Environmental Benefits of Trees in Urban Areas

By Greg McPherson and Jim Geiger

In the past, trees were often included in local plans primarily as beautification elements. Today many planners have realized that trees play a much greater role. They are a critical factor in human health and well being, affecting the overall quality of life in communities.

Over the past 20 years urban tree researchers have learned that trees in urban areas improve air quality, conserve energy, reduce storm water runoff, increase property values, attract businesses, reduce stress, increase healing, and decrease crime. More recently, researchers at the Center for Urban Forest Research have been able to place a dollar value on some of these benefits, such as storm water runoff, air quality, and energy conservation.

This PAS Memo discusses some specific environmental benefits of trees, reinforcing their importance as part of the overall urban infrastructure, specifically for watershed health, energy, air quality, and greenhouse gas reduction. Information on trees in parking lots is also included.

Watershed Benefits

The Clean Water Act regulations require municipalities to obtain a permit for managing their storm water discharges into water bodies. Each community's program must identify which best management practices (BMPs) will be implemented to reduce pollutant discharge. Healthy trees with large leaves and rough surfaces can reduce the amount of runoff and pollutant loading in receiving waters. Trees control runoff at the source by intercepting and storing rainfall, reducing runoff volumes and erosion of watercourses, as well as delaying the onset of peak flows. Rainfall that is stored temporarily on leaf and bark surfaces is called interception. Intercepted water evaporates, drips from leaf surfaces, and flows down stem surfaces to the ground. Saturation generally occurs after 1 to 2 inches of rain have fallen (Xiao et al. 2000). Rainfall interception by large trees is a relatively inexpensive first line of defense in the battle to control nonpoint-source pollution when compared with more expensive solutions like retention basins. Trees intercept a portion of rainfall that evaporates and never reaches the ground. Trees intercept a portion of rainfall that evaporates and never reaches the ground. Some rainfall runs to the ground along branches and some falls through gaps or drips off leaves and branches. Transpiration increases soil moisture storage potential.

Other watershed benefits of trees include:

* Root growth and decomposition increases the capacity and rate of soil infiltration by rainfall and reduces overland flow.
* Tree canopies reduce soil erosion by diminishing the impact of raindrops on barren surfaces.
* Transpiration through tree leaves reduces soil moisture, increasing the soil's capacity to store rainfall.

Watershed Benefits and Irrigation Costs

In most instances, watershed benefits of trees exceed the cost of irrigating them. For example, in Glendale, Arizona, a mature mesquite tree intercepts 1,600 gallons of rainwater annually and consumes about 1,100 gallons through irrigation (McPherson et al. 2004). Because the price of irrigation water ($0.0017) is about one-quarter the cost of controlling storm water ($0.0048), the annual watershed benefit is more than four times greater than the irrigation cost ($7.70 vs. $1.85/tree).

Interception Capacity

During large storm events, rainfall typically exceeds a tree's storage capacity, which is approximately 50 to 100 gallons. In these instances, the benefit is limited to the amount of rain that can be intercepted. However, during less extreme rainfall events, trees intercept a greater percentage of the rain. Because small storms are responsible for most pollutant runoff, the role of trees is critical in protecting water quality by substantially reducing runoff from these smaller storms.

Tree Architecture

The amount of rainfall trees intercept depends on their architecture, rainfall patterns, and climate. Tree crown characteristics that influence interception include:

* surface areas, including trunk and stem,
* textures,
* amount of gaps in the crown,
* foliation period, and
* tree dimensions, including height and diameter.

Trees with coarse textured surfaces retain more rainfall than ones with

smooth surfaces. Tree crowns with few gaps reduce throughfall to the ground. Species that are in-leaf when rainfall is plentiful are more effective than deciduous species that have dropped their leaves. In Mediterranean climates, winter rainfall patterns accentuate the value of evergreen species. Large trees generally intercept more rainfall than small trees because of greater surface areas and higher evaporation rates.
For more information, see Is All Your Rain Going Down the Drain?
http://cufr.ucdavis.edu/products/cufr_392_rain_down_the_drain.pdf>

Energy Benefits

Energy fuels economic growth and is an essential ingredient for quality of life. Greening cities with trees can help conserve this energy, and this technique is often a cost-effective solution. For example, the Center for Urban Forest Research found that strategically planting 50 million more shade trees in California cities on the east and west sides of buildings will provide savings equivalent to seven 100-megawatt power plants (McPherson and Simpson 2003). The cost of peak load reduction is $63/kW, considerably less than the $150/kW benchmark for cost-effectiveness.
For more information, see Green Plants or Power Plants?
<http://cufr.ucdavis.edu/products/3/cufr_148.pdf>

Principal Energy Benefits of Trees

Trees modify climate and conserve building energy use in three principal ways:
* Shading, which reduces the amount of radiant energy absorbed and stored by built surfaces.
* Transpiration, which converts liquid water to water vapor and thus cools by using solar energy that would otherwise result in heating of the air.
* Wind speed reduction, which reduces the infiltration of outside air into interior spaces and conductive heat loss, especially where thermal conductivity is relatively high (e.g., glass windows).

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

Tree Locations for Energy Efficiency

For individual buildings, strategically placed trees can increase energy efficiency in the summer and winter (Sand 1994, Simpson 1998). The west side is the most important side to shade. Plant evergreens to 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 the winter, solar access on the southern side of buildings can warm interior spaces.

"Solar-friendly" trees reduce blocking of winter sunlight. Their traits include open crowns during winter, leaves that drop early in the fall, new leaves that form late the spring, relatively small in height and width, and a slow growth rate. Examples include most species and cultivars of maple (Acer spp.), honey locust (Gleditsia spp.), and hackberry (Celtis spp.).

Locate trees to shade west and east windows, while providing solar access to the south.

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

Windbreaks

Trees planted as windbreaks can reduce heating costs in temperate climate cities. Windbreaks reduce wind speed and resulting infiltration of cold air by up to 50 percent, translating into potential annual heating savings of 10 to 12 percent (Heisler 1986).

Variations in Energy Savings

The amount of energy savings from trees varies regionally, as well as site by site. Savings are greatest in regions with the largest cooling and heating loads. A computer simulation of annual cooling savings for an energy-efficient home in Tucson found that three 25-foot tall trees saved $100 each year for cooling, a 25 percent reduction over previous years without the trees. 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.

Air Quality Benefits

In the U.S., 159 million people live in areas where ozone (O3) concentrations violate federal air quality standards. In addition, 100 million people live in areas with unhealthy levels of dust and other particulate matter (PM10). Air pollution is a serious health threat to many city dwellers, causing coughing, headaches, respiratory and heart disease, and cancer. Impaired health results in increased social costs for medical care, greater absenteeism, and reduced longevity.

Trees, sometimes called the "lungs of our cities," are important because of 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 U.S. Environmental Protection Agency (EPA) recognized tree planting as a measure for reducing O3 in State Implementation Plans (SIPs). This will create new opportunities to plant and care for trees as an air pollution control technology (Luley and Bond 2002). For more information, see Air Pollution Control -The Tree Factor
<http://cufr.ucdavis.edu/products/cufr562_Newsletter_Jan05_Special_Edition.pdf> .

Principal Air Quality Benefits of Trees

Trees provide air quality benefits in five ways:

* Absorbing gaseous pollutants (e.g., O3, nitrogen oxides [NOx], and sulfur dioxide [SO2]) through leaf surfaces.
* Intercepting particulate matter (e.g., dust, ash, pollen, and smoke) on plant surfaces.
* Releasing oxygen through photosynthesis.
* Transpiring water and shading building surfaces and paving, which lowers local air temperatures, thereby reducing ozone levels.
* Reducing evaporative hydrocarbon emissions from parked vehicles.

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 they can reduce ozone formation.

Trees freshen the air we breathe by releasing oxygen as a byproduct of photosynthesis. Net annual oxygen production varies, depending on tree species, size, health, and location. For example, a healthy 32-foot tall ash tree produces about 260 pounds of oxygen annually. A typical person consumes 386 pounds of oxygen per year. Therefore, two medium-sized, healthy ash trees can supply the oxygen required for one person over the course of a year.

Variations in Air Quality Benefits

The amount of gaseous pollutants and particulates removed by trees depends on tree size and architecture, and local meteorology and pollutant concentrations. Uptake rates are high when pollutant concentrations and leaf surface areas are high.

For example, in Western Washington, where air pollutant concentrations are low, annual O3 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 concentrations are higher, uptake rates for the Shamel ash and crape myrtle were 1.26 pounds and 0.19 pounds, respectively (McPherson et al. 2001).

In the Chicago region, 51 million trees remove about 250 tons of PM10, 200 tons of O3, 100 tons of SO2, and 20 tons of carbon monoxide annually. This environmental service is estimated to have an annual value of nearly $10 million (Nowak 1994).

Greenhouse Gas Reduction

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. With 50 to 70 percent of the world's population living in coastal areas, a predicted sea level rise of 6 to 37 inches could be disastrous.

Trees have been recognized as important storage sites for carbon dioxide (CO2), the primary greenhouse gas (Nowak and Crane 2002). At the same time, private markets dedicated to economically reducing CO2 emissions are emerging (McHale 2003). Carbon credits are trading for $0.11 to $20 per metric tonne, while the cost for a tree planting project in Arizona was $19/metric tonne (McPherson and Simpson 1999). As carbon reductions become accredited and prices rise, carbon credit markets could become
monetary resources for community tree programs.

Principal Carbon Dioxide Reduction Benefits of Trees

Urban trees reduce atmospheric CO2 in two ways:

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

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

The rate that trees sequester CO_2 depends on their growth and mature size. Large-stature oak and ash in climates with long growing seasons (Pacific Northwest and Southwest Desert) sequester the most CO_2. Small-stature trees like crabapple in regions with shorter growing seasons (Northern Mountain and Prairie) sequester the least (McPherson et al. 2002, 2003, 2004). Sequestration can range from 35 pounds/year for small, slow-growing trees to 800 pounds/year for larger trees growing at their maximum rate (Nowak 1994).

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 (such as North Dakota, Wyoming, Kentucky, and Indiana) will have greater CO_2 benefits from tree-related electricity savings than those in states with low emission rates (such as Vermont, Idaho, Washington, and Oregon).

As an example of what is happening in one region, Sacramento, California's six million trees remove approximately 335 thousand tons of atmospheric CO_2 annually, with a value of approximately $3.3 million (McPherson 1998). Of the total amount removed, 76 percent is sequestered and 24 percent is from avoided power plant emissions. Carbon dioxide released by tree care activities is only 3 percent of the total sequestered and avoided annually.

The key point here is that the carbon dioxide reduction by Sacramento's trees offset only 1.8 percent of total CO_2 emitted annually as a byproduct of human activity. This offset could be substantially increased by ensuring that tree planting, care, and preservation are an integral part of planning decision making, improving the strategic planting of trees to conserve energy, and committing to long-term stewardship of trees that maximizes future energy savings from new tree plantings.

Parking Lots and Trees

In urban areas, perhaps the greatest benefit from trees is the role they play in reducing the impacts of parking lots. According to a study by the Center for Urban Forest Research, parking lots occupy about 10 percent of the land in our cities. They act as miniature heat islands and are 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 (Scott et al. 1999). HC emissions are involved in O3 formation; 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.

Many parking lot ordinances specify one tree for a certain number of parking spaces or a certain amount of planted area per space. However, under these ordinances, trees can be clustered in islands or along the lot perimeter, often resulting in large areas of unshaded pavement.

To obtain more extensive shade it is necessary to increase tree numbers and provide more soil volume for tree roots, approximately 200 cubic feet (2.5 feet deep) for a 4-inch diameter tree, and about 1,500 cubic feet for a 24-inch diameter tree (see Figure 6). After the trees are installed, it is important that the new trees are pruned early to train their growth, the crowns are allowed to reach their full potential (no drastic pruning that disfigures the tree), and any dead trees are replaced.

Keys to Successful Parking Lot Shading

Perhaps most important make key planning decisions prior to starting the project:
* Provide adequate time to review shade plans and parking lot ratios.
* Certify that parking spaces and trees are located as per the ordinance.
* Inspect, inspect, inspect.

Parking Lot Tree Planting Rules of Thumb

Where appropriate, consult with your local city forester/arborist or other tree expert to address the following:
* Ensure adequate soil volume for tree roots by specifying a minimum planter width of six feet.
* Encourage the use of structural soils <http://www.hort.cornell.edu/uhi/outreach/csc/article.html> , a designed medium that can meet or exceed pavement design and installation requirements while remaining root penetrable and supportive of tree

growth. An additional reference for structural soils is Reducing Infrastructure Damage by Tree Roots <http://www.wcisa.net/pbItem.asp?PubID=5> (Costello and Jones 2003).
* Develop tree planting details and specifications that require loosening a large volume of soil where the tree will be planted. Because soils are heavily compacted prior to paving the lot, planting trees in small holes reduces root extension and poor drainage can kill the trees.
* Install parking lot lighting that does not conflict with required shade tree locations or growth. Light standards no greater than 16 feet in height are strongly encouraged.
* Do not allow planting of trees not on a community's Recommended Tree List (developed by the city forester or arborist). Revise the tree list if necessary.
* Consult the Recommended Tree List to identify tree species suitable for parking lots.
* Be sure crown diameters on parking lot plans correctly reflect crown diameters specified in the tree list. Correct diameters in the tree list if necessary.
* Be sure crown diameters for mature trees are not overstated in the tree list, thus allowing parking lot plans to reflect more shade than they can actually achieve. Correct if necessary.
* Follow up to ensure trees are actually planted and not removed shortly after planting.
* Pay particular attention to trees planted near store fronts, to make sure trees will not obstruct signs.
* Do not allow small-stature trees to be substituted for large-stature trees after the plans have been approved.
* Increase use of one-way aisles, angled parking spaces, and shared parking to reduce overall imperviousness (ULI, 1983; Center for Watershed Protection, 1998).

For more information, see Where Are All the Cool Parking Lots <http://cufr.ucdavis.edu/products/3/cufr_151.pdf> ? In addition, Sacramento's Parking Lot Ordinance: Environmental and Economic Costs of compliance < http://cufr.ucdavis.edu/products/cufr_74_EM01_62.PDF> provides further background.

Two feet of vehicle overhang into planter area is allowed, provided the planter is the correct minimum width. Vehicle overhang is not allowed into required setback areas (City of Sacramento 2002) <http://www.cityofsacramento.org/planning/longrange/shading_guide.pdf>

Planting trees in small holes reduces root extension and poor drainage can kill the trees <http://www.planning.org/practicingplanner/images/apa.icon4.gif> Because soils are heavily compacted prior to paving the lot, planting trees in small holes reduces root extension and poor drainage can kill the trees. Excavating the native soil and planting into the loosened backfill will improve tree growth and establishment (City of Sacramento 2002) <http://www.cityofsacramento.org/planning/longrange/shading_guide.pdf>

Conclusion

City trees work ceaselessly, providing environmental services that directly improve human health and our quality of life. The benefits of trees are directly related to tree size. Larger trees provide greater benefits than smaller trees, other things being equal. Therefore, providing adequate growing space for large-stature trees is critical. As residential lot sizes shrink and building footprints grow, space for large-stature trees dwindles. Hence, planning public rights-of-way, parks, and open space to accommodate large-stature trees is becoming critical. Portland's regional planning authority, Metro <http://www.metro-region.org/> , has a Green Streets <http://www.metro-region.org/article.cfm?ArticleID=262> program that combines narrower streets, pervious paving, and large trees in streetside swales to reduce runoff and treat pollutants. With proper planning and professional care, trees can be the ultimate multi-taskers, cleaning the air while they cool the city, protect our climate, and reduce polluted runoff.

For more information on the benefits of urban trees, visit the Center for Urban Forest Research <http://cufr.ucdavis.edu/> website. For assistance in developing a tree ordinance, see "Guidelines for Developing and Evaluating Tree Ordinances" at http://phytosphere.com/treeord/index.htm.

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How to Contact Local Tree Experts

Many medium to large cities have a city forester/arborist in a city department such as parks and recreation or public works and are available to participate in the local planning process. They are often the source for a community's Recommended Tree List. Local tree expert consultants can also be used in the planning process and are listed in the local phone book. The most reputable ones will have one or more of the following affiliations:

International Society of Arboriculture <http://www.isa-arbor.com/>

Society of Municipal Arborists <http://www.urban-forestry.com/mc/page.do?sitePageId=2806>

American Society of Consulting Arborists <http://www.asca-consultants.org/>

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