2005 (201) 7: 34-40

Trees With Benefits

An expert examines the energy, watershed and air quality benefits of trees, while recognizing that other economic, social, aesthetic and environmental attributes are of equal or greater importance.

by E. Gregory McPherson

City trees are living umbrellas that protect us from the elements, clean the air and water, and nurture a sense of well-being. Over the past 20 years research has revealed the value of these benefits to the health and pocketbooks of city dwellers. Just as nursery professionals and landscape contractors should understand the principles of tree physiology and management, they should know how city trees improve the quality of life. Moreover, they should understand why the services trees provide are important, as well as how planning and management can optimize benefits beyond aesthetics.

Energy benefits. Energy fuels economic growth and is an essential ingredient for quality of life. Conserving energy by greening our cities is important because it is often more cost-effective than building new power plants. For example, planting 50 million more shade trees in California cities provides savings equivalent to seven 100-megawatt power plants. The cost of peak load reduction is \$63 per kilowatt, considerably less than the \$150 per kilowatt benchmark for cost-effectiveness.

Trees modify climates and conserve the energy use of buildings in three ways (figure, opposite):

- Shading — reduces the amount of radiant energy absorbed and stored by built surfaces.
- Transpiration — converts water to vapor and thus cools by using solar energy that would otherwise result in heating air.
- Wind-speed reduction — reduces the infiltration of outside air into interior spaces and conductive heat loss, especially where thermal conductivity is relatively high, such as with glass windows.

By reducing electricity demand, trees reduce emissions of air pollutants at power plants, as well as their use of water in cooling towers. These avoided emissions can be greater than annual pollutant uptake rates for a mature tree.

Shade trees can provide another benefit — lower concentrations of ozone. The rate of ozone formation increases as air temperatures increase. By cooling the air and shading impervious surfaces such as paving and rooftops, trees can reduce ozone concentrations. Temperature differences of more than 9° have been observed between city centers and more vegetative suburban areas.

For individual buildings, strategically placed trees can increase energy efficiency in summer and winter. The west side of a home is the most important side to shade, where evergreens provide both summer shade and winter wind protection. The east side is the second most important side to shade. Deciduous trees on the east provide summer shade and more winter solar heat gain than evergreens.

In winter, solar access on the southern side of buildings can warm interior spaces. Solar-friendly trees reduce the blocking of winter sunlight. Their traits include open crowns during winter, leaves that are early to drop and late to leaf out, relatively small size and a slow growth rate. Examples include most species and cultivars of maple, honeylocust and ash.

To maximize summer shade and minimize winter shade, locate trees about 10 to 20 feet south of the home. As plants grow taller, prune lower branches to allow more sun to reach the building (provided this will not weaken the tree's structure). At other locations, keep trees at least 5 to 10 feet from the structure to avoid building conflicts, but within 30 to 50 feet to effectively shade windows and walls.

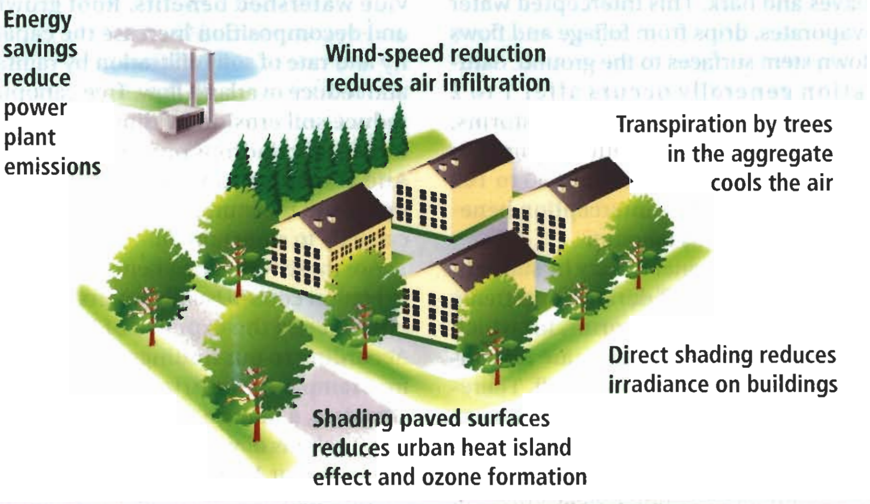
Paved patios and driveways can become heat sinks that warm the home during the day. Shade trees can make them cooler and more comfortable spaces. If a residence has an air conditioner, shade and cooler air temperatures can increase the unit's efficiency — but do not plant vegetation so close that it obstructs airflow around the unit.

Trees planted as windbreaks can reduce heating costs in temperate-climate cities. Windbreaks reduce wind speed and the resulting infiltration of cold air by up to 50 percent, translating into potential annual heating savings of 10 to 12 percent. Windbreak design is influenced by lot size, as many lots are not large enough to plant evergreen windbreaks.

Ideally, the windbreak should be longer than the building being sheltered, planted perpendicular to the prevailing wind and about 25 to 50 feet from the building. It should also consist of dense evergreens that will grow twice the height of the building being sheltered. Most conifers can be spaced about 6 feet on center, with rows spaced 10 to 12 feet apart. Remember that snow collects behind a windbreak. (This can be a problem if a driveway is located between the trees and home.)

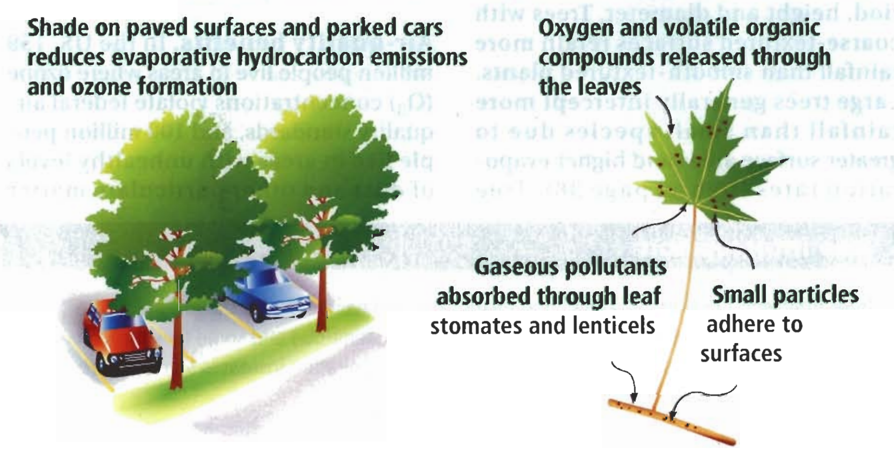
Trees around buildings

Trees save heating and cooling energy by shading buildings, lowering summertime temperatures and reducing wind speeds. Secondary benefits from energy conservation are reduced water consumption and pollutant emissions by power plants.



Tree absorption

Trees absorb gaseous pollutants, retain particles on their surfaces, and release oxygen and volatile organic compounds. Cooling urban heat islands and shading parked cars can reduce ozone formation.



MIKE THOMAS

The amount of energy savings from trees varies regionally, as well as site by site (figure, page 36). Savings are greatest in regions with the largest cooling and heating loads. A computer simulation made by myself and colleagues at the Center for Urban Forest Research (CUFR), USDA Forest Service, Pacific Southwest Research Station in Davis, CA, looked at annual cooling savings for an energy-efficient home in Tucson, AZ. It showed that three 25-foot-tall trees saved $100 each year for cooling — a 25 percent reduction. In Denver, two 25-foot-tall trees saved $15 each year for heating (4 percent savings) and $30 for cooling (24 percent savings). The total $45 savings represented a 9 percent reduction in annual heating and cooling costs.

Watershed benefits. According to federal Clean Water Act regulations, municipalities must obtain a permit for managing storm water discharges into bodies of water. Each city's program must identify which best management practices it will implement to reduce its pollutant discharge. Healthy trees are little 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 (figure, page 36).

Rainfall interception by large trees is a relatively inexpensive first line of defense in the battle to help control pollution. Interception is referred to when rain is stored temporarily on canopy leaves and bark. This intercepted water evaporates, drips from foliage and flows down stem surfaces to the ground. Saturation generally occurs after 1 to 2 inches of rainfall. During large storms, rainfall exceeds the amount required to fill tree crown storage, about 50 to 100 gallons per tree. The interception benefit is limited to this amount.

Trees protect water quality by substantially reducing runoff during less extreme rainfall events. Small storms, for which tree interception is greatest, are responsible for most pollutant wash off. Therefore, urban forests generally produce more benefits through water-quality protection than through flood control.

The amount of rainfall trees intercept depends on their structure, rainfall patterns and climate. Tree crown characteristics that influence interception include trunk, stem and surface areas, textures, amount of gaps, foliation period, height and diameter. Trees with coarse-textured surfaces retain more rainfall than smooth-textured plants. Large trees generally intercept more rainfall than small species due to greater surface areas and higher evaporation rates (figure, page 38). Tree crowns with few gaps reduce throughfall to the ground. In Mediterranean climates, winter rainfall patterns accentuate the value of evergreen species.

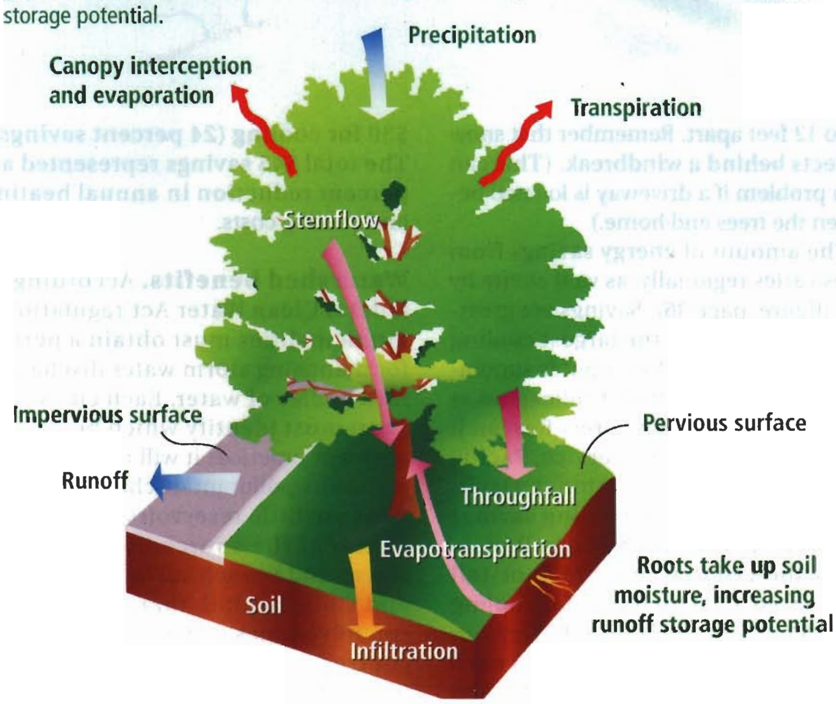
There are other ways that trees provide watershed benefits. Root growth and decomposition increase the capacity and rate of soil infiltration by rainfall and reduce overland flow. Tree canopies reduce soil erosion by diminishing the impact of raindrops on barren surfaces. And transpiration through leaves reduces soil moisture, increasing the soil's capacity to store rainfall.

Are these watershed benefits offset by irrigation costs? Usually watershed benefits exceed the expense of irrigation. According to our findings at the CUFR, for example, in the Arizona desert city of Glendale, a mature mesquite intercepts 1,600 gallons of water annually and consumes about 1,100 gallons through irrigation. Because the price of irrigation water is one-quarter the cost of controlling storm water per gallon, the annual watershed benefit is more than four times greater than the irrigation cost ($7.70 vs. $1.85 per tree).

Air-quality benefits. In the US, 159 million people live in areas where ozone (O_3) concentrations violate federal air-quality standards, and 100 million people live in areas with unhealthy levels of dust and other particulate matter

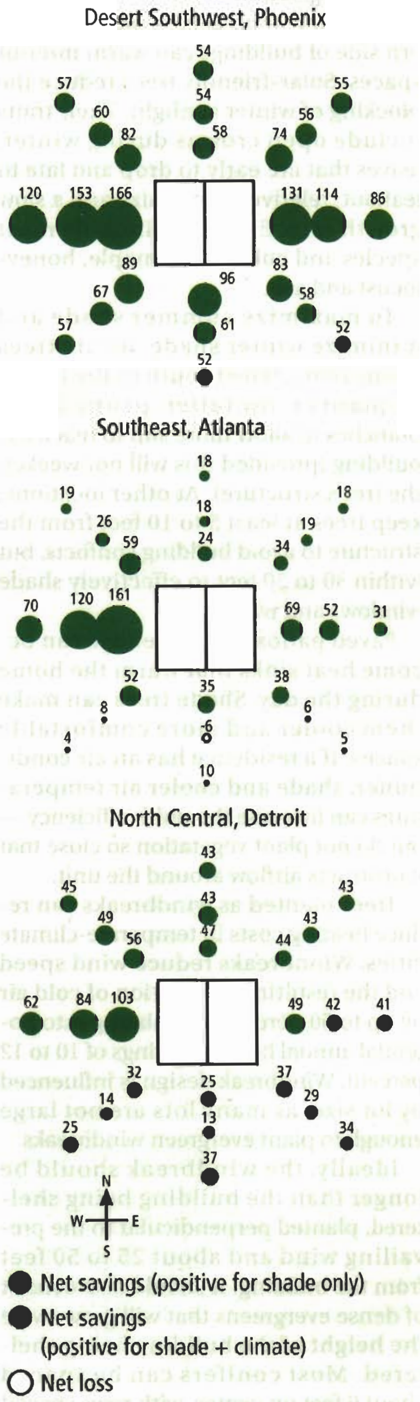
Tree interception

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



Heating and cooling savings

Heating and cooling savings vary by tree location and region. Savings are greatest in warmer climates, for trees opposite west- and east-facing walls, and for trees closest to the building. The circles show avoided carbon dioxide (CO_2) savings (kg/tree/year) for trees at different locations. Circle size is proportional to the magnitude of net benefit due to shade and climate effects on energy use, which, in turn, affects avoided CO_2 emissions. To derive this, modeled are 35-year-old trees at the locations shown around a typical residence in each city.



MIKE THOMAS; SOURCE: CENTER FOR URBAN FOREST RESEARCH

(PM_{10}). Air pollution is a serious health threat to many city dwellers, causing coughing, headaches, respiratory problems and heart disease, as well as cancer. Impaired health results in increased social costs for medical care, greater absenteeism and reduced lifespan.

Trees, sometimes called "the lungs of our cities," are important due to their ability to remove contaminants from the air. Air-quality management districts have funded tree-planting projects to control dust and other small particles. Recently, the EPA recognized tree planting as a measure for reducing O_3 in State Implementation Plans. This creates new opportunities to plant and care for trees as an air-pollution control.

Trees provide air-quality benefits in five ways (figure, page 35):

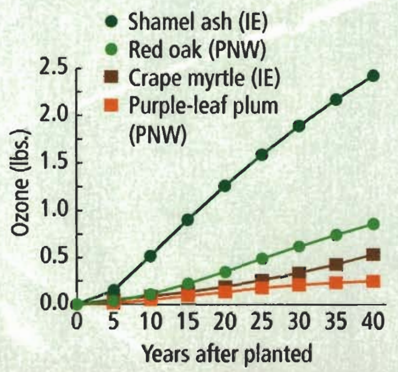
- They absorb gaseous pollutants (such as O_3, nitrogen oxides [NO_x] and sulfur dioxide [SO_2]) through leaf surfaces.
- They intercept particulate matter (such as dust, ash, pollen and smoke) on plant surfaces.
- They release oxygen through photosynthesis.
- They transpire water and shade building surfaces and paving, which lowers local air temperatures, thereby reducing ozone levels.
- They reduce evaporative hydrocarbon emissions from parked vehicles.

In addition, trees can adversely affect air quality. Most trees emit biogenic volatile organic compounds (BVOC) such as isoprenes and monoterpenes that can contribute to ozone formation. The contribution of BVOC emissions from city trees to ozone formation depends on complex geographic and atmospheric interactions that have not been studied in most cities.

Trees also help absorb gaseous pollutants through leaf stomates. Secondary methods of pollutant removal include adsorption of gases through plant surfaces and uptake through bark pores. Once gases enter foliage they diffuse into intercellular spaces, where some react with inner leaf surfaces and others are absorbed by water films to form acids. This is usually good, unless concentrations are toxic. Trees also intercept small airborne particles. Although some particles are absorbed, most adhere to plant surfaces. Species with hairy or rough leaf, twig and bark surfaces are efficient interceptors. Intercepted particles are often thrown into the atmosphere when the wind blows. They can be harmful to people until these particles fall to the ground or are intercepted.

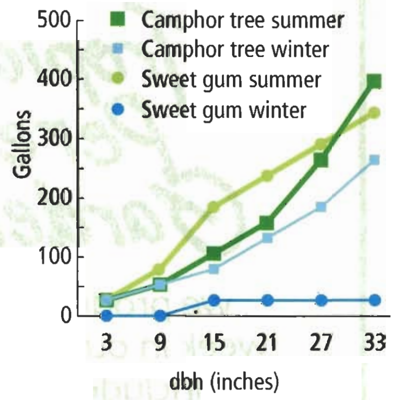
Ozone uptake

Ozone uptake rates reflect tree size, as well as pollutant concentrations. Rates are higher for large-stature trees than small-stature trees. Trees in the more polluted Inland Empire (IE) region of Southern California absorb more ozone than similar-sized trees in the less polluted Pacific Northwest (PNW).



Rainfall interception

This figure shows modeled rainfall interception for different-sized *Cinnamomum camphora* (camphor tree) and *Liquidambar styraciflua* (sweet gum) during similar summer (44 hours, 0.8 inches) and winter (41 hours, 0.85 inches) events in Santa Monica, CA.



The ultimate fate of contaminants transferred from the atmosphere depends on the pollutant. For example, absorbed SO_2 has been associated with sulfur movement throughout the entire tree, including diffusion from roots in the soil. Heavy metals, chloride and fluoride are less mobile, accumulating in leaves until they fall. Materials adhering to plant surfaces are washed off by rainfall, contaminating soil or storm water runoff below the crown. Storm water management, leaf collection and disposal practices influence the fate of these contaminants.

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-foot-tall ash, produces about 260 pounds of net oxygen annually. A typical person consumes 386 pounds 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. Once trees die, oxygen is released through decomposition.

The amount of gaseous pollutants and particulates removed by trees depends on plant size and structure, as well as local meteorology and pollutant concentrations. Ozone uptake rates are high when pollutant concentrations and leaf surface areas are high (figure, left). For example, in our findings in western Washington, where air-pollutant concentrations are low, annual O_3 uptake rates for a 20-year-old red oak and purple-leaf plum were 0.35 pounds and 0.13 pounds, respectively. In Los Angeles, where pollutant concentrations are higher, uptake rates for similar-size shamel ash and crape myrtle were 1.26 pounds and 0.19 pounds, respectively. And in the Chicago area, 50.8 million trees were estimated to remove 234 tons of PM_{10}, 210 tons of O_3, 93 tons of SO_2 and 17 tons of carbon monoxide annually. Dr. David Nowak of the US Forest Service valued this environmental service at $9.2 million.

Parking lots occupy about 10 percent of the land in our cities and act as miniature heat islands and sources of motor vehicle pollutants. By shading cars and lowering parking lot temperatures, trees can reduce evaporative emissions of hydrocarbons (HC) that leak from fuel tanks and hoses. HC emissions are involved in O_3 formation, and parked cars contribute 15 to 20 percent of total motor vehicle HC emissions. Parking lot tree planting is one practical strategy communities can use to meet and sustain mandated air-quality standards.

Greenhouse gas benefits. Human activities and fossil fuel consumption add greenhouse gases to the atmosphere, resulting in gradual temperature increases. This warming is expected to have a number of adverse effects. With 50 to 70 percent of the world's population living in coastal areas, a predicted sea level rise of 6 to 37 inches due to melting polar ice caps could be disastrous. Increasing frequency and duration of extreme weather taxes emergency management resources. Some

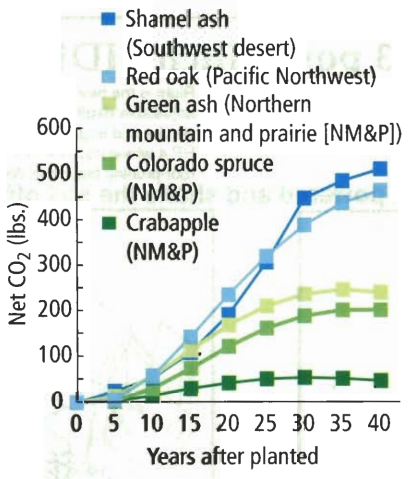
SOURCE: CENTER FOR URBAN FOREST RESEARCH

Saving energy

Trees sequester carbon dioxide (CO_2) 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.

Carbon dioxide uptake

Net carbon dioxide (CO_2) uptake rates for public trees that do not shade buildings reflect the importance of tree growth. Large-stature oak and ash in climates with long growing seasons provide the greatest net CO_2 benefits.



plants and animals may become extinct as habitat becomes restricted.

Urban forests have been recognized as important storage sites for carbon dioxide (CO_2), the primary greenhouse gas. At the same time, private markets dedicated to economically reducing CO_2 emissions are emerging. In 1999, Jim Simpson, research meteorologist at the US Forest Service, and I found that carbon credits were selling for $11 to $20 per metric ton, while the cost for a tree-planting project in Arizona was $19 per metric ton. 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 (figure, above): First, trees directly sequester CO_2 as woody and foliar biomass while they grow. Second, trees near buildings can reduce the demand for heating and air conditioning, thereby reducing emissions associated with electric power production.

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

The rate that trees sequester CO_2 depends on their growth and size at maturity. Large-stature oak and ash in climates with long growing seasons, such as in the Pacific Northwest and Southwest deserts, sequester the most CO_2 (figure, above). Small-stature trees, like crabapple, in regions with shorter growing seasons sequester the least. Sequestration can range from 35 pounds per year for small, slow-growing trees to 800 pounds per year for larger trees growing at their maximum rates.

Regional variations in climate and the mix of fuels that produce energy can have a tenfold effect on CO_2 emission reductions from power plants. Cities in states with relatively high CO_2 emission rates (i.e. Indiana, Kentucky, North Dakota and Wyoming) have greater CO_2 benefits from tree-related electricity savings than those in states with low emission rates (i.e. Idaho, Oregon, Vermont and Washington).

One of the most comprehensive studies of atmospheric CO_2 reduction by an urban forest was conducted in 1998 at the CUFR. It found that 6 million trees in Sacramento, CA, removed approximately 335,000 tons of atmospheric CO_2 annually, with an implied value of $3.3 million. Of the total amount removed, 76 percent was sequestered (an average of 77 to 95 pounds per tree by sector), and 25 percent was due to avoided power plant emissions. The CO_2 released by tree-care activities was 3 percent of the total sequestered and avoided annually. Reduction of CO_2 by Sacramento's urban forest offset 1.8 percent of total CO_2 emitted annually as a byproduct of human consumption. These savings could have been substantially increased through strategic planting and long-term stewardship that maximized future energy savings from new tree plantings.

City trees work ceaselessly, providing environmental services that directly improve human health and the quality of life. Although the annual monetary value of each service is relatively small, total benefits for mature trees usually exceed $100 per tree. On the other hand, annual tree-care costs typically range from $10 to $40 per tree. Therefore, annual benefits are usually two to four times greater than costs. For example, according to a study conducted at the CUFR in 2001, ratios of annual benefits to costs were 1.52:1 in Santa Monica, CA; 1.85:1 in Modesto, CA; 2.18:1 in Fort Collins, CO; and 2.41:1 in Glendale, AZ.

Large trees provide greater benefits than small trees. As residential lot sizes shrink and building footprints grow, however, space for large-stature trees dwindles. Hence, planning public rights of way, parks and open spaces to accommodate large trees is critical.

With proper planning and professional care, trees can be the ultimate multitaskers, cleaning the air while they cool the city, protecting our climate and reducing polluted runoff.

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