growing trees, but this advantage can be lost if the fast-growing trees die at younger ages. Large trees have the capacity to store more CO_2 than smaller trees (fig. 26). To maximize CO_2 sequestration, select tree species that are well suited to the site where they will be planted. Consult with your local landscape professional or arborist to select the right tree for your site. Trees that are not well adapted will grow slowly, show symptoms of stress, or die at an early age. Unhealthy trees do little to reduce atmospheric CO_2 and can be unsightly liabilities in the landscape.

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

- Maximize use of woody plants, especially trees, as they store more CO_2 than do herbaceous plants and grasses.
- Plant more trees where feasible and immediately replace dead trees to compensate for CO_2 lost through tree and stump removal.
- Create a diverse assemblage of habitats, with trees of different ages and species, to promote a continuous canopy cover over time.
- Reduce maintenance by reducing grass and planting drought-tolerant or environmentally friendly landscapes.
- Group species with similar landscape maintenance requiments together and consider how irrigation, pruning, fertilization, weed, pest, and disease control activities can be minimized.
- Reduce CO_2 associated with landscape management by using push mowers (not gas or electric), hand saws (not chain saws), pruners (not gas or electric shears), and rakes (not leaf blowers), and employ landscape professionals who don't have to travel far to your site.
- Consider the project's lifespan when making species selection. Fast-growing species will sequester more CO_2 initially than will slow-growing species, but may not live as long.
- Provide ample space belowground for tree roots to grow so that they can maximize CO_2 sequestration and tree longevity.
- When trees die or are removed, salvage as much wood as possible for use as furniture and other long-lasting products to forestall decomposition.
- Plant trees, shrubs, and vines in strategic locations to maximize summer shade and reduce winter shade, thereby reducing atmospheric CO_2 emissions associated with power production.

Guidelines for Reducing Stormwater Runoff

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

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

- Select tree species with architectural features that maximize interception, such as large leaf surface area and rough bark surfaces that store water (Metro 2002).
- Increase interception by planting large trees where space permits (fig. 27).
- Match trees to rainfall patterns so that they are in leaf when precipitation is greatest.
- Select conifers because they have high interception rates, but avoid shading south-facing windows to maximize solar heat gain in winter.
- Plant low-water-use tree species where appropriate and native species that, once established, require little supplemental irrigation.
- In bioretention areas, such as roadside swales, select species that tolerate inundation, are long-lived, wide-spreading, and fast-growing (Metro 2002).
- Do not pave over streetside planting strips for easier weed control because this can reduce tree health and increase runoff.

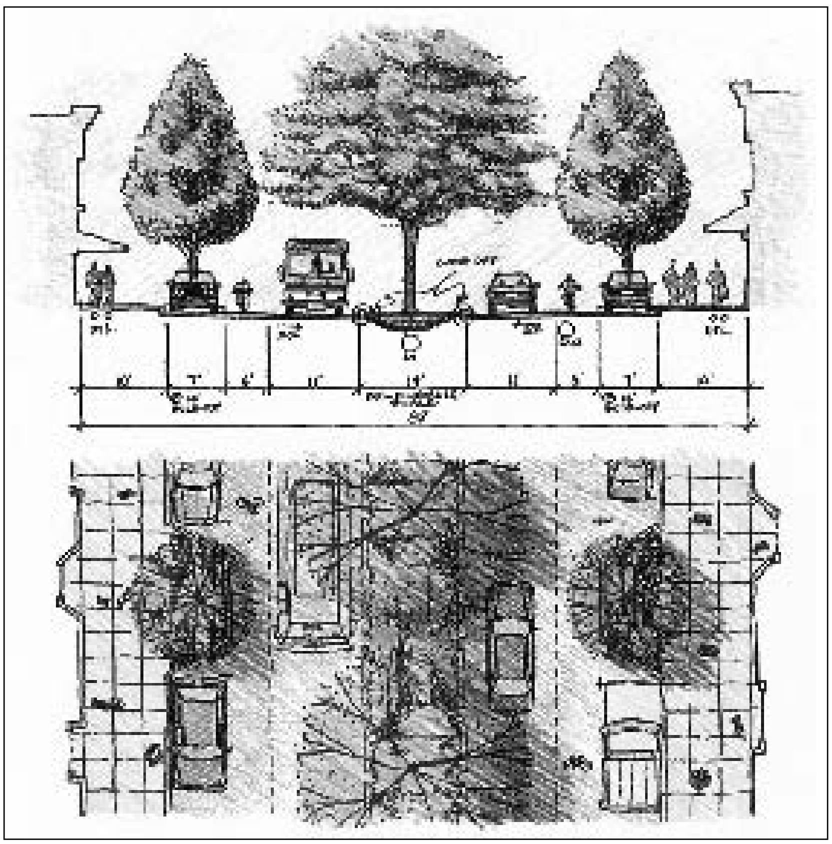


Figure 27—Tree crowns can create a continuous canopy for maximum rainfall interception, even in commercial areas. In this example, a swale in the median filters runoff and provides ample space for large-stature trees. Parking-space sized planters contain the soil volume required to grow healthy, large trees (from Metro 2002).

Guidelines for Improving Air Quality

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

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

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

- Select species that tolerate pollutants that are present in harmful concentrations. For example, in areas with high O_3 concentration avoid sensitive species such as white and green ash (see "Common and Scientific Names" section), tulip poplar, and Austrian pine (Noble and others 1988).
- Conifers have high surface-to-volume ratios and retain their foliage year round, which may make them more effective than deciduous species.
- Species with long petioles (leaf stems; e.g., ash, maple) and hairy plant parts (e.g., oak, birch, sumac) are especially efficient interceptors.
- Uptake depends on proximity to the pollutant source and amount of biomass. Where space permits, plant multilayered stands near the source of pollutants.
- Consider the local meteorology and topography to promote air flow that can "flush" pollutants at night and avoid trapping them in the urban canopy layer during the day.
- In areas with unhealthy ozone concentrations, maximize use of plants that emit low levels of biogenic volatile organic compounds (BVOCs) to reduce ozone formation.
- Sustain large healthy trees—they produce the greatest benefits.
- To reduce emissions of VOCs and other pollutants, plant trees to shade parked cars and conserve energy.
- Plant trees that tolerate pollution in polluted or heavily populated areas.

Avoiding Tree Conflicts With Infrastructure

- Before planting, contact your state hotline, such as Holey Moley or one-call, to locate underground water, sewer, gas, and telecommunications lines.
- Avoid locating trees where they will block illumination from streetlights or views of street signs in parking lots, commercial areas, and along streets.
- Check with local transportation officials for sight visibility requirements. Keep trees at least 30 ft away from street intersections to ensure visibility.

- Avoid planting shallow-rooting species near sidewalks, curbs, and paving. Tree roots can heave pavement if planted too close to sidewalks and patios. Generally, avoid planting within 3 ft of pavement, and remember that trunk flare at the base of large trees can displace soil and paving for a considerable distance. Be aware of strategies to reduce infrastructure damage by tree roots such as meandering walks around trees and selecting deep-rooting species (Costello and Jones 2003).
- Select only small trees (<25 ft tall) for location under overhead power lines. Do not plant directly above underground water and sewer lines (fig. 28).

For trees to deliver benefits over the long term they require enough soil volume to grow and remain healthy. Matching tree species to the site's soil volume can reduce sidewalk and curb damage as well. Figure 29 shows recommended soil volumes for different sized trees.

Maintenance requirements and public safety issues influence the type of trees selected for public places. The ideal public tree is not suscep-

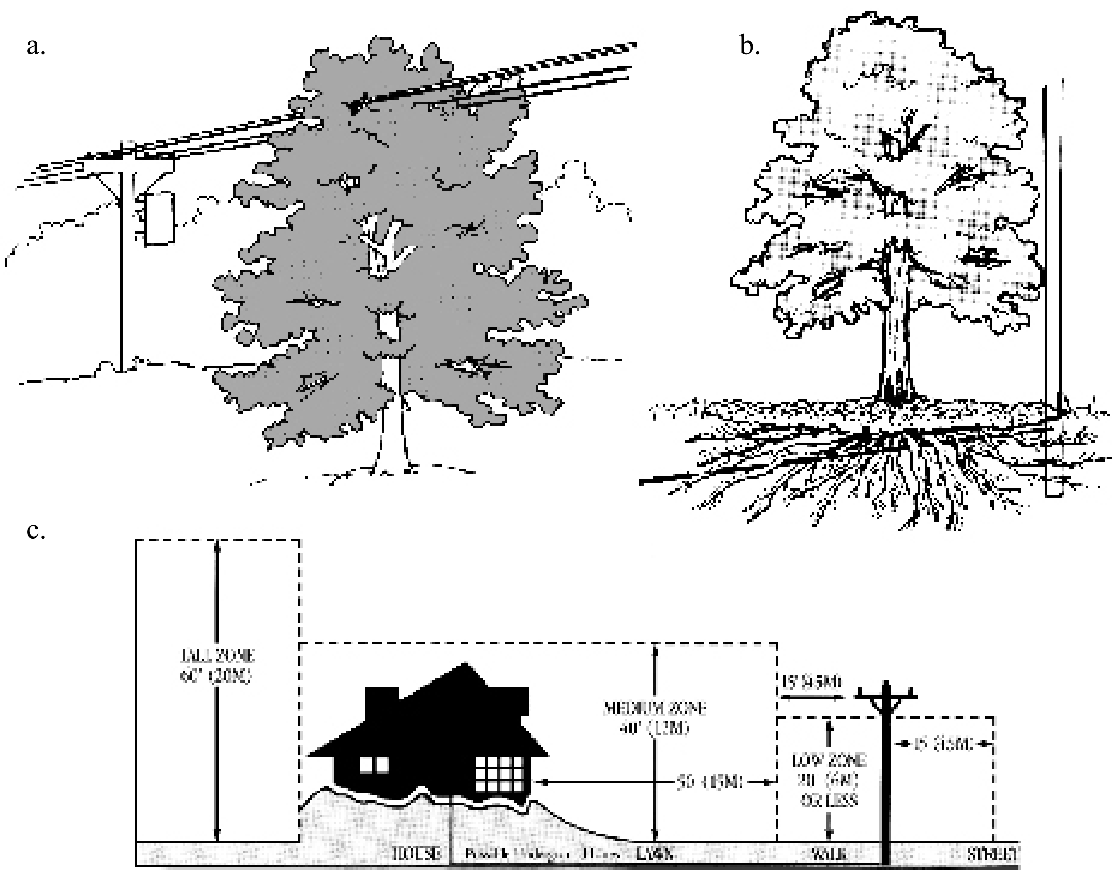
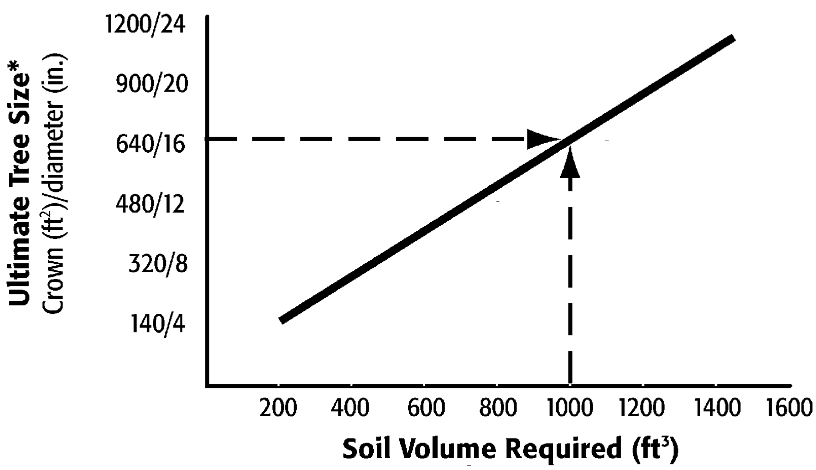


Figure 28—(a,b) Know where power lines and other utility lines are before planting. (c) Under power lines use only small-growing trees ("low zone") and avoid planting directly above underground utilities. Larger trees may be planted where space permits ("medium" and "tall zones") (from ISA 1992). Copyright International Society of Arboriculture. Used with permission.

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

SOIL VOLUME FOR TREES



*** The ultimate tree size is defined by the projected size of the crown and the diameter of the tree at breast height.**

Figure 29. Developed from several sources by Urban (1992), this graph shows the relationship between tree size and required soil volume. For example, a tree with a 16-in diameter at breast height with 640 ft² of crown projection area under the drip-line requires 1,000 ft³ of soil (from Costello and Jones 2003).

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.

The root ball is critical to survival

The health of the tree's root ball is critical to its survival. If the tree is in a container, check for encircling woody roots the diameter of a pencil or larger by sliding off the container. Roots should penetrate to the edge of the root ball, but not densely circle the inside of the container. If the tree has many of these roots circling around the outside of the root ball or the root ball is very hard, it is said to be pot-bound. If the tree trunk is buried deep in the container and there are encircling roots, then the roots may girdle the tree. Do not purchase trees that are pot-bound to this degree.

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, whereas a poor trunk bends a little and pivots at or below the soil line—a tell-tale sign indicating a poorly anchored or deeply buried tree.

Plant the tree in the right size hole

Within the root ball, find the depth to the first branch root. Dig the planting hole according to this depth. Soil balls most commonly have 4 to 6 in of soil over the roots. Place the tree so that the root flare is at the top of the soil. Make the hole two to three times as wide as the root ball and loosen the sides of the hole if it is a hard clay soil. Backfill with the native soil unless it is very rocky or sandy, in which case you may want to add composted organic matter such as peat moss or shredded bark (fig. 30).

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

Unless it is a poorly drained soil, use the extra soil left after planting to build a berm outside the root ball that is 6 in high and 3 ft in diameter. Soak the tree, and gently rock it to settle it in. Cover the basin with a 4-in layer of mulch, but do not place mulch against the tree trunk. Water the new tree with 2 to 5 gal of water three times a week, and increase the amount of water as the tree grows larger. Generally, a tree requires about 1 in of water a week unless it rains. Having a rain gauge or soil moisture sensor (tensiometer) can help determine tree watering needs.

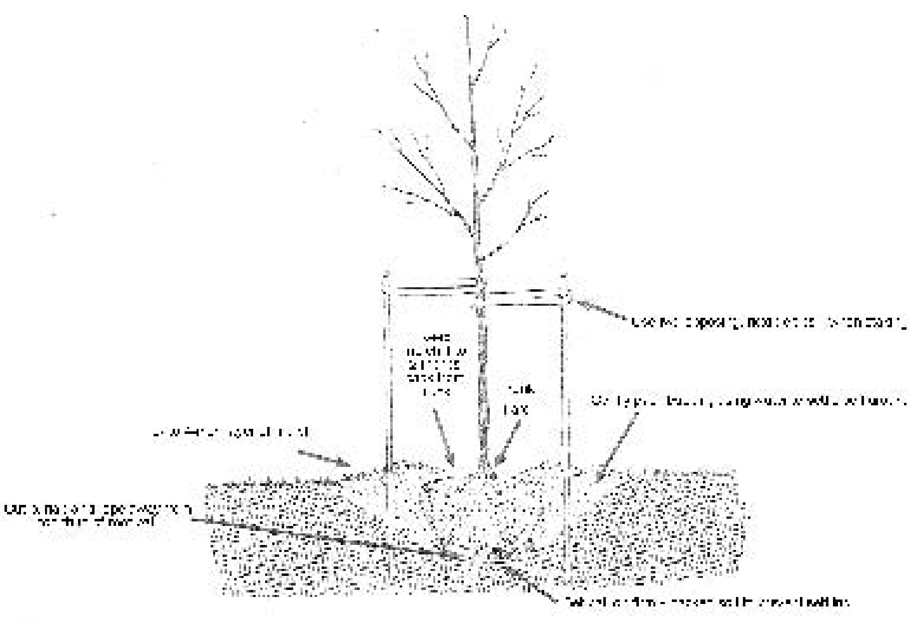


Figure 30—Prepare a broad planting area, plant tree with the root flare at ground level, and provide a watering ring to retain water (from Head and others 2001).

- Inspect your tree several times a year, and contact a local certified arborist if problems develop.

- If your tree needed staking to keep it upright, remove the stake and ties after 1 year or as soon as the tree can hold itself up. The staking should allow some tree movement, as this movement sends hormones to the roots causing them to grow and create greater tree stability. It also promotes trunk taper and growth.
- Reapply mulch and irrigate the tree as needed.
- Leave lower side branches on young trees for the first year and prune back to 4 to 6 in to accelerate tree diameter development. Remove these lateral branches after the first full year. Prune the young tree to maintain a central main trunk and equally spaced branches. As the tree matures, have it pruned on a regular basis by a certified arborist or other experienced professional.
- By keeping your tree healthy, you maximize its ability to produce shade, intercept rainfall, reduce atmospheric CO_2, and provide other benefits. For additional information on tree selection, planting, establishment, and care see the following resources:
    - *Planting Trees and Shrubs for Long-Term Health* (Hargrave and others 2002)
    - *How to Prune Trees* (Bedker and others 1995)
    - *Trees and Ice Storms: The Development of Ice Storm-Resistant Urban Tree Populations* (Hauer and others 1994)
    - *How to Identify and Manage Dutch Elm Disease* (Haugen 1998)
    - *How to Identify, Prevent, and Control Oak Wilt* (O'Brien and others 2000)
    - *Tree City USA Bulletin* series (Fazio, undated)
    - International Society of Arboriculture (ISA) brochures (www.isa-arbor.com and www.treesaregood.com)
    - *Native Trees, Shrubs, and Vines for Urban and Rural America* (Hightshoe 1988)
    - *Principles and Practice of Planting Trees and Shrubs* (Watson and Himelick 1997)
    - *Arboriculture* (Harris and others 1999)
    - *Training Young Trees for Structure and Form* video (Costello 2000)
    - *An Illustrated Guide to Pruning* (Gilman 2002)
- Contact your state urban forestry coordinator, ISA representative, and Cooperative Extension Educators for research-based information and workshops.

Common and Scientific Names

Plants

Common name	Scientific name
Arborvitae	*Thuja occidentalis* L.
Austrian pine	*Pinus nigra* J.F. Arnold
Black Hills spruce	*Picea glauca* (Moench) Voss var. *densata* Bailey
Blackgum	*Nyssa* spp.
Colorado spruce	*Picea pungens* Engelm.
Cottonwood	*Populus* spp.
Crabapple	*Malus* spp.
Eastern redcedar	*Juniperus virginiana* L.
Ginkgo	*Ginkgo biloba* L.
Green ash	*Fraxinus pennsylvanica* Marshall
Hackberry	*Celtis occidentalis* L.
Hackberry	*Celtis* spp.
Honeylocust	*Gleditsia triacanthos* L.
Japanese pagodatree	*Sophora japonica* L.
Kentucky coffeetree	*Gymnocladus dioicus* (L.) K. Koch
Maple	*Acer* spp.
Oak	*Quercus* spp.
Poplar	*Populus* spp.
Red oak	*Quercus rubra* L.
Silver maple	*Acer saccharinum* L.
Sweetgum	*Liquidambar styraciflua* L.
Sycamore	*Platanus* spp.
Tulip poplar	*Liriodendron tulipifera* L.
White ash	*Fraxinus americana* L.
White fir	*Abies concolor* (Gordon & Glend.) Lindl. ex Hildebr.

Insects

Common name	Scientific name
Asian long-horned beetle	*Anoplophora glabripennis* (Motschulsky)
Emerald ash borer	*Agrilus planipennis* Fairmaire

Pathogens

Common name	Scientific name
Dutch elm disease	*Ophiostoma ulmi* (Buisman) Nannf. and *Ophiostoma novo-ulmi* (Brasier)

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Metric Equivalents

When you know:	Multiply by:	To find:
Inches (in)	25.4	Millimeters (mm)
Feet (ft)	0.305	Meters (m)
Square feet (ft^2)	0.0929	Square meters (m^2)
Miles (mi)	1.61	Kilometers (km)
Square miles (mi^2)	2.59	Square kilometers (km^2)
Gallons (gal)	0.00378	Cubic meters (m^3)
Pounds (lb)	0.454	Kilograms (kg)
Pounds per square feet (lb/ft^2)	4.882	Kilograms per square meter (kg/m^2)
Tons (ton)	0.907	Metric tonne (t)
Thousand British thermal units (kBtu)	1.05	Megajoules (MJ)
Kilowatt hours (kWh)	3.6	Megajoules (MJ)

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Glossary of Terms

AFUE: See annual fuel utilization efficiency.

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

anthropogenic: Produced by humans.

avoided power plant emissions: Reduced emissions of CO_2 or other pollutants that result from reductions in building energy use owing to the moderating effect of trees on climate. Reduced energy use for heating and cooling results in reduced demand for electrical energy, which translates into fewer emissions by 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 plants, or a combination of these elements.

biogenic: Produced by living organisms.

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

- *Celtis occidentalis*: 0.0 (isoprene); 0.0 (monoterpene)
- *Quercus rubra*: 14.2 (isoprene); 1.2 (monoterpene)
- *Malus* spp.: 0.0 (isoprene); 0.1 (monoterpene)

BVOC: See biogenic volatile organic compounds.

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

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

Ccf: One hundred cubic feet.

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

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

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

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

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

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

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

d.b.h.: See diameter at breast height.

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

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

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

emission factor: The rate of CO_2, NO_2, SO_2, and PM_{10} output resulting from the consumption of electricity, natural gas, or any other fuel source.

ET: See evapotranspiration.

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. Evergreens may be broadleaved or coniferous (cone-bearing with needlelike leaves).

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

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

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

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

interception: 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 1 kilowatt (1,000 watts) of power expended for 1 hour. One kWh is equivalent to 3.412 kBtu.

LAI: See leaf area index.

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

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

LSA: See leaf surface area.

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

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

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

metric tonne: A measure of weight (abbreviated "t") 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 for compounds of nitric acid (NO), nitrogen dioxide (NO_2), and other oxides of nitrogen. Nitrogen oxides are typically created during combustion processes and are major contributors to smog formation and acid deposition. NO_2 may cause numerous adverse human health effects.

NO_2: See nitrogen oxides.

O_3: See ozone.

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

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

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

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

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

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

RU: See resource unit.

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

SEER: See seasonal energy efficiency ratio.

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

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

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

SO_2: See sulfur dioxide.

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

stem flow: Amount of rainfall that travels down the tree trunk and onto the ground.

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

t: See metric tonne.

therm: A unit of heat equal to 100,000 British thermal units (BTUs) or 100 kBtu. Also, 1 kBtu is equal to 0.01 therm.

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

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

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

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

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

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

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

VOCs: See volatile organic compounds.

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

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

Appendix A. Procedures for Estimating Benefits and Costs

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 or 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 with "typical" tree species.

To account for differences in the mature size and growth rates of different tree species, we report results for typical small, medium, and large deciduous trees: crabapple (see "Common and Scientific Names" section), red oak, and hackberry, respectively. Results are reported for 5-year intervals for 40 years.

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

Growth Modeling

A complete inventory of Minneapolis's street trees was in progress when this study started. By spring 2003 the inventory included 35,106 trees and over 5,000 available planting spaces. The city indicated that the sample trees were representative of the remaining population, and the inventory was suitable for sampling to develop growth models representative of the predominant tree species.

Tree-growth models developed from Minneapolis data were used as the basis for modeling tree growth for this report. Using Minneapolis's tree inventory, we measured a stratified random sample of 17 tree species to establish relations between tree age, size, leaf area, and biomass.

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

- 0–3 in
- 3–6 in
- 6–12 in
- 12–18 in
- 18–24 in
- 24–30 in
- 30–36 in
- 36–42 in
- >42 in

Thirty to 50 trees of each species were randomly selected for surveying, along with an equal number of alternative trees. Tree measurements included d.b.h. (to nearest 0.1 cm by sonar measuring device), tree crown and bole height (to nearest 0.5 m by clinometer), crown diameter in two directions (parallel and perpendicular to nearest street to nearest 0.5 m by sonar measuring device), tree condition and location. Replacement trees were sampled when trees from the original sample population could not be located. Tree age was determined by street-tree managers. Fieldwork was conducted in June and July 2004.

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

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

Reporting Results

Results are reported in terms of annual values per tree planted. To make these calculations realistic, however, mortality rates are included. Based on our survey of regional municipal foresters and commercial arborists, this analysis assumed that 40 percent of the hypothetical planted trees died over the 40-year period. Annual mortality rates were 1 percent for the 40 years, or 40 percent total. 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 directly connected with tree-size variables such as trunk d.b.h., tree canopy cover, and LSA. For instance, pruning and removal costs usually increase with tree size expressed as d.b.h. For some parameters, such as sidewalk repair, costs are negligible for young trees but increase relatively rapidly as tree roots grow large enough to heave pavement. For other parameters, such as air-pollutant uptake and rainfall interception, benefits are related to tree canopy cover and leaf area.

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

Benefit and Cost Valuation

Source of cost estimates

Frequency and costs of tree management were estimated based on surveys with municipal foresters from Stevens Point and Waukesha, Wisconsin, Lansing, Michigan, Glen Ellyn, Illinois, and Minneapolis, Minnesota. In addition, commercial arborists in Merton and Appleton, Wisconsin, and Troy, Michigan, provided information on tree management costs on residential properties.

Pricing benefits

Electricity and natural-gas prices for utilities serving Minneapolis were used to quantify energy savings for the region. Control costs were used to estimate willingness-to-pay for air-quality improvements. For example, the prices for air-quality benefits were estimated by using marginal control costs (Wang and Santini 1995). If a developer is willing to pay an average of $1 per pound of treated and controlled pollutant to meet minimum standards, then the air pollution mitigation value of a tree that intercepts one pound of pollution, eliminating the need for control, should be $1.

Calculating Benefits

Energy Benefits

The prototypical building used as a basis for the simulations was typical of post-1980 construction practices, and represents 30 percent of the total single-family residential housing stock in the Midwest region. The house was a one-story, wood-frame, slab-on-grade building with a conditioned floor area of 2,180 ft^2, window area (double-glazed) of 242 ft^2, and insulation of R19 (walls), R32 (ceiling), and R5 (foundation). The central cooling system had a **seasonal energy efficiency ratio (SEER)** of 10, and the natural-gas furnace had an **annual fuel utilization efficiency (AFUE)** of 78 percent. Building footprints were square, reflecting average impacts for a large number of buildings (McPherson and Simpson 1999). Buildings were simulated with 1.5-ft overhangs. Blinds had a visual density of 37 percent and were assumed to be closed when the air conditioner was operating. Summer thermostat settings were 78 °F; winter settings were 68 °F during the day and 60 °F at night. Because the prototype building was larger, but more energy efficient, than most other construction types, our projected energy savings can be considered similar to those for older, less thermally efficient, but smaller buildings. The energy simulations relied on typical meteorological data from Minneapolis (Marion and Urban 1995).

Calculating energy savings

The dollar value of energy savings was based on regional average prices of $0.00759/kWh for residential electricity and $0.0098 kBtu (0.98/**therm**) for natural gas. Electricity and natural-gas prices were for 2004 for Minnesota (Xcelenergy 2004 and Centerpoint Energy 2004, respectively). Homes were assumed to have central air conditioning and natural-gas heating.

Calculating shade effects

Residential yard trees were within 60 ft of homes so as to directly shade walls and windows. **Shade effects** of these trees on building energy use were simulated for small, medium, and large trees at three tree-to-building distances, following methods outlined by McPherson and Simpson (1999). The small tree (crabapple) had a visual density of 85 percent during summer and 15 percent during winter. The medium tree (red oak) had a density of 81 percent during summer and 26 percent during winter, and the large tree (hackberry) had a density of 88 percent during summer and 47 percent during winter. Small trees were leafless October 1 to May 20, medium trees November 7 to May 10, and large trees October 20 to May 20. Results of shade effects for each tree were averaged over distance and weighted by occurrence within each of three distance classes: 28 percent at 10 to 20 ft, 68 percent at 20 to 40 ft, and 4 percent at 40 to 60 ft (McPherson and Simpson 1999). Results are reported for trees shading east-, south-, and west-facing surfaces. Our results for public trees are conservative in that we assumed that they do not provide shading benefits. For example, in Modesto, California, 15 percent of total annual dollar energy savings from street trees was due to shade and 85 percent due to **climate effects** (McPherson and others 1999a).

Calculating climate effects

In addition to localized shade effects, which were assumed to accrue only to residential yard trees, lowered air temperatures and windspeeds from increased neighborhood **tree cover** (referred to as climate effects) produced a net decrease in demand for winter heating and summer cooling (reduced windspeeds by themselves may increase or decrease cooling demand, depending on the circumstances). Climate effects on energy use, air temperature, and windspeed, as a function of neighborhood canopy cover, were estimated from published values (McPherson and Simpson 1999). Existing tree canopy plus building cover was 33 percent based on estimates for Minneapolis (McPherson and Simpson 1999). Canopy cover was calculated to increase by 6.7, 8.9, and 9.8 percent for 20-year-old small, medium, and large trees, respectively, based on an effective lot size (actual lot size plus a portion of adjacent street and other rights-of-way) of 10,000 ft^2, and one tree on average was assumed per lot. Climate effects were estimated by simulating effects of wind and air-temperature reductions on energy use. Climate effects accrued for both public and yard trees.

Calculating windbreak effects

Trees near buildings result in additional windspeed reductions beyond those from the aggregate effects of trees throughout the neighborhood. This leads to a small additional decrease in annual heating energy use of about 0.6 percent per tree for the Midwest 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, as their crowns are leafless and above the ground, and therefore do not block winds near ground level.

Atmospheric Carbon Dioxide Reduction

Calculating reduction in CO_2 emissions from power plants

Conserving energy in buildings can reduce CO_2 emissions from power plants. These avoided emissions were calculated as the product of energy savings for heating and cooling based on the CO_2 emission factors (table A-1) and were based on data for Minnesota where the average fuel mix is 1.9 percent hydroelectric, 2.6 percent natural gas, 65 percent coal, 26.1 percent nuclear, and 4.6 percent other (US EPA 2003). The value of \$15/ton CO_2 reduction (table A-1) was based on the average of high and low estimates by CO2e.com (2002).

Calculating carbon storage

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

Calculating CO_2 released by power equipment

Tree-related emissions of CO_2, based on gasoline and diesel fuel consumption during tree care in our survey cities, were calculated by using the value 0.47 lb CO_2/in d.b.h. This amount may overestimate CO_2 release associated with less intensively maintained residential yard trees.

Calculating CO_2 released during decomposition

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

Air-Pollutant Emissions Reduction

Table A1—Emissions factors and implied values for CO_2 and criteria air pollutants

	Emission factor		Implied value
	Electricity (lb/MWh)[a]	Natural gas (lb/MBtu)[b]	($/lb)[c]
CO_2	1,604.10	117.65	0.01
NO_2	3.81	0.1	3.34
SO_2	3.4	0	2.06
PM_{10}	0.67	0.01	2.84
VOCs	0.66	0.01	3.75

VOC = volatile organic compound.
[a] Data are from US EPA (2003), except VOC data (Ottinger and others 1990).
[b] US EPA (1998).
[c] CO_2 from CO_2.com (2002). Other values based on the methods of Wang and Santini (1995) using emissions concentrations from US EPA (2004) and population estimates from the Metropolitan Council (2004).

Reductions in building energy use also result in reduced emission of air pollutants from power plants and space-heating equipment. **Volatile organic compounds (VOCs)** and nitrogen dioxide (NO_2)—both precursors of ozone formation—as well as sulfur dioxide (**SO_2**) and particulate matter of < 10-micron diameter (PM_{10}) were considered. Changes in average annual emissions and their monetary values were calculated in the same way as for CO_2 by using utility-specific emissions factors for electricity and heating fuels (Ottinger and others 1990, US EPA 1998). The price of emissions savings were derived from models that calculate the marginal cost of controlling different pollutants to meet air quality standards (Wang and Santini 1995). Emissions concentrations were obtained from US EPA (2003; table A-1), and population estimates from the U.S. Census Bureau (2002).

Calculating pollutant uptake by trees

Trees also remove pollutants from the atmosphere. The modeling method we applied was developed by Scott and others (1998). It calculates **hourly pollutant dry deposition** per tree expressed as the product of deposition velocity ($V_d = 1/[R_a + R_b + R_c]$), pollutant concentration (C), canopy-projection area (CP), and a time step. Hourly decomposition velocities for each pollutant were calculated during the growing season by using estimates for the resistances ($R_a + R_b + R_c$) for each hour throughout the year. Hourly concentrations for NO_2, SO_2, O_3, and PM_{10} and hourly meteorological data (i.e., air temperature, wind-speed, solar radiation) from Minneapolis and the surrounding area for 2003 were obtained from the Minnesota Pollution Control Agency and the University of Minnesota, respectively. The year 2003 was chosen because data were available and it closely approximated long-term, regional climate records. To set a value for pollutant uptake by trees we used the procedure described above for emissions reductions (table A-1). The monetary value for NO_2 was used for ozone.

Estimating BVOC emissions from trees

Annual emissions for biogenic volatile organic compounds (BVOCs) were estimated for the three tree species by using the algorithms of Guenther and others (1991, 1993). Annual emissions were simulated during the growing season over 40 years. The emission of carbon as isoprene was expressed as a product of the base emission rate (micrograms of carbon per gram foliar biomass per hour), adjusted for sunlight and temperature and the amount of dry, foliar biomass present in the tree. Monoterpene emissions were estimated by using a base emission rate adjusted for temperature. The base emission rates for the 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 Minneapolis, Minnesota, during the summer of 2004. The amount of foliar biomass present for each year of the simulated tree's life was unique for each species. Hourly air temperature and solar radiation data for 2003 described in the pollutant uptake section were used as model inputs.

Calculating net air-quality benefits

Net air-quality benefits were calculated by subtracting the costs associated with BVOC emissions from benefits owing to pollutant uptake and avoided 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).

Rainfall Interception by Tree Canopies

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

The volume of water stored in the tree crown was calculated from crown-projection area (area under tree **dripline**), **leaf area indices** (**LAI**, the ratio of leaf surface area to crown projection area), and the depth of water captured by the canopy surface. Gap fractions, foliation periods, and **tree surface saturation storage capacity** influence the amount of projected throughfall. The gap fractions are 15, 19, and 12 percent during summer, and 85, 74, and 53 percent during winter for crabapple, red oak, and hackberry, respectively. Tree surface saturation was 0.04 in for all three trees. Hourly meteorological and rainfall data for 2003 from the Minnesota Meteorological Network (MNMET) (Station: St. Paul Campus Climatological Observatory, latitude 44°56'52"N, longitude 93°06'13"W) were used for this simulation. Annual precipitation during 2003 was 24.5 in, close to the recent 30-year-average annual precipitation of 28.4 in. Storm events less than 0.1 in were assumed not to produce runoff and were dropped from the analysis. More complete descriptions of the interception model can be found in Xiao and others (1998, 2000).

Calculating the water quality protection and flood control benefit

Treatment of runoff is one way of complying with Federal Clean Water Act regulations by preventing contaminated stormwater from entering local waterways. Therefore, to estimate the value of rainfall intercepted and potential cost reductions in stormwater-management control—a value that includes the cost of collection, conveyance, and treatment—single-family residential sewer service fees were used ($3.43/**Ccf** per dwelling unit) (City of Minneapolis 2004). Sewer service fees cover the capital, operation, and improvements of the citywide sewer and stormwater-management systems. Although this value is not the current assessed cost of stormwater management in Minneapolis, the sewer service fee is a conservative proxy for the level of service currently provided. At $0.0046/gal, this fee is below the average price of stormwater-runoff reduction ($0.089/gal) assessed in similar studies (McPherson and Xiao 2004).

Esthetic and Other Benefits

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

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

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

The sales price of residential properties ranged widely by location within the region; for example, in 2004, median home prices ranged from $125,900 in Indianapolis to $263,300 in Chicago. By averaging the values for seven cities we calculated the average home price for Midwest communities as $160,843. Therefore, the value of a large tree that added 0.88 percent to the sales price of such a home was $1,418. To estimate annual benefits, the total added value was divided by the leaf surface area of a 40-year-old hackberry ($1,418/7,352 ft^2) to yield the base value of LSA—$0.19/ft^2. This value was multiplied by the amount of LSA added to the tree during 1 year of growth.

Calculating the esthetic 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 hackberry in the front yard increased the property sales price by $1,418. Approximately 75 percent of all yard trees, however, are in backyards (Richards and others 1984). Lacking specific research findings, it was assumed that backyard trees had 75 percent of the impact on "curb appeal" and sales price compared to front-yard trees. The average annual esthetic benefit for a tree on private property was estimated as $0.16/ft^2 of LSA. To estimate annual benefits, this value was multiplied by the amount of LSA added to the tree during 1 year of growth.

Calculating the base value of a street tree

The base value of street trees was calculated in the same way as front-yard trees. Because street trees may be adjacent to land with little value or resale potential, however, an adjusted value was calculated. An analysis of street trees in Modesto, California, sampled from aerial photographs (sample size: 8 percent of street trees), found that 15 percent were located adjacent to nonresidential or commercial property (McPherson and others 1999b). We assumed that 33 percent of these trees—or 5 percent 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 and others 1974, Schroeder 1982, Tyrvainen 1999), to our knowledge, the onsite and external benefits of park trees alone have not been isolated (More and others 1988). After reviewing the literature and recognizing an absence of data, we assumed that park trees had the same impact on property prices as street trees. Given these assumptions, we estimated typical large street and park trees to increase property values by $0.18/ft^2 and $0.19/ft^2 of LSA, respectively. Assuming that 80 percent of all municipal trees were on streets and 20 percent in parks, a weighted average benefit of $0.19/ft^2 of LSA was calculated for each tree.

Calculating Costs

Planting

Planting costs include the cost of the tree and the cost for planting, staking, and mulching the tree. Based on our survey of Midwest municipal and commercial arborists, planting costs depend on tree size. Costs ranged from $200 for a 1-in tree to $560 for a 3-in tree. In this analysis we assumed that a 2.5-in yard tree was planted at a cost of $400. The cost for planting a 1.5-in public tree was $200. These prices include the tree and planting, staking, and mulching by a professional.

Pruning

Pruning costs for public trees

After studying data from municipal forestry programs and their contractors, we assumed that young public trees were inspected and pruned every other year during the first 5 years after planting, at a cost of $25/tree. After this training period, pruning occurred once every 4 years for small trees (< 20 ft tall) at a cost of $50/tree. Medium trees (20 to 40 ft tall) were inspected/pruned every 8 years, and large trees (> 40 ft tall) every 10 years. More expensive equipment and more time was required to prune medium ($200/tree) and large trees ($300/tree) than small trees. After factoring in pruning frequency, annualized costs for pruning public trees were $12.50, $12.50, $25, and $30 per tree for young, small, medium, and large trees, respectively.

Pruning costs for yard trees

Based on findings from our survey of commercial arborists in the Midwest region, pruning cycles for yard trees were similar to public trees, but only 20 percent of all private trees were professionally pruned (**contract rate**). However, the number of professionally pruned trees grows as the trees grow. We assumed that professionals are paid to prune all large trees, 60 percent of the medium trees, and only 6 percent of the small and young trees (Summit and McPherson 1998). Using these contract rates, along with average pruning prices ($30, $90, $200, and $300 for young, small, medium, and large trees, respectively), we found the average annual costs for pruning a yard tree to be $0.18, $0.36, $4.80, and $8.57 for young, small, medium, and large trees.

Tree and Stump Removal

The costs for tree removal and disposal were $25 per in d.b.h. for public trees, and $35 per in d.b.h. for yard trees. Stump removal costs were $5 per in d.b.h. for both public and yard trees. Therefore, total costs for removal and disposal of trees and stumps were $30 per in d.b.h. for public trees, and $40 per in d.b.h. for yard trees.

Pest and Disease Control

Pests such as the emerald ash borer and Asian long-horned beetle, and diseases such as Dutch elm disease and elm phloem necrosis pose a serious threat to the health of Midwest trees. As a result, some cities and residents are investing in preventive treatments and aggressive control measures to reduce tree mortality. In Midwest communities, pest and disease control expenditures averaged about $0.13 per tree per year or approximately $0.0087 per in d.b.h. for public trees. Results of our survey indicated that only 1 percent of all yard trees were treated, and the amount of money spent averaged $145 per tree. The estimated cost for treating pests and diseases in yard trees was $1.45 per tree per year or $0.097 per in d.b.h.

Irrigation

Because of the region's warm summer climate, newly planted trees require irrigation for 1 to 3 years. Once planted, trees typically require 100 to 300 gal per year. Assuming a water price of $2.38/Ccf in Minneapolis, annual irrigation water costs are initially less than $1/tree per year. Trees planted in lawn areas with existing irrigation usually do not require supplemental irrigation after an establishment period. We assumed that all public and yard trees were irrigated by hand during a 2- to 3-year establishment period at an average annual cost of $0.40/tree based on Minneapolis water prices (City of Minneapolis 2004). After this time, trees were assumed to grow without supplemental watering.

Other Costs for Public and Yard Trees

Other costs associated with the management of trees include expenditures for infrastructure repair and root pruning, leaf-litter cleanup, litigation and liability, and inspection and administration. Cost data were obtained from the municipal arborist survey and assume that 50 percent of public trees are street trees and 50 percent are park trees. Costs for park trees tend to be lower than for street trees because there are fewer conflicts with infrastructure such as power lines and sidewalks.

Infrastructure conflict costs

Many Midwest municipalities have a substantial number of large old trees and deteriorating sidewalks. As trees and sidewalks age, roots can cause damage to sidewalks, curbs, paving, and sewer lines. Sidewalk repair is typically one of the largest expenses for public trees (McPherson and Peper 1995). Infrastructure-related expenditures for public trees in Midwest communities were high relative to other regions, averaging approximately $4.05/tree and $0.135/in d.b.h. on an annual basis. Roots from most trees in residential yards do not damage sidewalks and sewers. Therefore, the cost for yard trees was estimated to be only 2 percent of the cost for public trees.

Liability costs

Urban trees can, and do, incur costly payments and legal fees owing to trip-and-fall claims. A survey of Western U.S. cities showed that an average of 8.8 percent of total tree-related expenditures was spent on tree-related liability (McPherson 2000). Our survey found that Midwest communities spend $0.10/tree per year on average ($0.0033/in d.b.h.). Because street trees are closer to sidewalks and sewer lines than most trees in yards, we assumed that legal costs for yard trees were 10 percent of those for public trees (McPherson and others 1993).

Litter and storm cleanup costs

The average annual per tree cost for litter cleanup (i.e., street sweeping, storm-damage cleanup) was $0.15/tree ($0.0033/in d.b.h.). This value was based on average annual litter cleanup costs and storm cleanup, assuming a large storm results in extraordinary costs about once a decade. Because most residential yard trees are not littering the streets with leaves, it was assumed that cleanup costs for yard trees were 10 percent of those for public trees.

Green-waste disposal costs

Green-waste disposal and recycling costs were negligible for our survey of Midwest communities because 95 to 100 percent of green waste is recycled as mulch, compost, firewood, or other products. Fees from the sale of these products largely offset the costs of processing and hauling. Arborists and residents pay tipping fees for disposal of green waste, but these disposal costs are already included in the pruning and removal estimates.

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 $6.62/tree ($0.44/in d.b.h.). Trees on private property do not accrue this expense.

Calculating Net Benefits

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

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

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

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

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)

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

H = value of annual stormwater-runoff reductions

A = value of annual esthetic 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 (C) are the sum of costs for residential yard trees (C_Y) and public trees (C_P) where:

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

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

where

P = cost of tree and planting

T = average annual tree pruning cost

R = annualized tree and stump removal and disposal cost

D = average annual pest- and disease-control cost

I = annual irrigation cost

S = average annual cost to repair/mitigate infrastructure damage

Cl = annual litter and storm cleanup cost

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

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

Net benefits are …

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

$$\text{Net benefits} = B - C$$

Limitations of This Study

This analysis does not account for the wide variety of trees planted in the Midwest 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. Estimating esthetic and other benefits is difficult 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 differ widely depending on program characteristics. For example, our analysis does not incorporate costs incurred by utility companies and passed on to customers for maintenance of trees under power lines. As described in the examples in chapter 3, however, local cost data can be substituted for the data in this report to evaluate the benefits and costs of alternative programs.

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 percent annual interest rate.

Appendix B. Benefit–Cost Information Tables

Information in this appendix can be used to estimate benefits and costs associated with proposed tree plantings. The tables contain data for typical small, medium, and large trees: crabapple (see "Common and Scientific Names" section), red oak, and hackberry, respectively. Data are presented as annual values for each 5-year interval after planting. Annual values incorporate effects of tree loss. We assume that 1 percent of the trees planted die each year for the 40-year period.

For the benefits tables (tables B-1, B-4, and B-7), there are two columns for each 5-year interval. In the first column, values describe resource units (RUs): for example, the amount of air-conditioning energy saved in kilowatthours per year per tree, air-pollutant uptake in pounds per year per tree, and rainfall intercepted in gallons per year per tree. Energy and CO_2 benefits for residential yard trees are broken out by tree location to show how shading impacts differ among trees opposite west-, south-, and east-facing building walls. The second column for each 5-year interval contains dollar values obtained by multiplying RUs by local prices.

Costs for yard and public trees do not differ by planting location (i.e., east, west, south walls). Although tree and planting costs occur at year 1, we divided this value by 5 years to derive an average annual cost for the first 5-year period. All other costs are estimated values for each year and not values averaged over 5 years (tables B-2, B-5, and B-8).

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 for the public tree (tables B-3, B-6, and B-9).

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

Table B1—Annual benefits for the representative small tree (crabapple)

Benefits	Year 5 RU	Year 5 $	Year 10 RU	Year 10 $	Year 15 RU	Year 15 $	Year 20 RU	Year 20 $	Year 25 RU	Year 25 $	Year 30 RU	Year 30 $	Year 35 RU	Year 35 $	Year 40 RU	Year 40 $	40-year average RU	40-year average $
Cooling (kWh)																		
Yard: west	6	0.48	21	1.56	56	4.23	87	6.64	114	8.64	136	10.34	162	12.27	182	13.83	96	7.25
Yard: south	4	0.33	12	0.94	28	2.10	42	3.21	62	4.68	78	5.93	94	7.16	107	8.15	54	4.06
Yard: east	5	0.37	15	1.15	38	2.87	59	4.45	80	6.06	98	7.43	117	8.88	132	10.04	68	5.16
Public	4	0.33	12	0.94	26	1.96	39	2.92	56	4.21	70	5.32	82	6.24	92	6.97	48	3.61
Heating (kBtu)																		
Yard: west	148	1.45	432	4.24	857	8.40	1,243	12.18	1,650	16.17	1,994	19.55	2,130	20.87	2,216	21.71	1,334	13.07
Yard: south	116	1.13	286	2.80	345	3.39	415	4.07	681	6.67	908	8.90	773	7.58	631	6.18	519	5.09
Yard: east	141	1.38	407	3.99	796	7.80	1,150	11.27	1,538	15.08	1,868	18.30	1,987	19.47	2,059	20.18	1,243	12.18
Public	158	1.55	473	4.64	978	9.58	1,433	14.04	1,883	18.45	2,264	22.18	2,470	24.20	2,614	25.62	1,534	15.03
Net energy (kBtu)																		
Yard: west	211	1.93	638	5.80	1,415	12.63	2,118	18.82	2,789	24.81	3,357	29.89	3,747	33.15	4,038	35.55	2,289	20.32
Yard: south	158	1.46	410	3.74	622	5.49	838	7.28	1,297	11.35	1,690	14.84	1,717	14.74	1,705	14.34	1,055	9.15
Yard: east	190	1.75	559	5.14	1,174	10.67	1,736	15.72	2,337	21.14	2,847	25.74	3,156	28.35	3,382	30.22	1,923	17.34
Public	201	1.87	597	5.58	1,236	11.54	1,818	16.97	2,438	22.67	2,964	27.50	3,292	30.44	3,533	32.59	2,010	18.64
Net CO_2 (lb)																		
Yard: west	34	0.25	99	0.75	223	1.67	338	2.53	457	3.42	562	4.21	660	4.95	745	5.59	390	2.92
Yard: south	27	0.20	69	0.52	118	0.88	168	1.26	259	1.94	341	2.56	392	2.94	439	3.29	226	1.70
Yard: east	31	0.23	88	0.66	187	1.40	280	2.10	389	2.92	485	3.64	571	4.29	647	4.85	335	2.51
Public	32	0.24	91	0.68	189	1.42	281	2.11	390	2.93	487	3.65	573	4.29	647	4.85	336	2.52
Air pollution (lb)*																		
O_3 uptake	0.00086	0.00	0.00385	0.01	0.02545	0.09	0.05352	0.18	0.12835	0.43	0.20318	0.68	0.31757	1.06	0.43363	1.45	0.15	0.49
NO_2 uptake and avoided	0.03333	0.11	0.09903	0.33	0.22012	0.74	0.33296	1.11	0.46389	1.55	0.57699	1.93	0.67359	2.25	0.75251	2.52	0.39	1.32
SO_2 uptake and avoided	0.01693	0.03	0.0518	0.11	0.12646	0.26	0.19565	0.40	0.27064	0.56	0.33488	0.69	0.40208	0.83	0.45704	0.94	0.23	0.48
PM_{10} uptake and avoided	0.00469	0.01	0.01726	0.05	0.05642	0.16	0.14302	0.41	0.25763	0.73	0.27191	0.77	0.28466	0.81	0.29469	0.84	0.17	0.47
VOCs avoided	0.00401	0.02	0.0121	0.05	0.02817	0.11	0.04298	0.16	0.05883	0.22	0.0723	0.27	0.08472	0.32	0.09454	0.35	0.05	0.19
BVOCs released	0	0.00	□0.00005	0.00	□0.0003	0.00	□0.00104	0.00	□0.00237	□0.01	□0.00237	□0.01	□0.00237	□0.01	□0.00237	□0.01	0	□0.01
Avoided and net uptake	0.06	0.18	0.184	0.54	0.456	1.35	0.767	2.26	1.177	3.48	1.457	4.33	1.76	5.26	2.03	6.09	0.99	2.94
Hydrology (gal)*																		
Rainfall interception	9	0.04	30	0.14	83	0.38	144	0.66	251	1.15	358	1.64	605	2.78	859	3.95	292	1.34
Esthetics and other																		
Yard	---	0.09	---	1.33	---	2.57	---	4.07	---	5.83	---	7.86	---	7.40	---	6.86	---	4.50
Public	---	0.11	---	1.58	---	3.03	---	4.80	---	6.89	---	9.29	---	8.75	---	8.10	---	5.32
Total benefits																		
Yard: west	---	2.49	---	8.56	---	18.60	---	28.34	---	38.71	---	47.94	---	53.54	---	58.03	---	32.03
Yard: south	---	1.97	---	6.27	---	10.67	---	15.52	---	23.76	---	31.24	---	33.13	---	34.52	---	19.63
Yard: east	---	2.29	---	7.82	---	16.37	---	24.81	---	34.52	---	43.22	---	48.08	---	51.97	---	28.63
Public	---	2.44	---	8.52	---	17.72	---	26.80	---	37.12	---	46.42	---	51.53	---	55.59	---	30.77

Note: Annual values incorporate effects of tree loss. We assume an annual mortality of 1 percent, for a total mortality over 40 years of 40 percent. RU = resource unit.
*Values are the same for yard and public trees.

Table B2—Annual costs for the representative small tree (crabapple)

Costs	Year 5	Year 10	Year 15	Year 20	Year 25	Year 30	Year 35	Year 40	40-year average
Tree and planting									
Yard	80.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.00
Public	40.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00
Pruning									
Yard	0.17	0.32	0.30	3.84	3.60	3.36	3.12	2.88	2.08
Public	11.88	11.25	10.63	20.00	18.75	17.50	16.25	15.00	15.04
Remove and dispose									
Yard	0.84	1.74	2.70	3.72	4.80	5.94	7.14	8.40	4.01
Public	0.63	1.30	2.02	2.79	3.60	4.45	5.35	6.30	3.03
Pest and disease									
Yard	0.19	0.38	0.55	0.72	0.87	1.00	1.12	1.22	0.70
Public	0.01	0.03	0.04	0.05	0.07	0.08	0.09	0.09	0.05
Infrastructure repair									
Yard	0.05	0.09	0.14	0.18	0.22	0.25	0.28	0.30	0.17
Public	0.24	0.47	0.69	0.90	1.09	1.26	1.40	1.52	0.87
Irrigation									
Yard	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Public	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Cleanup									
Yard	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01
Public	0.01	0.02	0.02	0.03	0.04	0.05	0.05	0.05	0.03
Liability and legal									
Yard	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Public	0.02	0.03	0.05	0.05	0.06	0.06	0.06	0.06	0.05
Administration and other									
Yard	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Public	0.76	1.49	2.18	2.83	3.42	3.96	4.42	4.79	2.75
Total costs									
Yard	81.64	2.54	3.71	8.47	9.50	10.57	11.68	12.82	17.02
Public	53.93	14.60	15.64	26.66	27.02	27.35	27.62	27.83	26.87

Note: Annual values incorporate effects of tree loss. We assume an annual mortality of 1 percent, for a total mortality over 40 years of 40 percent.
*Although tree and planting costs occur in year 1, this value was divided by 5 years to derive an average annual cost for the first 5-year period.

Table B3—Annual net benefits for the representative small tree (crabapple)

Net benefits	Year 5	Year 10	Year 15	Year 20	Year 25	Year 30	Year 35	Year 40	40-year average
Yard: West	□79	6	15	20	29	37	42	45	15
Yard: South	□80	4	7	7	14	21	21	22	3
Yard: East	□79	5	13	16	25	33	36	39	12
Public	□51	-6	2	0	10	19	24	28	4

Note: Annual values incorporate effects of tree loss. We assume an annual mortality of 1 percent, for a total mortality over 40 years of 40 percent. See tables B1 for annual benefits and table B2 for annual costs.

Table B4—Annual benefits for the representative medium tree (red oak)

	Year 5		Year 10		Year 15		Year 20		Year 25		Year 30		Year 35		Year 40		40-year average	
Benefits	**RU**	**$**	**RU**	**$**	**RU**	**$**	**RU**	**$**	**RU**	**$**	**RU**	**$**	**RU**	**$**	**RU**	**$**	**RU**	**$**
Cooling (kWh)																		
Yard: west	58	4.39	129	9.79	182	13.82	213	16.13	233	17.67	238	18.08	238	18.06	235	17.82	191	14.47
Yard: south	19	1.46	51	3.84	79	5.97	103	7.81	120	9.12	134	10.15	141	10.72	146	11.06	99	7.52
Yard: east	34	2.60	82	6.24	120	9.11	144	10.89	159	12.11	168	12.76	171	13.01	172	13.04	131	9.97
Public	16	1.19	36	2.70	53	4.01	69	5.22	80	6.07	89	6.75	94	7.13	97	7.34	67	5.05
Heating (kBtu)																		
Yard: west	518	5.07	1,063	10.42	1,493	14.63	1,816	17.80	2,040	19.99	2,152	21.09	2,197	21.53	2,198	21.54	1,685	16.51
Yard: south	□226	□2.22	□517	□5.06	□633	□6.20	□485	□4.75	□363	□3.56	□211	□2.07	□95	□0.93	5	0.05	□316	□3.09
Yard: east	449	4.40	956	9.37	1,371	13.44	1,703	16.69	1,934	18.95	2,056	20.15	2,109	20.67	2,120	20.78	1,587	15.56
Public	663	6.50	1,363	13.36	1,898	18.60	2,275	22.30	2,533	24.82	2,657	26.04	2,702	26.48	2,697	26.43	2,099	20.57
Net energy (kBtu)																		
Yard: west	1,097	9.47	2,354	20.21	3,314	28.45	3,941	33.93	4,368	37.66	4,535	39.17	4,577	39.59	4,546	39.36	3,591	30.98
Yard: south	□34	□0.76	□11	□1.22	154	□0.23	544	3.06	838	5.56	1,126	8.07	1,318	9.79	1,463	11.12	675	4.42
Yard: east	793	7.01	1,777	15.60	2,572	22.55	3,138	27.58	3,529	31.06	3,737	32.90	3,824	33.68	3,838	33.81	2,901	25.53
Public	820	7.69	1,719	16.06	2,427	22.61	2,962	27.51	3,333	30.89	3,547	32.79	3,642	33.61	3,664	33.77	2,764	25.62
Net CO_2 (lb)																		
Yard: west	171	1.28	375	2.81	535	4.01	645	4.84	725	5.44	758	5.69	773	5.80	770	5.78	594	4.46
Yard: south	22	0.16	63	0.47	119	0.89	199	1.49	261	1.96	312	2.34	348	2.61	369	2.77	212	1.59
Yard: east	125	0.94	287	2.15	421	3.16	521	3.91	595	4.46	634	4.76	656	4.92	660	4.95	487	3.66
Public	121	0.90	260	1.95	375	2.81	469	3.52	538	4.03	578	4.34	601	4.51	607	4.56	444	3.33
Air pollution (lb)*																		
O_3 uptake	0.00795	0.03	0.03984	0.13	0.08345	0.28	0.15225	0.51	0.21233	0.71	0.29795	1.00	0.37069	1.24	0.44939	1.50	0.2	0.67
NO_2 uptake and avoided	0.15822	0.53	0.36318	1.21	0.53272	1.78	0.66411	2.22	0.75738	2.53	0.82001	2.74	0.8542	2.86	0.87457	2.92	0.63	2.10
SO_2 uptake and avoided	0.10847	0.22	0.25468	0.52	0.37249	0.77	0.45546	0.94	0.51324	1.06	0.54813	1.13	0.56477	1.16	0.57186	1.18	0.42	0.87
PM_{10} uptake and avoided	0.02478	0.07	0.06511	0.18	0.1217	0.35	0.20712	0.59	0.31488	0.89	0.43811	1.24	0.44121	1.25	0.44212	1.26	0.26	0.73
VOCs avoided	0.02277	0.09	0.05272	0.20	0.07681	0.29	0.09383	0.35	0.1056	0.40	0.11229	0.42	0.11523	0.43	0.11607	0.44	0.09	0.33
BVOCs released	□0.00027	0.00	□0.01979	□0.07	□0.09655	□0.36	□0.2875	□1.08	□0.57971	□2.17	□0.9732	□3.65	□0.9732	□3.65	□0.9732	□3.65	□0.49	-1.83
Avoided and net uptake	0.322	0.93	0.756	2.18	1.091	3.10	1.285	3.53	1.324	3.42	1.243	2.88	1.373	3.30	1.481	3.65	1.11	2.87
Hydrology (gal)*																		
Rainfall interception	59	0.27	196	0.90	394	1.81	767	3.53	1,095	5.04	1,671	7.68	2,160	9.94	2,690	12.38	1,129	5.19
Esthetics and other																		
Yard	---	4.01	---	7.84	---	10.52	---	12.22	---	13.08	---	13.25	---	12.86	---	12.04	---	10.73
Public	---	4.73	---	9.26	---	12.43	---	14.44	---	15.45	---	15.65	---	15.19	---	14.23	---	12.67
Total benefits																		
Yard: west	---	15.97	---	33.95	---	47.89	---	58.05	---	64.63	---	68.68	---	71.48	---	73.20	---	54.23
Yard: south	---	4.62	---	10.17	---	16.09	---	23.83	---	29.05	---	34.23	---	38.50	---	41.95	---	24.81
Yard: east	---	13.16	---	28.68	---	41.14	---	50.77	---	57.05	---	61.48	---	64.69	---	66.83	---	47.97
Public	---	14.53	---	30.36	---	42.77	---	52.52	---	58.83	---	63.35	---	66.55	---	68.58	---	49.69

Note: Annual values incorporate effects of tree loss. We assume an annual mortality of 1 percent, for a total mortality over 40 years of 40 percent. RU = resource unit.
*Values are the same for yard and public trees.

Table B5—Annual costs for the representative medium tree (red oak)

Costs	Year 5	Year 10	Year 15	Year 20	Year 25	Year 30	Year 35	Year 40	40-year average
Tree and planting									
Yard	80.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.00
Public	40.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00
Pruning									
Yard	0.17	4.32	4.08	6.86	6.43	6.00	5.57	5.14	4.57
Public	11.88	22.50	21.25	24.00	22.50	21.00	19.50	18.00	20.11
Remove and dispose									
Yard	1.47	2.73	3.91	5.02	6.05	7.01	7.89	8.70	4.92
Public	1.10	2.04	2.93	3.76	4.54	5.25	5.92	6.52	3.71
Pest and disease									
Yard	0.34	0.59	0.80	0.97	1.10	1.19	1.24	1.26	0.88
Public	0.03	0.04	0.06	0.07	0.08	0.09	0.09	0.10	0.07
Infrastructure repair									
Yard	0.08	0.15	0.20	0.24	0.27	0.30	0.31	0.32	0.22
Public	0.42	0.74	1.00	1.21	1.37	1.48	1.55	1.58	1.10
Irrigation									
Yard	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Public	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Cleanup									
Yard	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Public	0.02	0.03	0.04	0.04	0.05	0.05	0.06	0.06	0.04
Liability and legal									
Yard	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Public	0.06	0.08	0.09	0.10	0.10	0.10	0.09	0.09	0.09
Administration and other									
Yard	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Public	1.33	2.33	3.16	3.82	4.32	4.67	4.88	4.97	3.45
Total costs									
Yard	82.46	7.81	9.02	13.11	13.88	14.52	15.04	15.45	20.66
Public	55.21	27.77	28.53	33.01	32.95	32.64	32.09	31.31	33.61

Note: Annual values incorporate effects of tree loss. We assume an annual mortality of 1 percent, for a total mortality over 40 years of 40 percent.
*Although tree and planting costs occur in year 1, this value was divided by 5 years to derive an average annual cost for the first 5-year period.

Table B6—Annual net benefits for the representative meidum tree (red oak)

Net benefits	Year 5	Year 10	Year 15	Year 20	Year 25	Year 30	Year 35	Year 40	40-year average
Yard: west	□66	26	39	45	51	54	56	58	34
Yard: south	□78	2	7	11	15	20	23	27	4
Yard: east	□69	21	32	38	43	47	50	51	27
Public	□41	3	14	20	26	31	34	37	16

Note: Annual values incorporate effects of tree loss. We assume an annual mortality of 1 percent, for a total mortality over 40 years of 40 percent. See tables B4 for annual benefits and table B5 for annual costs.

Table B7—Annual benefits for the representative large tree (hackberry)

	Year 5		Year 10		Year 15		Year 20		Year 25		Year 30		Year 35		Year 40		40-year average	
Benefits	**RU**	**$**	**RU**	**$**	**RU**	**$**	**RU**	**$**	**RU**	**$**	**RU**	**$**	**RU**	**$**	**RU**	**$**	**RU**	**$**
Cooling (kWh)																		
Yard: west	74	5.61	188	14.30	254	19.29	301	22.82	323	24.51	333	25.26	334	25.36	333	25.26	268	20.30
Yard: south	30	2.25	84	6.35	140	10.63	191	14.49	233	17.66	263	19.98	283	21.49	292	22.15	189	14.38
Yard: east	47	3.60	124	9.38	181	13.71	224	17.02	250	18.98	267	20.24	275	20.90	280	21.22	206	15.63
Public	26	1.99	64	4.85	103	7.85	137	10.37	161	12.22	184	13.95	201	15.22	212	16.06	136	10.31
Heating (kBtu)																		
Yard: west	938	9.19	1987	19.47	2778	27.22	3400	33.32	3796	37.20	4028	39.48	4136	40.54	4105	40.23	3146	30.83
Yard: south	498	4.88	885	8.67	1464	14.35	2032	19.91	2555	25.04	2955	28.96	3227	31.62	3336	32.70	2119	20.77
Yard: east	871	8.53	1858	18.21	2663	26.09	3310	32.44	3742	36.67	4002	39.22	4131	40.49	4107	40.25	3085	30.24
Public	1041	10.20	2235	21.91	3096	30.34	3756	36.81	4149	40.66	4357	42.69	4434	43.45	4373	42.85	3430	33.61
Net energy (kBtu)																		
Yard: west	1678	14.80	3872	33.78	5319	46.51	6407	56.14	7026	61.71	7357	64.74	7478	65.90	7434	65.49	5821	51.13
Yard: south	795	7.13	1721	15.02	2865	24.98	3941	34.40	4882	42.70	5588	48.94	6059	53.12	6254	54.84	4013	35.14
Yard: east	1345	12.13	3094	27.59	4470	39.81	5552	49.46	6243	55.65	6669	59.46	6885	61.39	6904	61.47	5145	45.87
Public	1303	12.19	2875	26.76	4130	38.19	5122	47.18	5760	52.89	6195	56.64	6439	58.67	6488	58.91	4789	43.93
Net CO_2 (lb)																		
Yard: west	242	1.81	568	4.26	798	5.98	979	7.34	1097	8.22	1171	8.78	1213	9.10	1225	9.19	911	6.84
Yard: south	119	0.89	271	2.03	460	3.45	642	4.82	806	6.04	933	7.00	1024	7.68	1069	8.02	665	4.99
Yard: east	191	1.43	449	3.37	666	5.00	846	6.34	973	7.30	1062	7.96	1118	8.39	1140	8.55	806	6.04
Public	177	1.33	398	2.98	593	4.45	758	5.68	878	6.59	970	7.28	1034	7.75	1062	7.96	734	5.50
Air pollution (lb)*																		
O_3 uptake	0.0071	0.02	0.03305	0.11	0.09675	0.32	0.17952	0.60	0.28223	0.94	0.41529	1.39	0.54892	1.84	0.71616	2.39	0.28	0.95
NO_2 uptake and avoided	0.25532	0.85	0.62104	2.08	0.91762	3.07	1.16155	3.88	1.33272	4.46	1.45977	4.88	1.54222	5.16	1.5925	5.32	1.11	3.71
SO_2 uptake and avoided	0.15124	0.31	0.39276	0.81	0.58165	1.20	0.73365	1.51	0.83551	1.72	0.90936	1.87	0.955	1.97	0.98166	2.02	0.69	1.43
PM_{10} uptake and avoided	0.03625	0.10	0.09596	0.27	0.16046	0.46	0.25102	0.71	0.35863	1.02	0.4847	1.38	0.63589	1.81	0.80772	2.29	0.35	1.01
VOCs avoided	0.03362	0.13	0.0849	0.32	0.1249	0.47	0.15689	0.59	0.17802	0.67	0.19261	0.72	0.20106	0.75	0.20477	0.77	0.15	0.55
BVOCs released	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Avoided and net uptake	0.484	1.42	1.228	3.59	1.881	5.51	2.483	7.30	2.987	8.81	3.462	10.24	3.883	11.52	4.303	12.80	2.59	7.65
Hydrology (gal)*																		
Rainfall interception	133	0.61	374	1.72	807	3.71	1,394	6.41	2,146	9.87	3,071	14.13	3,987	18.34	5387	24.78	2162	9.95
Esthetics and other																		
Yard	---	9.07	---	15.72	---	20.93	---	24.85	---	27.59	---	29.29	---	30.06	---	30.02	---	23.44
Public	---	10.71	---	18.57	---	24.73	---	29.36	---	32.60	---	34.60	---	35.51	---	35.47	---	27.69
Total benefits																		
Yard: west	---	27.71	---	59.06	---	82.65	---	102.04	---	116.21	---	127.17	---	134.91	---	142.28	---	99.01
Yard: south	---	19.12	---	38.07	---	58.59	---	77.77	---	95.01	---	109.59	---	120.72	---	130.46	---	81.17
Yard: east	---	24.66	---	51.98	---	74.96	---	94.36	---	109.22	---	121.08	---	129.69	---	137.63	---	92.95
Public	---	26.26	---	53.62	---	76.60	---	95.93	---	110.76	---	122.89	---	131.79	---	139.93	---	94.72

Note: Annual values incorporate effects of tree loss. We assume an annual mortality of 1 percent, for a total mortality over 40 years of 40 percent. RU = resource unit.
*Values are the same for yard and public trees.

Table B8—Annual costs for the representative large tree (hackberry)

Costs	Year 5	Year 10	Year 15	Year 20	Year 25	Year 30	Year 35	Year 40	40-year average
Tree and planting*									
Yard	80.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.00
Public	40.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00
Pruning									
Yard	0.34	4.32	4.08	6.86	6.43	6.00	5.57	5.14	4.96
Public	11.88	22.50	21.25	24.00	22.50	21.00	19.50	18.00	20.61
Remove and dispose									
Yard	2.02	3.60	5.14	6.62	8.05	9.44	10.77	12.05	6.59
Public	1.51	2.70	3.85	4.97	6.04	7.08	8.08	9.04	4.96
Pest and disease									
Yard	0.46	0.78	1.06	1.28	1.46	1.60	1.69	1.75	1.18
Public	0.04	0.06	0.08	0.10	0.11	0.12	0.13	0.13	0.09
Infrastructure repair									
Yard	0.12	0.20	0.26	0.32	0.37	0.40	0.42	0.44	0.30
Public	0.58	0.98	1.32	1.60	1.83	2.00	2.12	2.19	1.48
Irrigation									
Yard	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Public	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Cleanup									
Yard	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01
Public	0.02	0.04	0.05	0.06	0.07	0.07	0.08	0.08	0.05
Liability and legal									
Yard	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02
Public	0.06	0.08	0.10	0.11	0.12	0.12	0.13	0.12	0.10
Administration and other									
Yard	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Public	1.83	3.09	4.16	5.04	5.75	6.29	6.66	6.88	4.65
Total costs									
Yard	83.33	8.93	10.57	15.11	16.34	17.47	18.49	19.42	23.10
Public	56.29	29.45	30.81	35.87	36.41	36.68	36.68	36.44	36.99

Note: Annual values incorporate effects of tree loss. We assume an annual mortality of 1 percent, for a total mortality over 40 years of 40 percent.
*Although tree and planting costs occur in year 1, this value was divided by 5 years to derive an average annual cost for the first 5-year period.

Table B9—Annual net benefits for the representative large tree (hackberry)

Net benefits	Year 5	Year 10	Year 15	Year 20	Year 25	Year 30	Year 35	Year 40	40-year average
Yard: west	□56	50	72	87	100	110	116	123	76
Yard: south	□64	29	48	63	79	92	102	111	58
Yard: east	□59	43	64	79	93	104	111	118	70
Public	□30	24	46	60	74	86	95	103	58

Note: Annual values incorporate effects of tree loss. We assume an annual mortality of 1 percent, for a total mortality over 40 years of 40 percent. See tables B7 for annual benefits and table B8 for annual costs.

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