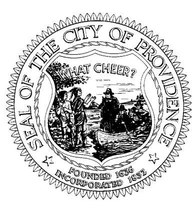
State of Providence's Urban Forest

Report

The 2006 Street Tree Inventory • STRATUM Benefits Analysis
Urban Tree Canopy Study



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Executive Summary

Overview

Understanding the size, distribution, and structure of Providence's urban forest is critical to effectively managing this important resource. Strategic short and long-term planning for street trees as well as the entire urban tree canopy requires us to know how many trees we have, their location, species, condition, and other factors that inform decision-making. For these reasons, the Parks Department conducted an initiative to study the city's trees in three phases: 1) a comprehensive street tree inventory (Providence Tree Tally), 2) an analysis of the environmental benefits and value of street trees (STRATUM), and 3) an urban tree canopy (UTC) study that measures the extent of the city's entire tree population. The description and results of the three efforts are included in this report, The State of Providence's Urban Forest.

Street Tree Inventory Results

- The final count was 24,999 street trees (includes 409 dead trees).
- There were approximately 95 different species. The top ten species account for nearly 75% of all street trees: Norway maple (18.8%), callery pear (11.6%), green ash (8.6%), honeylocust (7.4%), London planetree (7.0%), red maple (5.6%), zelkova (4.4%), flowering cherry (3.8%), littleleaf linden (3.8%), and sugar maple (2.5%).
- Norway maple has been reduced from 46.7% to 18.8% of street trees since 1988, a positive trend toward diversity.
- Maples account for 31.9% of all trees by genus, a diversity concern.
- Survey volunteers rated 23.2% of the trees in excellent condition, 48.9% good condition, 18.9% fair, 7.3% poor, and 1.6% dead.
- Tree diameter size class results show a desirably higher percentage of smaller (or younger) trees, which will help offset mortality over time. 39.9% of trees were 6 inches in diameter or less, and 25.2% of trees were 7 – 12 inches in diameter.
- Utility wires pass above or through 41.5% of the city's street trees.
- Tree planting spaces were most commonly sidewalk pits (52.4%). Additionally, there were 40.1% lawn strips and 7.6% lawn areas with no sidewalk. On average, sidewalk pit cutouts were 16.5 square feet in area and lawn strips were 3.89 feet wide, suggesting that limited growing space is a common problem.
- Over 25% of sidewalks directly adjacent to street trees were damaged in some way (9.8% cracked, 17.18% raised). Tree roots may not be the cause of damage at every location.
- Approximately 8% of street trees had some sort of "vertical treatment" installed around them, including 835 (3.3%) perimeter tree pit guards.
- One of every five street trees (19.1%) had mulch over its root system, and there were 355 (1.4%) tree grates.
- 16.2% of trees were in conflict with surrounding infrastructure of some kind, including 3,002 (12.0%) that were being choked by close pavement.

STRATUM Results

- Providence street trees provide $2.9 million in environmental benefits annually.

Providence STRATUM Analysis - Total Annual Benefits of Street Trees, 2006			
Benefit	**Amount**	**Sub-Value**	**Total Value**
Energy			
Electricity saved	1684 MWh	$202,132	
Natural Gas saved	633,812 therms	$1,026,528	**$1,228,660**
CO2			
CO2 stored	2,180 tons	$14,564	
CO2 avoided	2,527 tons	$16,945	
CO2 released	504 tons	-$3,367	**$28,143**
Air Quality			
Pollution intercepted	29 tons	$101,096	
Pollution avoided	12 tons	$101,863	
BVOC pollution emitted	2 tons	-$8,627	**$194,334**
Stormwater			
Stormwater intercepted	30.6 m. gallons		**$244,945**
Aesthetic/Other			
Incr. property values			**$1,236,649**
		TOTAL	**$2,932,731**

- For every dollar spent on the tree program, Providence is paid back $3.33 in benefits each year.
- The replacement value of Providence's street trees is $81.8 million, an average of $3,274 per tree.
- Street trees store 38,899 tons of carbon.

Urban Tree Canopy (UTC) Study Results

- Providence's total land area has 23% UTC, which is the layer of leaves, branches, etc. that covers the ground when viewed from above.
- There is 53% "possible" UTC (area that could physically have tree cover, minus existing trees, buildings, roads, and water bodies). 24% of Providence is not suitable for UTC.
- Further planning and analysis is needed to determine how much of the 53% "possible" UTC is truly viable for trees, taking into account specific land uses and other social and economic factors.
- More than 3/5 (62%) of the city's existing UTC is found in residential zones, followed by public land (25%), commercial zones (7%), and industrial zones (6%).
- Within land use types (i.e. when analyzed individually), results show residential zones have 26% UTC, public land 40%, commercial zones 11%, and industrial zones 9%.
- "Possible" UTC in residential zones is 47%, public land 12%, commercial zones 22%, and industrial zones 18%. Therefore, residential zones offer the best opportunity for increasing UTC.
- Comparisons of UTC between wards and city neighborhoods show an uneven distribution of UTC across the city.

Chapter 1 – Introduction

Importance of Trees and the Urban Forest

The urban forest confers a wide-range of benefits to the urban environment. These include 1) capturing pollutants in the air, 2) controlling urban microclimates by cooling urban heat sinks, 3) reducing building energy use from air conditioners and heating systems, 4) stimulating economic activity, and 5) acting as carbon sinks (Nowak et al 2000; McPherson et al 1999; Wolf 1999). In addition, trees and tree roots regulate storm water runoff by functioning as detention basins, reducing overland flow and delaying peak flow times (McPherson et al 1999). They prevent soil erosion, act as sound buffers for large urban areas, and provide wildlife habitat for birds and small animals (NADF). Finally, trees add beauty and character to city streets and neighborhoods.

Reducing Pollutants in the Air

Trees remove particulates and gaseous pollutants from the air, improving air quality and decreasing childhood asthma rates (Nowak et al 2000). McPherson et al reported an annual air-pollution uptake of 154 metric tons by the city of Modesto's urban forest or approximately 3.7lb/tree/yr. This equates to an implied value of $1.48 million ($16/tree) (McPherson et al 1999). A separate study of Brooklyn, NY conducted by Nowak in 2000 reported similar results. Brooklyn's trees remove an estimated 254 tons of pollution a year conferring $1.31 million worth of benefits to its inhabitants (Nowak et al 2000).

Controlling Urban Microclimates

Trees regulate air temperature in cities by providing shade, therefore counteracting increased temperatures caused by heat absorbed and radiated from pavement and buildings, known as the urban heat island effect. A study in New York City that measured microclimates along city streets recorded temperature variations as high as 21^{o}F between surfaces shaded by trees and unshaded surfaces found on the same street (Bassuk et al 1987). In addition, McPherson et al found that peak summer air temperatures were reduced .1^{o}C for every 1% increase in canopy cover (McPherson et al 1999). This cooling results in more comfortable environments for pedestrians on city streets in the heat of the summer.

Eastern White Pine

Reducing Building Energy Use

Trees also cool buildings through shading and evaporative processes, resulting in decreased energy use from air conditioners (Simpson et al 1998). Another study showed that shading of buildings resulted in an average decrease in energy use of 1222 kWh/tree, equating to $10/tree (McPherson et al 1999). According to the USDA, the evaporation from a single large tree can produce a cooling effect of 10 room-size air conditioners operating 20 hrs/day (NADF).

Carbon Sequestration

In addition to the regulation of microclimates, trees help regulate the global environment. Climate scientists believe that increased levels of greenhouse gases in the atmosphere such as CO_2 have been one of the primary contributors to global warming. Trees draw CO_2 from the air during photosynthesis and sequester it their trunks and roots (Stavins et al). In Modesto, McPherson et al found that this service was equivalent to $5 in benefits per tree (McPherson et al 1999).

Stimulating Economic Activity

In addition to their environmental benefits, trees also stimulate economic activity. Well-treed homes are known to have appraised values between 6%-12% higher than the other residential properties (NADF). In addition, a 1999 study by Kathleen L. Wolf from the University of Washington found that trees in commercial districts spur economic development by creating a more welcoming retail environment. Consumers consistently rated images of well-treed streetscapes higher than those with little to no vegetation. Furthermore, when asked to price 15 goods that were paired with each image, respondents priced similar items an average of 12% higher for well-treed storefronts over poorly treed ones (Wolf 1999).

Westminster Street, Downtown

Providence: A Brief Tree and Landscape History

Providence is the second largest city in New England, with an area of 18.47 square miles and a population of 173,618 (2000 Census). Located at the top of Narragansett Bay, the city is part of the coastal lowland of Rhode Island's Narragansett Basin. Comprised of seven major hills and predominantly sandy soils, Providence serves as the meeting point for several rivers: the Woonasquatucket River meets the Moshassuck River to form the Providence River, which joins the Seekonk River at the mouth of Narragansett Bay.

Providence is located in USDA Hardiness Zone 6, with a growing season of approximately 190 days from the end of April to mid-October. It is dominated by temperate deciduous tree species, including oak, maple, cherry, and birch. Although in constant change, the native forest type to the area was most likely oak-chestnut, and would have included white pine, red maple, black and yellow birch, and other species. However, increased population density following the turn of the century, in addition to species specific tree epidemics such as Dutch elm disease and chestnut blight, have greatly altered Providence's urban forest composition over the last 100 years.

Downtown Trees in Tree Pits

Providence's streetscape reflects a long and rich history stretching from the largely agricultural colonial period through the industrial era to its recent renaissance over the last 20 years. Street trees are located along roughly 370 miles of streets that make their way through the downtown and its 25 neighborhoods. Although primarily residential, most districts also house commercial zones. There are seven historic districts in Providence, as well as substantial industrial zoning concentrated near its major waterways. Although not specifically zoned as such, there is substantial institutional land acreage that houses college campuses, private schools, and hospitals.

In commercial and industrial zones, trees grow primarily in sidewalk tree pits. In contrast, tree lawns (under 4 feet wide on average) are common in residential neighborhoods throughout the rest of the city. The small square footage of both these site types often limits rooting space for large shade trees. Exceptions to this trend are

Blackstone Boulevard and Pleasant Valley Parkway, which contain wide, park-like planting strips in their centers that are maintained with considerable tree cover.

The Providence public park system also contains a significant portion of Providence's urban forest. The Parks Department oversees 1,200 acres and 112 park spaces, including 97 neighborhood parks, 11 downtown parks, 2 cemeteries, and the 430 acre Roger Williams Park. Two of these parks, Blackstone Park and Neutaconkanut Park, are designated conservation districts with large amounts of forest cover.

In 1901, Providence was home to over 50,000 trees according to archival information from the Providence Journal Bulletin. However, a sample survey of street trees performed by the City Forester in the mid-1970's found that the number dipped to a low of approximately 16,500. Providence regained a portion of its lost canopy by 1988, when a citywide inventory recorded 22,320 street trees. In 1989, a new partnership between the City and the Mary Elizabeth Sharpe Street Tree Endowment increased the rate of tree planting in the city to approximately 450 per year. In 1999-2000, a preliminary urban forest cover analysis conducted by the Providence Plan and other partners using remote sensing data and GIS mapping found that Providence had 18% canopy coverage. In addition, it showed that 60% of Providence trees were on private property, rather than in the public right of way or in public parks.

Benefit Street

Chapter 2 – The 2006 Street Tree Inventory

Background

The 1988 Street Tree Inventory

In 1988, the Providence Parks Department hired a private environmental consulting firm to inventory its urban forest. These specialists surveyed tree location, species, size, maintenance requirements, condition, and presence of overhead wires with the goal of creating an information-based management plan. The study found 22,320 street trees in Providence and 20,110 potential planting locations. The overall forest was relatively mature, with 60.1% of trees in size classes 6 inches diameter or greater. Overall diversity was poor, with 62% of the population in the maple genus. However, 72.1% of trees were rated in good or better condition. The resulting plan outlined goals and strategies for reducing tree hazard liability, producing accurate budget projections, and increasing tree survival and vigor.

A Pilot Project – The Downtown Tree Study

Inventory Volunteers

From fall 2005 through spring 2006, the Providence Parks Department partnered with the Downtown Improvement District, the Providence Foundation, community volunteers, and the Groundwork Providence E-team to survey all street trees in Providence's downtown district. In total, they found 1,182 trees, 61 empty pits, 69 sites containing stumps or dead trees, and 718 potential planting locations.

Within the downtown district, surveyors found 18 different tree species. However, 5 dominant species accounted for 76.3% of the population. The most common species were callery pear (21.4%), london planetree (15.7%), littleleaf linden (13.9%), honeylocust (12.9%), and green ash (12.4%). 72.9% of the trees were in excellent or good condition, but 49.8% were in smaller size classes, less than 6 inches in diameter. These findings formed the basis for the resulting Downtown Tree Management Plan, which sought to address the particular needs of the downtown forest, including goals and strategies for increasing the number of trees, species diversity, and the proportion of large, mature trees. A top priority was the removal of stumps, dead trees, and trees rated in poor condition. The study and its methods served as a model for the subsequent 2006 citywide street tree inventory.

2006 Street Tree Inventory Methods

In May 2006, the Providence Parks Department recruited and trained nearly 100 citizen volunteers to conduct a comprehensive inventory of Providence street trees. Three summer interns were also hired to assist in the survey, as well as a volunteer coordinator to manage the effort. From May through October, volunteers and interns surveyed all trees in the public right-of-way, including trees within medians and traffic triangles. All trees located in sidewalks were counted, or within 6 feet of the street at locations where no sidewalk existed (Fig. 2).

Volunteers underwent 5 total hours of training, including a 3-hour indoor training and a 2-hour field training. They were instructed to record data using Palm Pilots (Zire 31) programmed with Pendragon Forms software. In addition to a Palm Pilot, each volunteer pair was provided with a diameter tape, tree identification guide, and an assigned zone map. Volunteers were taught the fundamentals of tree identification and other inventory assessment techniques.

Figure 1. An inventory zone map.

Working in pairs or individually, volunteers surveyed 101 distinct zones in Providence, each zone averaging approximately 300 trees. Within their zone, they recorded tree location based on building address, species, diameter, condition and infrastructure factors affecting trees. Dead trees, stumps, and empty pits were also identified.

Upon completion of the inventory, the City Forester analyzed the data with the assistance of Provstat (the City's data management division), employing the USDA Forest Service's benefits analysis software, STRATUM (see Chapter 2). Environmental benefits provided by Providence's street trees were quantified using street tree inventory data and region specific information such a climate data and utility rates.

Inventory Results

Number of Trees

Volunteers and Parks staff counted a total of 24,999 street trees. The final number includes 409 standing dead trees. Compared to 22,320 street trees counted in the 1988 inventory, the 2006 number represents a 12.0% increase in the past 18 years. Trees are concentrated in residential neighborhoods rather than the downtown, commercial, or industrial zones. Street tree density (Fig. 2, calculated by trees per acre) is highest within most East Side neighborhoods, as well as Elmhurst, Elmwood, and the West End near Dexter Training Ground.

Providence Parks Department - Street Tree Density
Tree Tally 2006

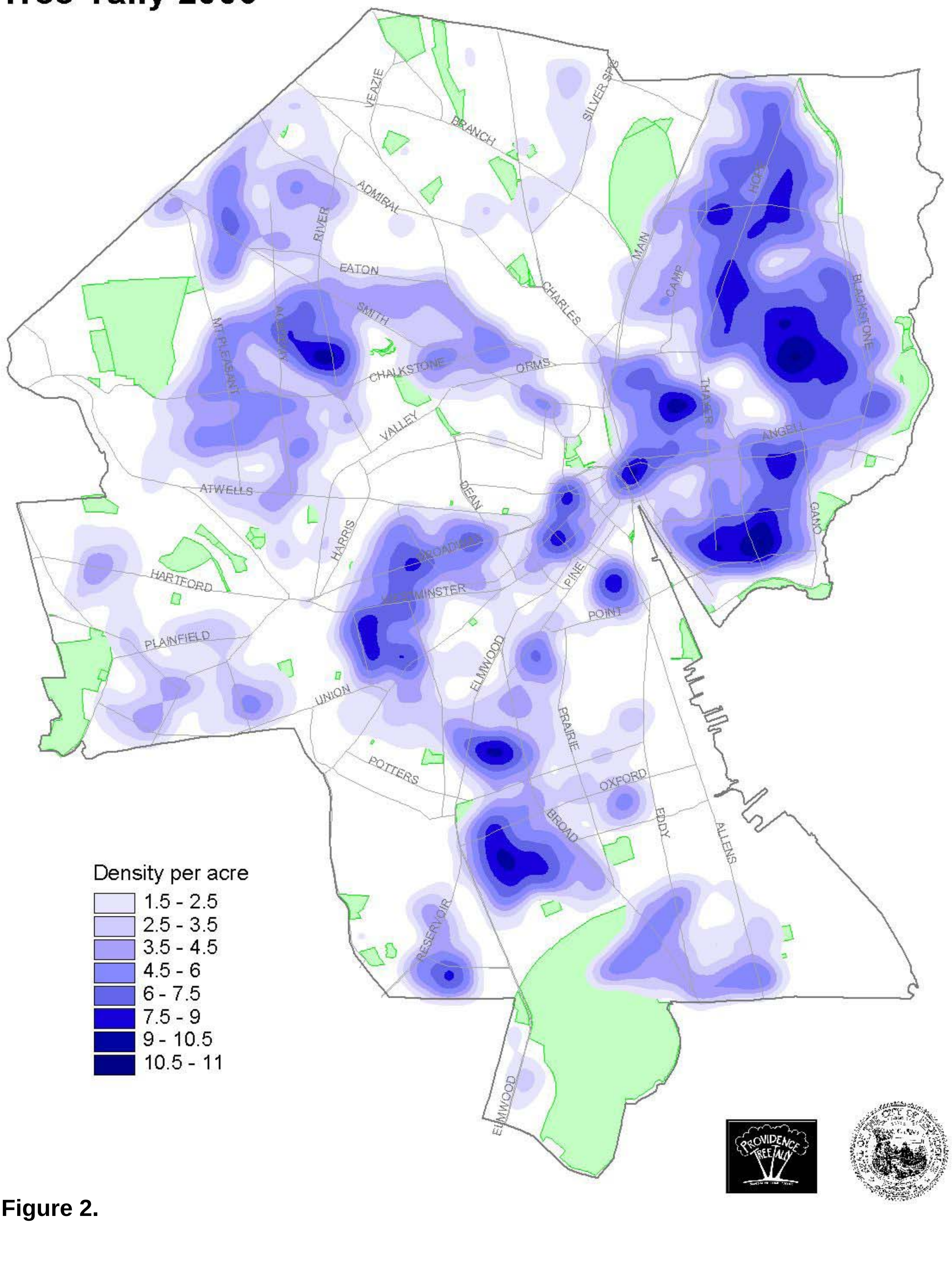


Figure 2.

Species

There are approximately 95 different tree species growing on the streets of Providence (Fig. 2), nearly twice the mean of 53 species reported by McPherson and Rowntree (1989) in their nationwide survey of street tree populations in 22 U.S. cities. However, the majority of trees are comprised of a much smaller number of species. The top ten species account for nearly 75% of all trees (Fig. 3).

Species diversity is critically important for the health and resiliency of the urban forest. A diverse population of trees can create a buffer against a potential disease or insect outbreak that affects one species or genus of tree. Some historic examples are Dutch Elm Disease (American elm), Chestnut Blight (chestnut), Asian Longhorned beetle (predominately maples), and Emerald Ash Borer (ash). A common guideline in urban forestry used to measure species diversity against the risks of monoculture is the “10-20-30” rule, whereby no more 10% of any species, 20% of any genus, or 30% of any botanical family is represented in a population.

Norway maple is the dominant street tree species in Providence at 18.8%. However, this is significantly less than the percentage found in 1988 (46.7%), a favorable trend. Norway maple was planted heavily in the mid-20th century as a replacement for the American elm, which suffered devastating losses due to Dutch Elm Disease. Many of these same Norway maples are past maturity and are in decline. Although a solid performer in terms of survivability and shade, the Norway maple is now rarely planted due to problems associated with heaving sidewalks, an aggressive tendency to invade woodlands, and diversity issues.

Conversely, the predominance of callery pear has increased greatly since 1988, from 1.9% to 11.6%. The popularity of callery pear is due to ease of transplanting, good survival rate, and showy white flowers in spring. Its drawbacks, especially for the cultivar ‘Bradford,” are poor structure, small size relative to other shade trees, and a shorter lifespan. Its use should be moderated to reduce its numbers.

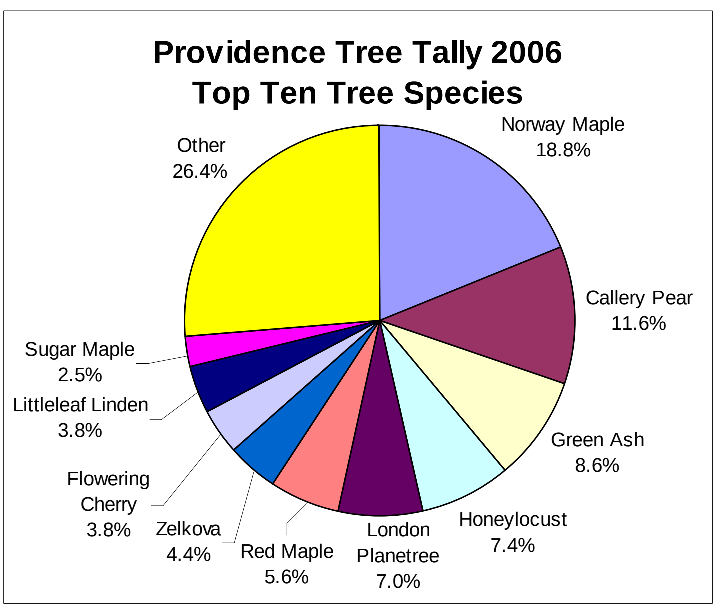


Figure 3.

The distribution of street tree by genus also looks relatively desirable when measured against the 20% goal of the "10-20-30" guideline (Fig. 4). The exception is maple (31.9%). The trend is downward, however, as approximately 62% of trees in 1988 were maple.

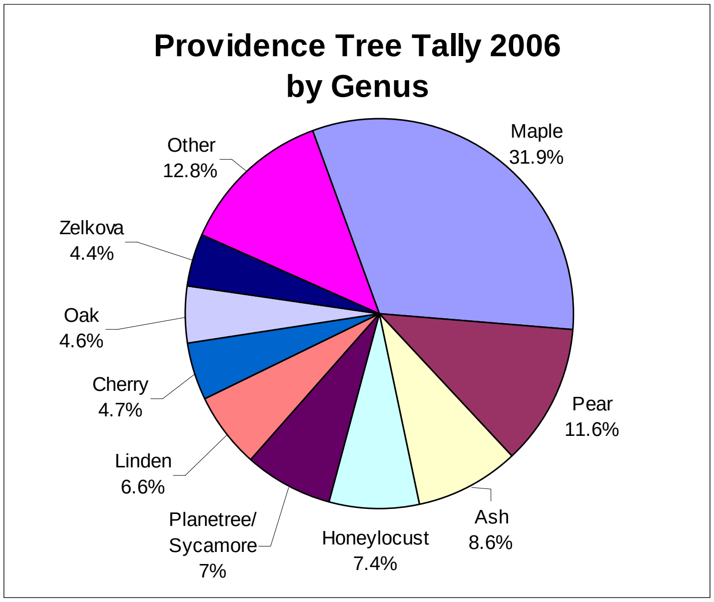


Figure 4.

Condition

Tree condition indicates a judgment of overall tree health based on the percentage of dead branches, the fullness and appearance of the crown, symmetry, and the existence of wounds or cavities on the trunk, major branches, and root flare. Designed for use by volunteers, the condition categories were excellent, good, fair, poor, and dead. The intent is to determine a broad assessment of street tree population health and identify dead trees, not to identify hazard trees or formulate risk assessment strategies, which require trained professional judgment. Trees were placed into categories based on the criteria by the New York City Parks Department:

- *Excellent* **–** full, well-balanced crown and limb structure; leaves normal size and color; few to no dead or broken branches; trunk solid; bark intact.
- *Good* **–** crown somewhat uneven or misshapen; some mechanical damage to bark or trunk; some signs of insects or disease; leaves somewhat below normal size and quantity; less than 20% dead or broken branches.
- *Fair* **–** crown uneven or misshapen; significant damage to the bark or trunk; leaves below normal size and quantity; between 20%-50% dead or broken branches.
- *Poor* **–** tree in irreversible decline; more than ½ of the tree already dead or removed; large cavities; major deformities; severe insect or disease damage.
- *Dead* **–** leaves absent; twigs dry and brittle.

According to the survey volunteers, the condition of trees in Providence is very good. More than 2/3 (72.1%) of street trees are in either good (48.9%) or excellent (23.2%) condition. Condition ratings are higher than they were in 1988, when 59.2% of trees were rated either good or excellent. One could conclude that trees received improved care during this period, compared to pre-1988. The reduction in the large, declining Norway maple population may have a part in the current upward swing in condition class. Another explanation may be that volunteers generally rate tree condition more favorably than the professional arborists who performed the 1988 survey, as volunteers are less likely to notice structural problems or signs of decay. Lastly, the recent surge in new tree planting (approximately 1,100 per year) is evident in the size class comparison between the two surveys, and young trees are most likely assessed as “excellent” (Fig. 5). The percentage of dead trees is almost identical to 1988.

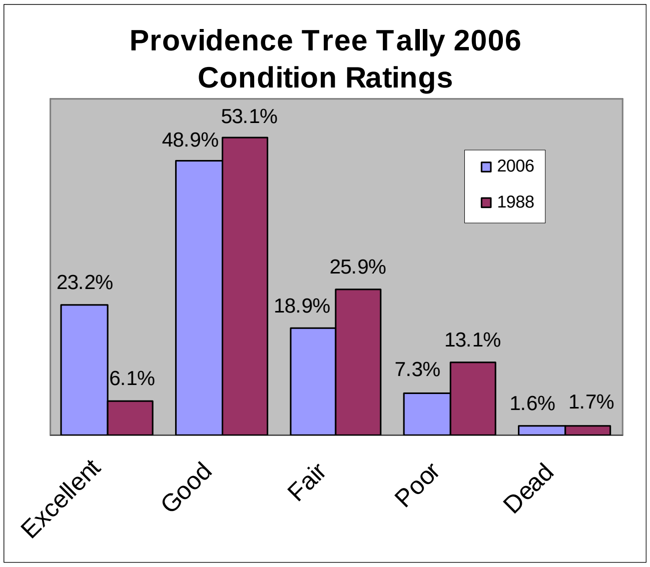


Figure 5.

Diameter

The diameter of each tree was measured at 4.5 feet above the ground (diameter at breast height, or dbh) with a diameter tape that converts circumference to diameter. Separated into age classes (Fig. 6), the inventory shows that trees are weighted toward the smaller diameter size classes, with 2/5 (39.9%) 6 inches dbh or less, and nearly 2/3 (65.1%) 12 inches dbh or less. Less than 3% are greater than 30 inches in diameter. A size class distribution curve of the sort with an uneven-aged population of trees (using size as an indicator of age) is important in terms of managing continuous canopy cover with steady maintenance practices and uniform costs. A high proportion of young trees is desirable in order to offset mortality over time, while the percentage of older trees declines with age (Richards 1982/83). Compared to an ideal percentage of 40% for trees within the 0-6 inch range (Center for Urban Forest Research, Pacific Southwest Research Station), Providence’s street tree population is almost right on target (39.9%). It is a long-term management goal to increase the number (although not necessarily the percentage) of trees in the largest size categories.

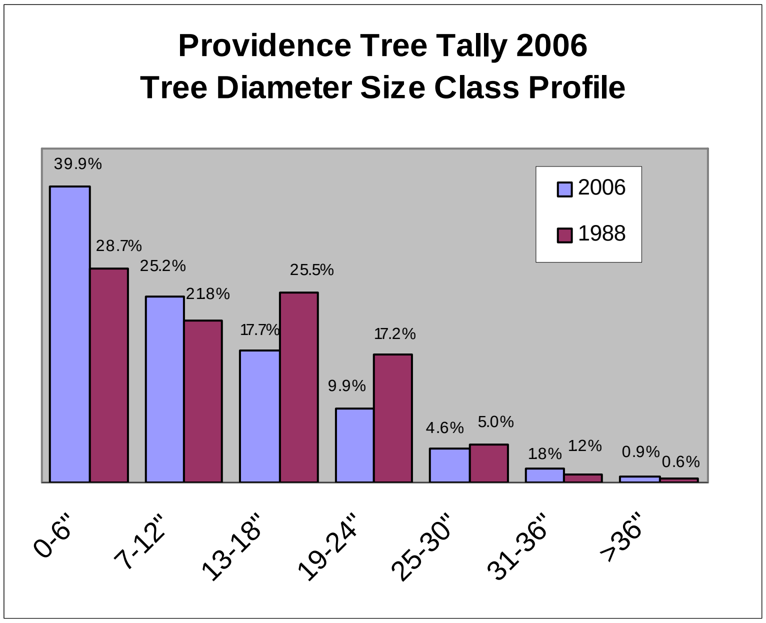


Figure 6.

Utility Wires

Overhead wires are common throughout Providence and can pose a serious conflict with street tree canopy. Line clearance pruning by utility companies is necessary but often compromises the structure of large shade trees. Proper species selection is crucial for avoiding future conflicts with wires. Improved enforcement of pruning standards by utility companies and better communication with the City's Forestry Division has resulted in better practices. Knowledge of where conflicts exist, as provided by the inventory, is important for this continued collaboration.

Inventory volunteers recorded when utility wires pass through or above street trees (house tap wires were not recorded). They found 41.5% of trees located below utility wires, a 20.8% decrease since 1988 (Fig. 7). Most likely, the decrease is due to more appropriate planting location decisions made by Forestry personnel.

Providence Tree Tally 2006 - Trees Below Utility Wires				
	2006		1988	
	#	%	#	%
Yes	10,371	41.5%	13,903	62.3%
No	14,628	58.5%	8,417	37.7%
Total	**24,999**	**100.0%**	**22,320**	**100.0%**

Figure 7.

Planting Space

Planting space is one of the most salient determinants of street tree health. Insufficient space can limit rainwater infiltration and root development, hampering growth and decreasing lifespan. In addition, when space is limited, street trees can interfere with urban infrastructure such as pavement, resulting in cracking or sidewalk heaving.

Lawn Strip

In Providence, there are three primary types of planting locations: sidewalk pits, lawn strips, and lawn areas with no sidewalk. Providing the most amount of space, lawn areas were the least common type of planting location (7.6%). Sidewalk pits were the most common planting location type (52.4%), followed by lawn strips at 40.1% (Fig. 8). Citywide, lawn strips averaged 3.89 ft in width, while sidewalk pits averaged 16.5 sq ft in area. Presently, Forestry maintains a minimum standard of 24 sq ft for new tree pits, employing even larger pits where space allows, and has instituted a "tree rescue" program that retroactively expands tree pits for large trees. These efforts strive to increase the number of long-lived, mature trees in Providence.

Providence Tree Tally 2006 - Planting Space Type			
	#	**%**	**Avg. Dimension**
Sidewalk Pit	14,403	52.4%	16.5 sf.
Lawn Strip	11,013	40.1%	3.89 ft.
Lawn Area (no sidewalk)	2,078	7.6%	
Total	**27,494**	**100.0%**	

Figure 8.

Sidewalk Condition

Maximizing planting space for trees while maintaining the public right-of-way is a significant challenge for tree resource managers. Trees can heave or crack sidewalks when planting space is inadequate and the resulting sidewalk repairs can injure tree roots and compact soil. However, increased planting space and appropriate tree selection can improve sidewalk integrity and maximize tree health by reducing future sidewalk replacement.

Inventory volunteers rated 63.9% of sidewalks adjacent to trees in good condition, 9.8% were cracked, and 17.8% were raised (Fig. 9). Planting locations without sidewalks account for the remaining 8.5%. It is unclear whether all of the damage to sidewalks adjacent to trees is due to tree root interference, or if other forces contributed to the condition, such as natural weathering, high impact pedestrian activity, vehicle damage, or other factors.

Providence Tree Tally 2006 - Sidewalk Condition		
	#	**%**
Good	15,974	63.9%
Cracked	2,452	9.8%
Raised	4,445	17.8%
No sidewalk	2,128	8.5%
Total	**24,999**	**100.0%**

Figure 9.

Vertical & Horizontal Treatments

City trees face numerous health threats from the congested urban environment, including damage from cars, bikes, pedestrian traffic, dogs, compacted soils, and many other factors. Vertical and horizontal treatments can provide protection from injury and prolong the life of trees. Vertical treatments, such as bollards, can protect trees from car doors and motor vehicle accidents, and perimeter tree pit guards can restrict pedestrian access, preventing soil compaction and dog-related damage. In addition, regular mulching of tree pits can retain soil moisture, promoting root growth and overall tree health. However if improperly installed, vertical and horizontal treatments can actually impair tree growth. Tree guards and grates positioned too close to tree trunks may choke them as they grow.

In Providence, 92.6% of trees have no vertical treatments, 3.3% have perimeters guards, and 2.0% of have a low wall (Fig. 10). In contrast, only 66.9% of trees have no horizontal treatment, 19.1% are mulched, 9.7% have plantings at their base, and 7.5% have bricks or blocks around their perimeter (Fig. 11). Although not all trees require vertical protection, installation of tree pit guards and other properly managed treatments can greatly benefit tree health and vigor, particularly in high traffic commercial districts.

Bollards

Providence Tree Tally 2006 - Vertical Treatments		
	#	%
Bollards	268	1.1%
Low Wall	497	2.0%
Perimeter Guard	835	3.3%
Tall Guard	275	1.1%
Other	239	1.0%
None	23,147	92.6%
Total	**25,261**	**N/A**

Figure 10.

Providence Tree Tally 2006 - Horizontal Treatments		
	#	%
Bricks or Blocks	1,881	7.5%
Grate	355	1.4%
Mulch	4,784	19.1%
Plantings	2,426	9.7%
Other	578	2.3%
None	16,729	66.9%
Total	**26,753**	**N/A**

Figure 11.

Infrastructure Conflicts

Infrastructure conflicts from choking tree grates, guy wires, and close pavement can compromise the health of a tree by restricting its growth. However, similar to overhead wires, proper species selection, site improvements, and public education can greatly decrease the risk of tree injury by urban infrastructure.

Volunteers found that 83.8% of trees were free of infrastructure conflicts (Fig. 12). Close paving accounted for 12.0% of these conflicts, while 3.2% had debris in their canopy, and 1.1% had supporting stakes and ties that had been left on too long and were girdling the tree. In addition, although occurring at a rate of less than 1%, choking grates, choking guy wires, electrical outlets, and tree lights also threatened Providence's street trees. The City will use this data to provide remedial treatment.

Providence Tree Tally 2006 - Infrastructure Conflicts		
	#	%
Awning/Sign	120	0.5%
Canopy Debris	806	3.2%
Choking Grates	128	0.5%
Choking Guy Wires	7	0.0%
Choking Stake Ties	272	1.1%
Close Paving	3,002	12.0%
Electrical Outlet	77	0.3%
Tree Lights	83	0.3%
None	20,939	83.8%
Total	**25,434**	**N/A**

Figure 12.

Choking Tree Grate

Chapter 4 – Resource Function and Value

STRATUM

STRATUM is a computer application developed by the USDA Forest Service's Southwest Pacific Research Station that analyzes the structure, function, and value of a street tree population based on inventory data. The program calculates the environmental benefits of trees, and uses regional tree data, climate data, local utility rates, property values, and annual forestry expenses to derive its results and provide cost-benefit ratios. STRATUM enables tree resource managers to make information-based decisions about program expenditures and future investment of resources.

Goldenraintree leaf

U.S. Forest Service researchers have illuminated clear environmental and value-based incentives for urban trees, especially large, mature trees that provide the most canopy. In the Northeastern United States, large shade trees at 40 years of age produce on average 5x more benefits annually than small trees, such as cherries and crabapples, of a comparable age (McPherson et al, 2007). Additionally, on average, large, shade trees have longer life spans than ornamental trees, providing more benefits over the course of their lifetimes due to exponentially greater foliage and biomass.

FUNCTION AND VALUE OF STREET TREES IN PROVIDENCE

In the spring of 2007, A STRATUM analysis was conducted using the 2006 street tree inventory data. Environmental benefits and resource value were quantified.

Energy Savings

Regional energy prices and typical energy use data was used in the STRATUM model to calculate energy savings and value. In the summer, trees reduce electricity costs by decreasing the demand for air conditioning and fans. Trees provide shade and combat the urban heat island effect, which is caused by the absorption of radiant energy by built surfaces. In addition, leaf transpiration uses solar energy that would otherwise contribute to higher temperatures. In the winter, trees serve as windbreaks, inhibiting the movement of outside air into buildings and reducing heat loss.

Each year, Providence's street trees contribute $1,228,660 in energy savings. $1,026,528 is saved from reduced consumption of natural gas in the winter, equivalent to 633,813 therms of avoided heat loss (Fig. 13). The remaining $202,132 is from the 1,684 MWh of decreased electricity use due to lower ambient temperatures during warm months.

Providence STRATUM Analysis - Total Annual Benefits of Street Trees, 2006			
Benefit	**Amount**	**Sub-Value**	**Total Value**
Energy			
Electricity saved	1684 MWh	$202,132	
Natural Gas saved	633,812 therms	$1,026,528	**$1,228,660**
CO2			
CO2 stored	2,180 tons	$14,564	
CO2 avoided	2,527 tons	$16,945	
CO2 released	504 tons	-$3,367	**$28,143**
Air Quality			
Pollution intercepted	29 tons	$101,096	
Pollution avoided	12 tons	$101,863	
BVOC pollution emitted	2 tons	-$8,627	**$194,334**
Stormwater			
Stormwater intercepted	30.6 m. gallons		**$244,945**
Aesthetic/Other			
Incr. property values			**$1,236,649**
		TOTAL	**$2,932,731**

Figure 13.

Atmospheric Carbon Dioxide Reduction

On a global level, trees help combat global climate change by sequestering atmospheric CO_2 in their woody biomass. Additionally, they reduce CO_2 emissions from power production and natural gas consumption by reducing overall energy use.

Providence's street trees provide $28,143 of benefits annually in atmospheric CO_2 reduction. 2,180 tons of CO_2 are stored in the City's street trees annually, and 2,527 tons are avoided each year through reduced energy use. In total, the net reduction of CO_2 produced by street trees amounts to 4,203 tons, marginally reduced by the 504 tons of CO_2 emissions associated with annual tree planting and maintenance, including vehicle, chainsaw, chipper, and other equipment use. However, the amount of CO_2 released during maintenance is offset 9-fold by the amount of CO_2 avoided and stored by the trees.

In total, 38,899 tons of carbon are stored in the street tree population.

Air Quality Improvement

Trees directly improve local air quality by absorbing gaseous pollutants such as nitrogen dioxide (NO_2), and by intercepting airborne particulates. In addition, trees indirectly contribute to better air quality by reducing ground-level ozone (O_3) levels that are exacerbated by high ambient air temperatures. However, slightly reducing the sum of these benefits, trees produce biogenic volatile organic compounds (BVOC), which can contribute to O_3 formation and reduce air quality. The STRATUM model calculates air pollutant emissions based on the regional mix of fuels used to produce electricity, natural gas consumption, and hourly weather data.

In Providence, street trees intercept 29 tons of pollution and avoid 12 tons of pollution each year, totaling $202,959 in savings based on the estimated cost of meeting the Environmental Protection Agency's air quality standards. Taking into account the 2 tons of pollution created by BVOC emissions, Providence street trees net $194,334 in air quality benefits annually.

Stormwater Runoff Reductions

In urban areas with large amounts of impervious surface, high stormwater runoff is a large concern regarding the health of local waterways. Providence uses a combined sewer system wherein large influxes of stormwater can result in periodic sewage overflows. However, trees act as mini-reservoirs that uptake water and facilitate water infiltration into the soil. Leaves and branches intercept rainfall, delaying peak flows and reducing the likelihood of storm drain or combined-sewer overflows. In addition, root growth and decomposition increases rainwater infiltration, redirecting flow away from the sewer system. Trees also act as soil stabilizers, preventing soil loss during storm events. Each year, Providence's street trees intercept 30.6 million gallons of stormwater runoff, equivalent to a replacement value of $244,495 for the above listed services.

Aesthetic, Property Value, Social, Economic and Other Benefits

The greatest economic value provided by Providence's street trees relates to aesthetic, property value, social, and economic benefits. Among these are beautification, improved human health, privacy, increased comfort due to shade provision, and sense of place. Using species-specific data about annual increases in leaf area and research comparing differences in sale prices of homes with and without trees, STRATUM estimates homeowners "willingness-to-pay" for the above attributes. According to STRATUM, Providence receives $1,236,649 in annual benefits each year from increased property value due to its street trees.

Total Annual Net Benefits and Benefit-Cost Ratio (BCR)

In total, Providence's street trees provide $2,932,731 worth of benefits annually in the form of energy savings, CO_2 removal, air quality improvement, stormwater uptake, and aesthetic value. When this value is compared to the amount of money the City spends on its tree program, Providence' is paid back $3.33 in benefits each year.

The replacement value of Providence's street trees is $81,855,622, or $3,274 per tree.

White oak tree, private yard.

Chapter 5 – Urban Tree Canopy

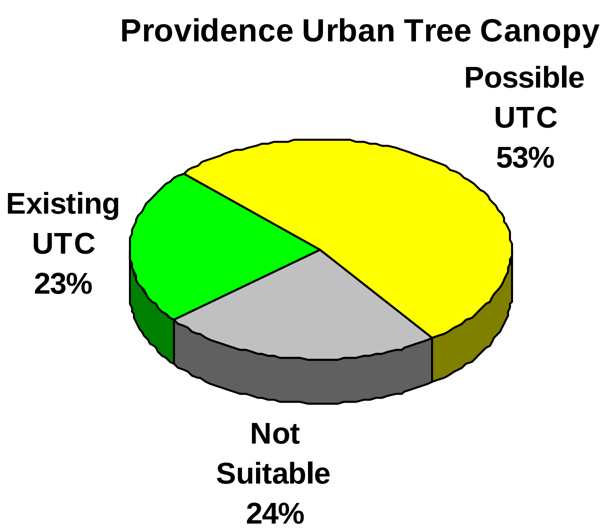
Jackson Walkway in Downtown

Urban Tree Cover (UTC) is the layer of leaves and branches that cover the ground when viewed from above. It is an important measure of urban forest health and distribution, although it does not directly measure the environmental benefits the urban forest provides. A snapshot in time, UTC mapping analysis provides baseline data for future comparisons of canopy growth or decline. It is also a planning tool for determining which city neighborhoods most need tree planting, and what areas offer the greatest potential for increasing tree cover.

In 2007, the Parks Department contracted a private company, NCDC Imaging, to collect satellite imagery and perform GIS analysis to calculate existing and possible UTC in Providence. Quickbird satellite imagery taken September 21, 2007 was used to derive land cover types - tree canopy, grass, impervious surfaces, or water. Using a UTC analysis model developed by the USDA Forest Service in conjunction with the University of Vermont Spatial Analysis Lab, the imagery was overlayed with land cover data that included parcels and buildings, public right of way (PROW), neighborhood boundaries, ward boundaries, and zoning types designated by the City Department of Planning and Development.

According to the study, Providence's land area has 23% existing urban tree cover (Fig. 14), which is 5% more than the results of a similar study conducted by the Providence Plan in 1999. Other east coast cities that have employed the UTC methodology are Baltimore (20%), Boston (29%), Burlington, VT (43%), Frederick, MD (12%), New York City (24%), and Pittsburgh (38%).

Possible UTC is defined as acreage that could physically have tree cover, where none currently exists. It was calculated by subtracting the area of existing UTC, buildings, roads, and water bodies from the city's total area. In Providence, 53% of its area is possible UTC. However, assuming the multitude of uses for urban land that render portions of it undesirable for trees, further analysis and planning is needed to show where trees can be planted in a truly realistic and viable way.



UTC by Land Use Type

Providence's land area by land use type is 55% residential, 15% commercial, 14% industrial, 15% public lands, and 1% unclassified. Of the City's 23% existing UTC discussed above, 62% of it can be found in residential zones, 7% commercial, 6% industrial, and 25% on public lands. UTC percentage was also calculated within each land use type. Residential zones have 26% UTC, commercial 11%, industrial 9%, and public lands 40%.

Results on possible UTC by land use show that nearly half (47%) of the City's possible UTC is located in residential areas, followed by 22% commercial, 18% industrial, and 12% on public lands. Within each land use type, the possible UTC is 46% for residential areas, 76% for commercial, 67% for industrial, and 42% for public land.

Thus, despite the fact that residential zones hold more than 3/5 of Providence's existing UTC, possible UTC statistics show that residential areas still offer the best opportunity for increasing citywide tree cover. The potential for stewardship by residents, both for street trees and backyard trees, strengthens the notion that residential neighborhoods should be the primary choice for strategic tree planting.

Providence Urban Tree Canopy by Land Use Type

Category by Land Use Type		Ft2	Acres	Percent UTC: Citywide	% of Total	% Within Land Use Type
Land Area						
	Residential	286731522	6582.45	55%		
	Commercial	80643499.2	1851.32	15%		
	Industrial	75768699.6	1739.41	14%		
	Public Land	78547392	1803.2	15%		
	Unclassified	2700720	62	1%		
	Total	**524391832.8**	**12038.38**	**100%**		
Existing UTC						
	Residential	75641068.8	1736.48	14%	62%	26%
	Commercial	8788665.6	201.76	2%	7%	11%
	Industrial	6984410.4	160.34	1%	6%	9%
	Public Land	31170229.2	715.57	6%	25%	40%
	Total	**122584374**	**2814.15**	**23%**	**100%**	
Possible UTC						
	Residential	130481802	2995.45	25%	47%	46%
	Commercial	61092900	1402.5	12%	22%	76%
	Industrial	50726491.2	1164.52	10%	18%	67%
	Public Land	32889978	755.05	6%	12%	42%
	Total	**275191171.2**	**6317.52**	**53%**	**100%**	

Figure 15.

UTC by Ward

When the data is analyzed according to ward boundaries, the results show an uneven distribution of UTC across the city. Ward size accounts for some difference in the sheer acreage of UTC that wards hold compared to others. In terms of percentage UTC within a ward, some differences between wards can be explained by the existence of large parks, institutional campuses, and natural areas that fall within the boundaries of several wards. Wards that hold large tracts of industrial land show lower UTC. The remaining differences are that some areas have fewer street trees and yard trees spread throughout, most likely due to economic or social reasons beyond the scope of this study.

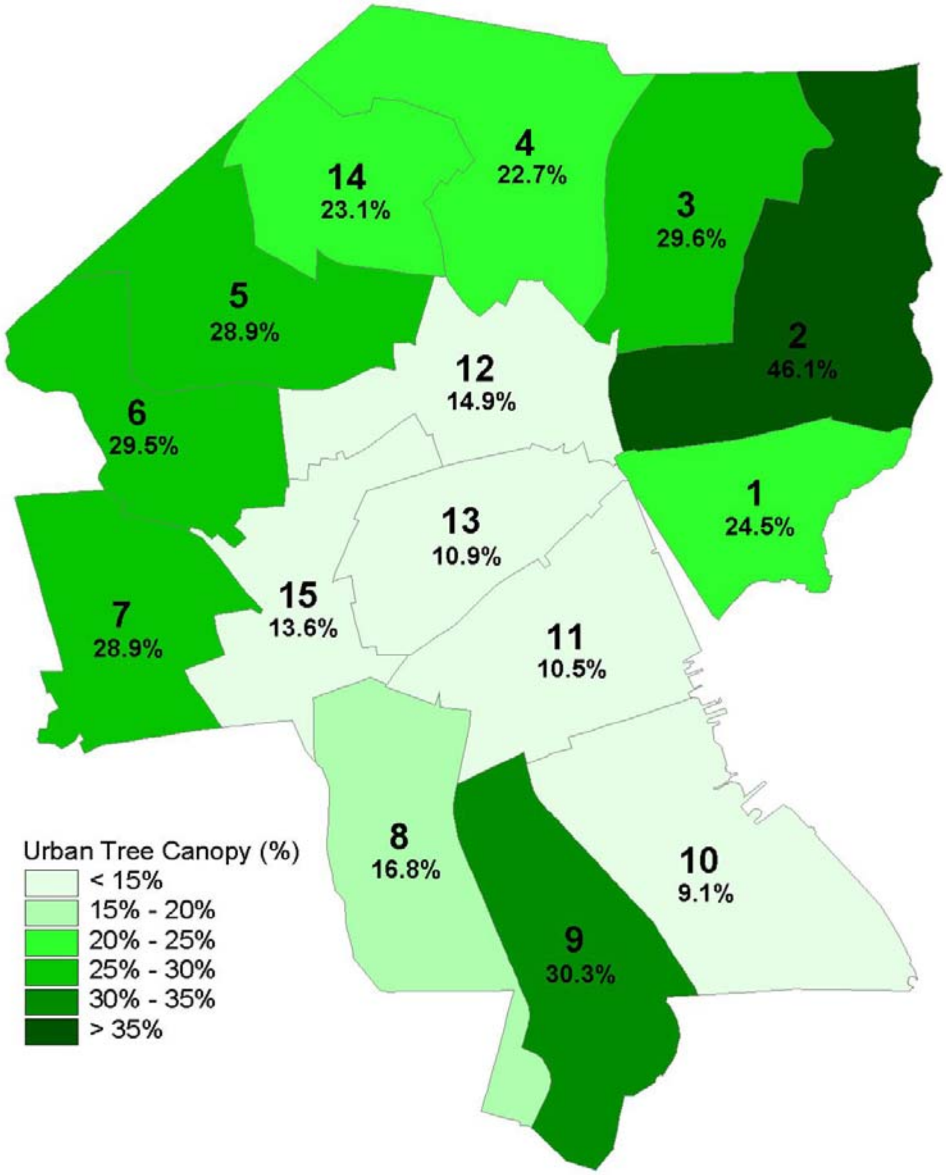


Figure 16. UTC by Ward (provided by Provstat, City of Providence)

Ward 2 is the largest ward (1,233 acres) and holds 1/5 of all UTC citywide (20.2%). Nearly half of Ward 2 is covered with tree canopy (46.1%), whereas the next highest UTC % is 30.3% (Ward 9). Swan Point Cemetery, Blackstone Park, Blackstone Blvd, Butler Hospital, and the campuses of Brown University and the Rhode Island School of Design are all located in Ward 2 and have extensive woodlands or numbers of trees. Other wards with higher UTC are Ward 9 at 30.3% (includes Roger Williams Park), Ward 3 at 29.6% (includes North Burial Ground), Ward 6 at 29.5% (includes Woonasquatucket River riparian lands and undeveloped woodlands), Ward 7 at 28.9% (includes Neutaconkanut Park), and Ward 5 at 28.5% (includes Rhode Island College and Triggs Golf Course).

By contrast, Ward 10 is the second largest ward (1,078 acres), but has the lowest percentage UTC (9.1%). Nearly half of this area, the portion that borders Narragansett Bay, is zoned for industrial use that includes shipyards, oil and natural gas storage facilities, and other heavy industry. Much of the soil is contaminated, and the area is devoid of trees. Ward 11 has the second lowest UTC at 10.5% (includes significant industrial zoning and commercial zones such as portions of the Downtown and the Jewelry District), Ward 13 has 10.9% (includes the Downtown, Federal Hill, and major highway interchanges), and Ward 15 has 13.6% (includes significant industrial zoning such as the mill district along Valley St).

The highest possible UTC is located in Ward 13 (76.9%), Ward 11 (72.8%), and Ward 10 (65.9%). Planting projects and outreach can be focused in these areas, although further analysis is needed to determine how much of the "possible" area designations are actually feasible based on land use and other factors. The data show that all wards are capable of achieving increased canopy cover.

Providence Urban Tree Canopy by Ward

	Land Area			Existing UTC			Possible UTC		
Ward	**Ft2**	**Acres**	**%**	**Acres**	**Ward %**	**Citywide %**	**Acres**	**Ward %**	**Citywide %**
1	24599646.9	564.7	4.7%	138.28	24.5%	4.9%	243.6	43.1%	3.8%
2	53714077.6	1233.1	10.2%	567.95	46.1%	20.2%	425.49	34.5%	6.7%
3	35066765.7	805.0	6.7%	238.39	29.6%	8.5%	367.67	45.7%	5.8%
4	44704237.7	1026.3	8.5%	232.72	22.7%	8.3%	558.2	54.4%	8.8%
5	36423243.5	836.2	6.9%	241.33	28.9%	8.6%	405.13	48.5%	6.4%
6	29205180.5	670.5	5.6%	197.49	29.5%	7.0%	317.32	47.3%	5.0%
7	31761092.7	729.1	6.1%	210.69	28.9%	7.5%	352.01	48.3%	5.6%
8	36319713.0	833.8	6.9%	139.65	16.7%	5.0%	470.54	56.4%	7.4%
9	37951552.8	871.3	7.2%	263.62	30.3%	9.4%	395.69	45.4%	6.2%
10	46959896.3	1078.1	9.0%	97.74	9.1%	3.5%	710.47	65.9%	11.2%
11	36231413.1	831.8	6.9%	87.59	10.5%	3.1%	605.34	72.8%	9.5%
12	32758773.7	752.0	6.2%	111.7	14.9%	4.0%	407.87	54.2%	6.4%
13	24491395.7	562.3	4.7%	61.35	10.9%	2.2%	432.46	76.9%	6.8%
14	26079222.4	598.7	5.0%	138.39	23.1%	4.9%	300.37	50.2%	4.7%
15	28123208.1	645.6	5.4%	87.59	13.6%	3.1%	348.35	54.0%	5.5%
TOTAL	**524389419.6**	**12038.4**	**100.0%**	**2814.47**	**23.4%**	**100.0%**	**6340.51**	**52.7%**	**100.0%**

Figure 17.

UTC by Neighborhood

The study also calculated UTC for Providence's 25 designated neighborhoods. Due to a difference in total land area boundaries represented on the GIS map provided by the City for neighborhoods, the percentage of total UTC (21.4%) differs from the previous figures discussed. The map includes neighborhood boundaries that extend into portions of Narragansett Bay and the Providence River that are not included on the ward boundary map or the parcel map, providing a less accurate total calculation. However, the total citywide acreage for existing UTC is identical to the ward analysis calculation.

Among Providence's 25 neighborhoods, Blackstone (40.1%) and Manton (38.9%) have the greatest existing UTC, followed by South Elmwood (38.2%), Wayland (31.7%), College Hill (30.0%), Silver Lake (28.1%), Hope (27.9%), and Mount Pleasant (27.1%). Many of the same reasons previously discussed account for the high proportion of UTC in these neighborhoods. The Blackstone neighborhood includes Swan Point Cemetery, Butler Hospital, Blackstone Blvd., and many well-treed streets and residential properties. Manton contains the Woonasquatucket corridor and undeveloped woodland areas that comprise its relatively small acreage. South Elmwood includes Roger Williams Park, Wayland has Blackstone Park, College Hill includes the well-treed campus and streets of Brown University, Silver Lake holds Neutaconkanut Park, and Mount Pleasant has Rhode Island College and Triggs Golf Course. Interestingly, the Hope

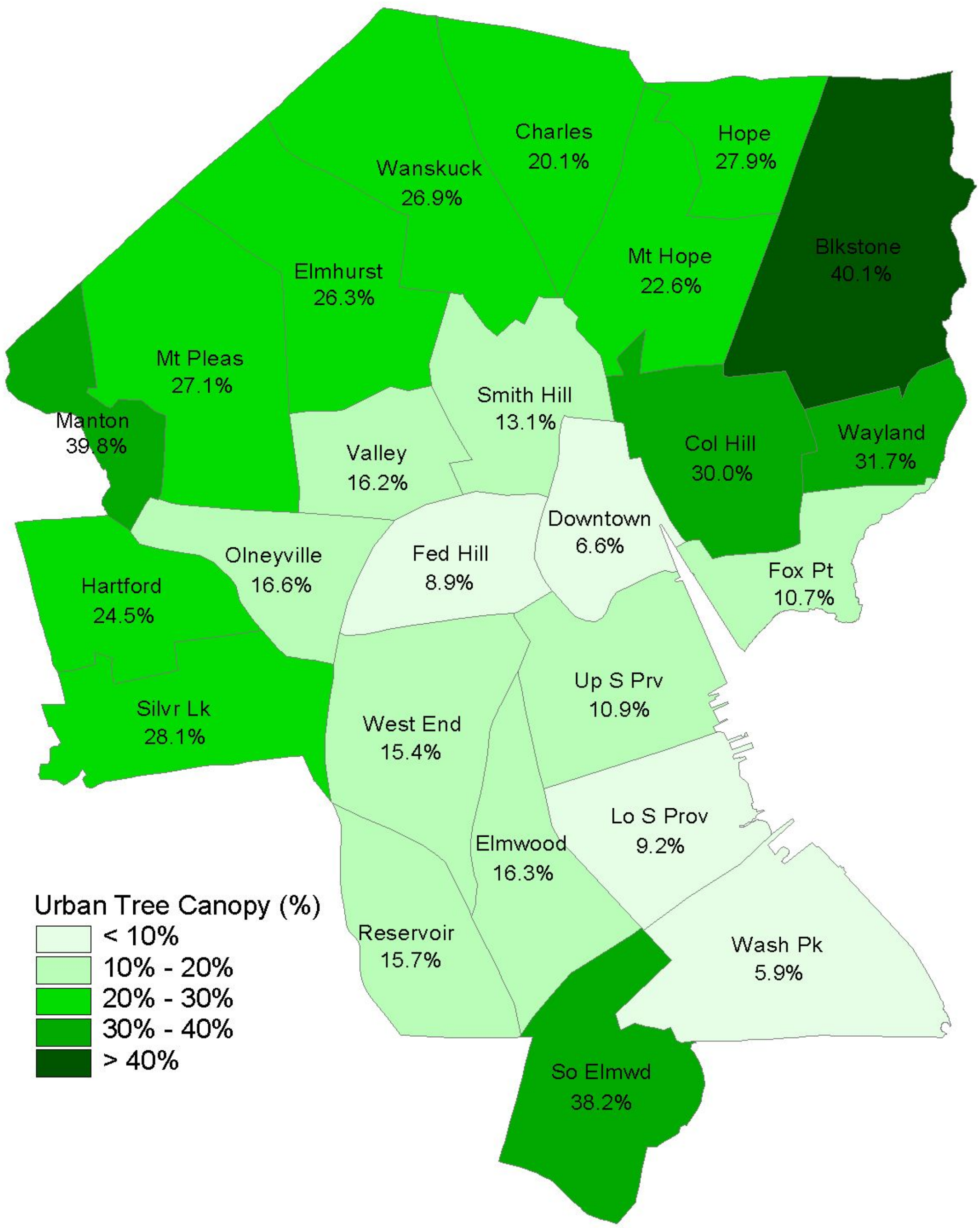


Figure 18. UTC by Neighborhood (provided by Provstat, City of Providence)

neighborhood (27.9%) does not have a large park or major institution; it achieves its canopy cover with street trees and backyard trees alone.

With less than 10% existing UTC, the Downtown, Federal Hill, Lower South Providence, and Washington Park neighborhoods have the lowest tree cover in the city. Upper South Providence (64.7%) and Federal Hill (68.0%) have the greatest possible UTC growth based on this analysis. In addition, the West End (57.4%), Mount Hope (55.3%), Downtown (54.3%) and Charles (53.8%) are neighborhoods with large potential for UTC growth. Wayland (27%), Fox Point (29%), and Blackstone (25%) have the least potential for UTC growth.

Providence Urban Tree Canopy by Neighborhood

	Land Area			Existing UTC			Possible UTC		
Neighborhood	**Ft2**	**Acres**	**%**	**Acres**	**Nbhd %**	**Citywide %**	**Acres**	**Nbhd %**	**Citywide %**
Blackstone	49993960.3	1147.7	8.7%	460.40	40.1%	16.3%	287.80	25.1%	4.7%
Charles	23293846.7	534.8	4.1%	107.63	20.1%	3.8%	287.54	53.8%	4.7%
College Hill	20344933.6	467.1	3.5%	140.21	30.0%	5.0%	188.61	40.4%	3.1%
Downtown	22011839.2	505.3	3.8%	33.56	6.6%	1.2%	274.52	54.3%	4.5%
Elmhurst	27985150.6	642.5	4.9%	168.88	26.3%	6.0%	295.19	45.9%	4.8%
Elmwood	19167517.7	440.0	3.3%	71.92	16.3%	2.6%	262.92	59.8%	4.3%
Federal Hill	15633430.5	358.9	2.7%	32.04	8.9%	1.1%	244.22	68.0%	4.0%
Fox Point	22798227.6	523.4	4.0%	56.12	10.7%	2.0%	150.64	28.8%	2.5%
Hartford	18268952.7	419.4	3.2%	102.81	24.5%	3.7%	224.15	53.4%	3.7%
Hope	11794888.0	270.8	2.1%	75.66	27.9%	2.7%	120.73	44.6%	2.0%
Lower South Providence	23911758.4	548.9	4.2%	50.50	9.2%	1.8%	257.17	46.8%	4.2%
Manton	11515955.5	264.4	2.0%	105.13	39.8%	3.7%	108.42	41.0%	1.8%
Mount Hope	23495108.6	539.4	4.1%	121.63	22.6%	4.3%	298.25	55.3%	4.9%
Mount Pleasant	33418208.4	767.2	5.8%	208.00	27.1%	7.4%	394.77	51.5%	6.5%
Olneyville	15399084.9	353.5	2.7%	58.77	16.6%	2.1%	183.53	51.9%	3.0%
Reservoir	18626096.2	427.6	3.2%	67.08	15.7%	2.4%	196.53	46.0%	3.2%
Silver Lake	22004372.7	505.2	3.8%	141.82	28.1%	5.0%	232.56	46.0%	3.8%
Smith Hill	16231308.7	372.6	2.8%	48.91	13.1%	1.7%	205.66	55.2%	3.4%
South Elmwood	24491486.9	562.2	4.3%	214.83	38.2%	7.6%	198.60	35.3%	3.2%
Upper South Providence	17114249.9	392.9	3.0%	42.84	10.9%	1.5%	254.27	64.7%	4.2%
Valley	13063867.9	299.9	2.3%	48.70	16.2%	1.7%	151.60	50.5%	2.5%
Wanskuck	30336178.0	696.4	5.3%	187.63	26.9%	6.7%	354.63	50.9%	5.8%
Washington Park	50614867.0	1162.0	8.8%	68.18	5.9%	2.4%	498.19	42.9%	8.1%
Wayland	14887541.7	341.8	2.6%	108.26	31.7%	3.8%	92.02	26.9%	1.5%
West End	26935945.7	618.4	4.7%	95.13	15.4%	3.4%	354.82	57.4%	5.8%
Total	**573338777.3**	**13162.0**	**100.0%**	**2816.67**	**21.4%**	**100.0%**	**6117.33**	**46.5%**	**100.0%**

Figure 19.

Chapter 5 – Conclusion

The results of these studies demonstrate a number of positive indicators for Providence's urban forest. First, the number of street trees has increased from 1988 to 2006 by 12%. Despite the loss a significant number of aging Norway maple trees, tree planting has outpaced removals along city streets. Much of the credit can be attributed to the success of the Providence Neighborhood Planting Program, established in 1989. Also, the city's total urban tree canopy is comparable to that of other Northeastern cities, with 23% UTC. This figure shows 5% more UTC than the results of a 1999 study of Providence's tree canopy, although the difference may be attributable to significantly sharper image resolution and more refined computer analysis techniques. In any case, the UTC was higher than expected, with gains made not only by street tree planting but also by recent tree canopy requirements for developers adopted within the 2004 City Zoning Ordinance.

The street tree population is increasing in diversity. Over 95 species are represented, and this number will grow as new species, varieties, and cultivars are selected for planting. More importantly, the percentage of Norway maples has declined dramatically since 1988, from 46.7% to 18.8%. The threat posed by monoculture – devastating losses to one species by a new insect or disease – has been reduced. The predominance of trees within the genus "maple" must still be monitored, as well as the growing number of callery pear trees. Other positive signs include an improved overall condition rating since 1988, a high percentage of trees in smaller size (diameter) categories to offset tree mortality as the population matures, and a reduced percentage of trees planted under utility wires. One in five trees is mulched, demonstrating tree care is being practiced by many of the city's residents and neighborhood associations.

These results also alert us to several problems that seem to plague cities and their trees across the country. Providence trees suffer from a lack of adequate space, especially below ground. The average sidewalk tree pit size is approximately 16 square feet, and the average width of a lawn strip is less than 4 feet wide. The forestry department currently specifies a *minimum* tree pit size for new tree plantings of 24 square feet, with wider openings preferable where space allows. Improved growing space is needed for the health and long-term success of trees. Over 3,000 trees are in direct contact or conflict with the adjacent pavement, meaning that they have literally run out of room to grow. One quarter of the trees have a cracked or raised sidewalk square immediately adjacent to them.

Both the street tree inventory and the UTC study show that some neighborhoods have an ample number of trees and canopy cover, while other neighborhoods are severely lacking. UTC varies from 40.1% (Blackstone) to 5.9% (Washington Park). Trees have direct, measurable effects on air quality, water quality, real estate values, and other factors that contribute to the quality of life for Providence residents. Effort should be made to increase UTC in all neighborhoods, with special emphasis on neighborhoods with the least amount of trees.

For the first time, we can express the value of our street trees in quantifiable environmental and monetary terms. While tree managers and environmentalists have long touted the importance of trees to the environment and our communities, we now know approximately how much energy is saved, how much air pollution is trapped, how much stormwater is intercepted, and how much carbon is stored by Providence's street trees. Overall, these trees provide $2.9 million dollars in benefits annually, a terrific investment of city resources towards community health and well-being. Additionally, for every $1 spent on the tree program, the city receives $3.33 in benefits each year.

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Appendix A - STRATUM Methodology and Procedures

(From *Northeast Community Tree Guide: Benefits, Cost, and Strategic Planning.* General Technical Report, USDA Forest Service, Pacific Southwest Research Station.)

Approach

Overview

Because benefits from trees differ owing to regional differences in tree growth, climate, air pollutant concentrations, rainfall patterns, building characteristics, and other factors, we divided the United States into 20 climate zones. A reference city is designated for each climate zone, and intensive data are collected for modeling tree benefits. Criteria for selection as a reference city include:

- Updated inventory to trees by address.
- Detailed information on tree management costs.
- Long-tenured city foresters who can help age trees because they know when they were planted or when different neighborhoods were developed and street trees planted.
- Good contacts within other city departments to obtain data on sidewalk repair costs, trip/fall costs, and litter cleanup costs.
- Capability to provide the resources needed to conduct the study, including an aerial lift truck for 5 days to sample foliar biomass.

The Borough of Queens was selected as the reference city for the Northeast region because it best met these criteria. During 2005, data were collected on tree growth and size for predominant street tree species in Queens, and other geographic information was assembled to model tree benefits. A subset of these data is used in this guide, and the entire data set is incorporated into the I-Tree STRATUM database for the Northeast region (see www.itreetools.org).

In this study, annual benefits and costs over a 40-year planning horizon were estimated for newly planted trees in three residential yard locations (east, south, and west of the dwelling unit) and a public street-side or park location. 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, storm water-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 a small (Kwanzan cherry), medium (red maple), and large (Japanese zelkova) deciduous tree and for a conifer (eastern white pine) (see “Common and Scientific Names” section). The selection of these species was based on data availability, and not intended to endorse their use in large numbers. In fact, the Kwanzan cherry has a poor form for a street tree and in certain areas zelkova is overused. Relying on too few species can increase the likelihood of catastrophic loss owing to pests, diseases, or other threats. Results are reported for 5-year intervals for 40 years.

Mature tree height is frequently used to characterize 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 characterize mature tree size. These additional measurements are useful indicators for many functional benefits of trees that relate to leaf-atmosphere process (e.g., interception, transpiration, photosynthesis). Tree growth rates, dimensions, and LSA estimates are based on tree growth modeling.

Growth Modeling

Growth models are based on data collected in the Borough of Queens, New York City. An inventory of Queens’ street trees was provided by the City of New York Department of Parks and Recreation. The inventory was conducted in 1995 and updated to account for dead tree removals and new plantings. It included 255,742 trees representing 242 species.
Tree-growth models developed from Borough of Queens data were used as the basis for modeling tree growth for this report. Using Queens’ tree inventory, a stratified random sample of 21 tree species was measured to establish relations among 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:

1. 0-2.9 in
2. 3-5.9 in
3. 6-11.9 in
4. 12-17.9 in
5. 18-23.9 in
6. 24-29.9 in
7. 30-35.9 in
8. 36-41.9 in
9. >42 in

Thirty to 60 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 0.5m 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. A total of 910 trees were measured. Field work was conducted in August 2005.

Tree coring was used in Queens to estimate planting dates instead of using historical research conducted in other reference cities. Unlike other cities, where even-aged stands exist along streets planted at the time of development, street trees in Queens were of all ages because several generations had come and gone. Dr. Brendan Buckley of Lamont-Doherty Earth Observatory's Tree Ring laboratory, supervised the coring of 150 randomly sampled trees to establish mean tree age. These trees represented a subsample of the original 910 sample trees. One to two trees in size classes 2 through 9 were cored for each species. Coring was conducted from October 2005 through April 2006. Cores were analyzed in the lab and tree age established. Central Forestry and horticulture provided tree ages for an additional 104 sample trees in d.b.h. classes 8 and 9, based on building records, and 34 trees in d.b.h. classes 1 and 2 based on planting records. These data were pooled with ring-count data to develop regressions based on the mean age for each d.b.h. size class.

Crown volume and leaf area were estimated from computer processing of tree-crown images obtained by using 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 species, we selected the typical small, medium, and large tree species for this report.
The conifer is included as a windbreak tree located more than 50 ft from the residence, so it does not shade the building. Tree dimensions are derived from growth curves developed from street trees in the Borough of Queens, New York City (Peper et al., in press) (fig. 17).

Reporting Results

Results are reported in terms of annual values per tree planted. However, to make these calculations realistic, mortality rates are included. Based on our survey of regional municipal foresters and commercial arborists, this analysis assumed that 34 percent of the hypothetical planted trees died over the 40-year period. Annual mortality rates were 2.8 percent for the first 5 years, and 0.57 percent per year after that. 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 Fairfield and Mansfield, Connecticut, as well as the Borough of Queens, New York City. In addition, commercial arborists in the New York metropolitan region provided information on tree management costs on residential properties.

Pricing benefits

Electricity and natural gas prices for utilities serving Queens were used to quantify energy savings for the region. Costs of preventing or repairing damaged from pollution, flooding, or other environmental risks were used to estimate what society is willing to pay for clean air and water (Wang and Santini 1995). For example, the value of storm water runoff reduction owing to rainfall interception by trees is estimated by using marginal control costs. If a community or developer is will to pay an average of $0.01 per gallon of treated and controlled runoff to meet minimum standards, then the storm water runoff mitigation value of a tree that intercepts 1,000 gallon of rainfall, eliminating the need for control, should be $10.

Calculating Benefits

Calculating Energy Benefits—

The prototypical building used as a basis for the simulations was typical of post-1980 construction practices, and represents approximately one-third of the total single-family residential housing stock in the Northeast region. The house was a one-story, wood-frame, building with a basement and total conditioned floor area of $2{,}090^2$, window area (double-glazed) of 262 ft2, and wall and ceiling insulation of R13 and R27, respectively. The central cooling system had a seasonal energy efficiency ration (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 ^{0}F; winter settings were 68 ^{0}F during the day and 60 ^{0}F at night. Because the prototype building was larger, but more energy efficient, than most other construction types, our projected energy saving can be considered similar to those for older, less thermally efficient, but smaller buildings. The energy simulations relied on typical meteorological data from New York City (Marion and Urban 1995).

Calculating energy savings—

The dollar value of energy savings was based on regional average residential electricity and natural gas prices of $0.14/kWh and $1.48/therm, respectively. Electricity and natural gas prices were for 2006 for New York City (Con Edison 2006a and 2006b, 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 deciduous trees and a conifer at three tree-to-building distances, following methods outlined by McPherson and Simpson (1999). The small tree (Kwanzan cherry) had a visual density of 75 percent during summer and 20 percent during winter. The medium tree (red maple) had a density of 73 percent during summer and 17 percent during winter. The large tree (Japanese zelkova) had a visual density of 74 percent during summer and 15 percent during winter, and the conifer (eastern white pine) had a density of 28 percent year round. Crown densities for calculating she were based on published values where available (Hammond et al.1980, McPherson 1984).

Foliation periods for deciduous trees were obtained from the literature (Hammond et al. 1980, McPherson 1984) and adjusted for New York City's climate based on consultation with the Central Forestry and horticulture project coordinator and borough forestry directors (Lu 2006). Large trees were leafless November 1 through May 1, medium and small trees November 15 through May 4, and conifers were evergreen. 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. The conifer is included as a windbreak tree located greater than 50 feet from the residence so it does not shade the building. Our results for public trees are conservative in that we assumed that they do not provide shading benefits. For example, in Modesto, California, 125 percent of total annual dollar energy savings from street trees was due to shade and 85 percent due to climate effects (McPherson et al. 1999).

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 a 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 cover for Queens was 20 percent and building cover was estimated to be 15 percent based on Grove and colleagues (2006). Canopy cover was calculated to increase by 2.2, 4.5, 8.9, and 3.0 percent for 20-year-old, small, medium, and large deciduous and coniferous 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 air-temperature and wind 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 reduction in annual heating energy use of about 0.5 percent per tree for conifers in the Mid-Atlantic 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 because their crowns are leafless during winter and do not block winds near ground level.

Atmospheric Carbon Dioxide Reduction

Calculating reduction in carbon dioxide emissions from power plants—

Conserving energy in buildings can reduce carbon dioxide (CO_2) emissions from power plants. These avoided emissions were calculated as the product of energy savings for heating and cooling based on CO2 emission factors (table 18) and were based on data for the Northeast region where the average fuel mix is 29.0 percent coal, 28.0 percent nuclear, 20.5 percent natural gas, 10.4 percent fuel oil, 8.8 percent hydro, and 3.2 percent biomass/other (US EPA 2003). Fuel mixes and emissions outputs for the region are based on a population-weighted average for the portions of the states that are included in the region. For each state, the percentage of people living within the region was estimated. Values for each component of the fuel mix and the emissions outputs for each component (US EPA 2003) were then multiplied by the percentage of affected residents for each state. Finally, the fractional amounts for the fuel mix components and the emission outputs were summed for all states. The value of $0.003 per lb CO_2 reduction (table 18) was based on the average value in Pearce (2003).

Calculating carbon storage—

Sequestration, the net rate of CO_2 storage in above-and below ground biomass over the course of one growing season, was calculated by using tree height and d.b.h. data with biomass equations (Pillsbury et al. 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 biomass each year.

Calculating CO2 released by power equipment—

Tree-related emissions of CO2, based on gasoline and diesel fuel consumption during tree care in our survey cities, were calculated by using the value 0.15 lb CO_2 /in d.b.h. (Lu 2006). This amount may overestimate CO_2 release for less intensively maintained residential yard trees.

Calculating carbon dioxide released during decomposition—

To calculate CO_2 released through decomposition of dead wood 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).

Calculating reduction in air pollutant emissions—

Reductions in building energy use also result in reduced emission of air pollutants from power plants and space-heating equipment. Volatile organic hydrocarbons (VOCs) and nitrogen dioxide (NO_2)-both precursors of ozone (O_3) 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 for CO_2, by using utility-specific emissions factors for electricity and heating fuels (Ottinger et al.1990, US EPA 1998). The price emissions savings were derived from models that calculate the marginal damage cost of different pollutants to meet air quality standards (Wang and Santini 1995). Emissions concentrations were obtained from US EPA (2003; table 18), and population estimates from the U.S. Census Bureau (2006).

Calculating pollutant uptake by trees—

Trees also remove pollutants from the atmosphere. The modeling method we applied was developed by Scott et al. (1998). It calculates hourly pollutant dry deposition per tree expressed as the product of deposition velocity (Vd = 1/[Ra + Rb + Rc]), pollutant concentration ©, canopy-projection area (CP), and a time step, where Ra, Rb, and Rc are aerodynamic, boundary layer, and stomatal resistances. Hourly deposition 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 2003 for NO_2, SO_2, O_3 and PM_{10} for New York City and the surrounding area were obtained from the US EPA. Hourly air temperature and windspeed data were obtained from the National Oceanic and Atmospheric Administration, and solar radiation model based on weather data from John F. Kennedy (JFK) airport (for a description of the model, see DeGaetano et al. 1993). 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 18). 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 et al. (1991, 1993). Annual emissions were simulated during the growing season over 40 years. The emission of carbon as isoprene was expressed as a product of the base emission rate (micrograms of carbon per gram of dry 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 ann7ual emissions.

Annual dry foliar biomass was derived from field data collected in New York City during the summer of 2005. 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. A study in the Northeastern United States found that species mix had no detectable effects on O_3 concentrations (Nowak et al. 2000). The O_3 reduction benefit from lowering summertime air temperatures, thereby reducing hydrocarbon emissions from anthropogenic and biogenic sources, were estimated as a function of canopy cover following McPherson and Simpson (1999). They used peak summer air temperatures reductions of 0.2 ^{O}F for each percentage increase in canopy cover. Hourly changes in air temperature were calculated by reducing this peak air temperature at every hour based on hourly maximum and minimum temperatures for that day, scaled by magnitude of maximum total global solar radiation for each day relative to the maximum value for the year. However, this analysis does not incorporate the effects of lower summer air temperatures on O_3 formation rates owing to atmospheric processes.

Stormwater Benefits

Estimating rainfall interception by tree canopies—

A numerical simulation model was used to estimate annual rainfall interception (Xiao et al. 2000). The interception model accounted for water intercepted by the tree, as well as throughfall and stem flow. Intercepted water is stored temporarily on canopy leaf and bark surfaces. Rainwater drips from leaf surfaces, 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 wind speed at different heights above the ground and resulting rates of evaporation.

The volume of water stored in the tree crown was calculated from crown-projection area (area under tree drip line), 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 through fall. Tree surface saturation was 0.04 in. for all trees. Hourly meteorological and rainfall data for 2000 for JFK airport (Station: JFK International Airport, New York City, NY; latitude $40^{O}38'28.5''$ N, longitude $73^{O}46'41.9''$W) were used for this simulation. Annual precipitation during 2000 was 41.0 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 et al. (1998, 2000).

Calculating water quality protection and flood control benefit—

Treatment of runoff is one way of complying with federal Clean Water Act regulations by preventing contaminated storm water from entering local waterways. Lacking data for Queens, we relied on storm water management fee for Washington, D.C., as the basis for calculating the implied value of each gallon of storm water intercepted by trees. In Washington, D.C., the monetized benefit value is $0.04/gal based on projected costs and water savings from the Water and Sewer Authority's 2002 Long-Term Control Plan (Greeley and Hansen 2002).

Aesthetic 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 net benefit associated with trees. This approach had 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 Mid-west region, and the need to extrapolate results from front-yard, streets, parks, and non residential 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 differed widely by location within the region. By averaging the values for several cities, we calculated the average home price for Northeast communities as $291,000. Therefore, the value of a large tree that added 0.88 percent to the sales price of such a home was $2,566. To estimate annual benefits, the total added value was divided by the LSA of a 30-year-old zelkova ($2,566/4,256 ft^2) to yield the base value of LSA, $0.60/$ft^2$. This value was multiplied by the amount of LSA added to the tree during one year of growth.

Calculating the aesthetic value of a residential yard tree—

To calculate the base value for a large tree on private residential property we assumed that a 30-year-old zelkova in the front yard increased the property sales price by $2,566. Approximately 75 percent of all yard trees, however, are in backyards (Richards et al. 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 aesthetic benefit for a tree on private property was estimated as $0.45/$ft^2$ LSA. To estimate annual benefits, this value was multiplied by the amount of LSA added to the tree during 1year growth.

Calculating the base value of a public tree--

The base value of a public tree was calculated in the same way as front-yard trees. However, because street and park trees may be adjacent to land with little value or resale potential, an adjusted value was calculated. A citywide street tree reduction factor (91 percent) was applied to prorate trees' value based on the assumption that public trees adjacent to different land uses make different contributions to property sales prices. For this analysis, the land use factor reflects the proportion of street trees in Queens by land use and the reduction factor is the value of a tree in an area of that use relative to single-home residential. Land use and reduction factors, shown respectively, were single-home residential (76 percent, 100 percent), multi-home residential (10 percent, 70 percent), small commercial (8 percent, 66 percent), industrial/institutional/large commercial (6 percent, 40 percent), park/vacant/other (2 percent, 40 percent) (Gonzales 2004, McPherson 2001).

Although the impact of parks on real estate values has been reported (Hammer et al. 1974, Schroeder 1982, Tyrvainen 1999), to our knowledge, the onsite and external benefits of park trees alone have not been isolated (More et al. 1988). After reviewing the literature and recognizing an absence of data, we made the conservative estimate that park trees have half (50 percent) as much impact on property prices as street trees.

Given these assumptions, typical large street and park trees we estimated to increase property values by \$0.55 and \$0.30/ft^2 LSA, respectively. Assuming that 80 percent of all municipal trees were on streets and 20 percent in parks, a weighted average benefit of \$0.50/ft^2 LSA was calculated for each tree.

Calculating Costs

Tree management costs were estimated based on surveys of municipal foresters and commercial arborists in the region.

Planting—

Planting costs include the cost of the tree and the cost for planting, staking, and mulching the tree. Based on our survey of northeast municipal and commercial arborists, planting costs depend on tree size. Costs ranged from \$200 for a 1-in. tree to \$1,000 for a 3-in. tree. In this analysis we assumed that a 2-in. yard tree was planted at a cost of \$600. The cost for planting a 2-in. public tree was \$400.

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 once during the first 5 years after planting, at a cost of \$15 per tree. After this training period, pruning occurred once every 10 years for all trees. Pruning costs were \$35, \$70, and \$280 for small (<20 ft tall), medium (<20 to 40 ft tall), and large trees (<40 ft tall). More expensive equipment and more time were required to prune large trees than small trees. After factoring in pruning frequency, annualized costs were \$3, \$3.50, \$7, and \$28 per tree for public young, small, medium, and large trees, respectively.

Pruning costs for yard trees—

Based on findings from our survey of commercial arborists in the Northeast region, pruning cycles for yard trees were more frequent than reported for public trees. We assumed that young yard trees were inspected and pruned almost annually during the first 5 years after planting, and once every 4 years thereafter. However, survey findings indicate that only 20 per cent of all private trees are professionally pruned and the number of professionally pruned trees increases as the trees grow (Summit and McPherson 1998). Accordingly, 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 and conifers. Using these contract rates, along with average pruning prices (\$150, \$400, \$600, and \$800 for young, small, medium, and large trees, respectively.

Tree and Stump Removal

The costs for tree removal and disposal were \$18.33/in d.b.h. for public trees, and \$50/in d.b.h. for yard trees. Stump removal costs were \$6.5/in d.b.h. for public and \$10/in d.b.h. for yard trees. Therefore, total costs for removal and disposal of trees and stumps were \$24.84/in d.b.h. for public trees, and \$60/in d.b.h. for yard trees.

Pest and Disease Control

Expenditures for pest and disease control in the Northeast are modest. They averaged about \$0.22 per tree per year or approximately \$0.02/in d.b.h. for public trees. Results of our survey indicated that only a few yard trees were treated, so we assumed no expenditures for treating pests and diseases in yard trees.

Irrigation Costs

Rain falls fairly regularly throughout most of the Northeast region and sufficiently that irrigation is not usually needed after establishment. In New York City, trees are watered for the first two summers after planting. We included initial irrigation costs with planting costs in this report.

Other Costs for Public and Yard Trees

Other costs associated with the management of trees include expenditures for infrastructure repair/root pruning, leaf-litter cleanup, litigation/liability, and inspection/administration. Cost data were obtained from the municipal arborist survey and assume that 80 percent of public trees are street trees and 20 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 Northeast municipalities have a substantial number of large, old trees and deteriorating sidewalks. As tress 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 Pepper 1995). Infrastructure-related expenditures for public trees in Northeast communities were comparable to other regions, averaging approximately \$3.28 per tree on an annual basis. Roots from most trees in residential yards do not damage sidewalks and sewers. Therefore, we did not include this cost for yard trees.

Liability costs—

Urban trees can 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).

However, communities in our Northeast survey did not report any tree-related liability expenditures. Therefore, we did not include costs for public or yard trees.

Litter and storm cleanup costs—

The average annual per-tree cost for letter cleanup (I.E., street sweeping storm damage cleanup) was \$0.74/tree (\$0.05in d.b.h.). This value was based on average annual litter cleanup 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 considerable for our survey of Northeast communities, where 75 to 95 percent of green waste is recycled as mulch, compost, firewood, or other products. Fees from the sale of these products partially offset the costs of processing and hauling. However, tipping fees for disposal of green-waste in landfills are relatively high. Survey results indicate that the average annual per-tree cost for green-waste disposal is \$3.23 per public tree (\$0.27/in d.b.h.). We assumed that disposal costs for yard trees were 10 percent of those for public trees, and this cost is shown under the category Administration/ Inspection/Other. Tree removal and green-waste disposal costs associated with losses from exotic forest pests like Asian long-horned beetle and Emerald ash borer can be substantial, and are not included in any part of this analysis.

Inspection and administration costs—

Municipal tree programs have administrative costs for salaries of supervisors and clerical staff, operating costs, and overhead. Our survey found that the average annual cost for inspection and administration associated with street- and park-tree management was \$5.96 per tree (\$0.50/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 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 human health (e.g., reduced exposure to cancer-causing UV radiation) and greater psychological well being through visual and direct contact with plants. However, on the cost side, increased health care may be incurred because of nearby trees owing to allergies and respiratory ailments related to pollen. We assumed that these intangible benefits and costs were reflected in what we term "aesthetics and other benefits."

The property owner can obtain additional economic benefits from 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 s.

Reductions in atmospheric CO_2 concentrations owing to trees are an example of benefits realized at the global scale. Annual benefits (B) are calculated as:

$B = E + AQ + CO_2 + H + A$ 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 CO_2 reductions (sequestration, avoided emissions, release owing to tree care and decomposition)
H = value of annual storm water-runoff reductions
A = value of annual aesthetics and other benefits

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) equal the costs for residential yard trees (C_Y) and public trees (C_P):

$C_Y = P + T + R + D + I + S + Cl + L$
$C_P = P + T + R + D + I + S + Cl + L + A$ 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 of tree-related claims
A = annual program administration, inspection, and other costs
Net benefits are calculated as the difference between total benefits and costs: Net benefits = B - C

Appendix B

City of Providence

Importance Values for Most Abundant Public Trees

5/21/2007

Species	Number of Trees	% of Total Trees	Leaf Area (ft^2)	% of Total Leaf Area	Canopy Cover (ft^2)	% of Total Canopy Cover	Importance Value
Norway maple	4,702	19.0	10,685,788	22.9	4,555,278	27.1	23.0
Callery pear	2,901	11.7	3,643,952	7.8	921,305	5.5	8.3
Green ash	2,147	8.7	3,366,778	7.2	1,189,250	7.1	7.6
Honeylocust	1,850	7.5	3,324,120	7.1	1,385,422	8.2	7.6
London planetree	1,751	7.1	3,651,415	7.8	1,409,565	8.4	7.8
Red maple	1,411	5.7	2,656,667	5.7	813,503	4.8	5.4
Japanese zelkova	1,104	4.5	1,374,785	2.9	480,564	2.9	3.4
Littleleaf linden	943	3.8	1,342,889	2.9	407,199	2.4	3.0
Sugar maple	635	2.6	1,655,091	3.5	456,114	2.7	2.9
Plum	582	2.3	208,752	0.4	117,314	0.7	1.2
Linden	495	2.0	896,239	1.9	266,036	1.6	1.8
Northern red oak	449	1.8	2,403,411	5.1	869,519	5.2	4.0
Pin oak	438	1.8	2,281,214	4.9	799,758	4.8	3.8
Silver maple	422	1.7	1,660,849	3.6	462,283	2.8	2.7
Crabapple	383	1.5	139,112	0.3	67,371	0.4	0.7
Elm	350	1.4	477,371	1.0	124,970	0.7	1.1
Kwanzan cherry	339	1.4	105,162	0.2	60,869	0.4	0.7
Sweetgum	307	1.2	524,201	1.1	184,142	1.1	1.2
Maple	273	1.1	447,183	1.0	184,771	1.1	1.1
Other trees	3,324	13.4	5,904,573	12.6	2,054,593	12.2	12.8
Total	24,806	100.0	46,749,572	100.0	16,809,826	100.0	100.0

City of Providence

Replacement Value for Public Trees by Species

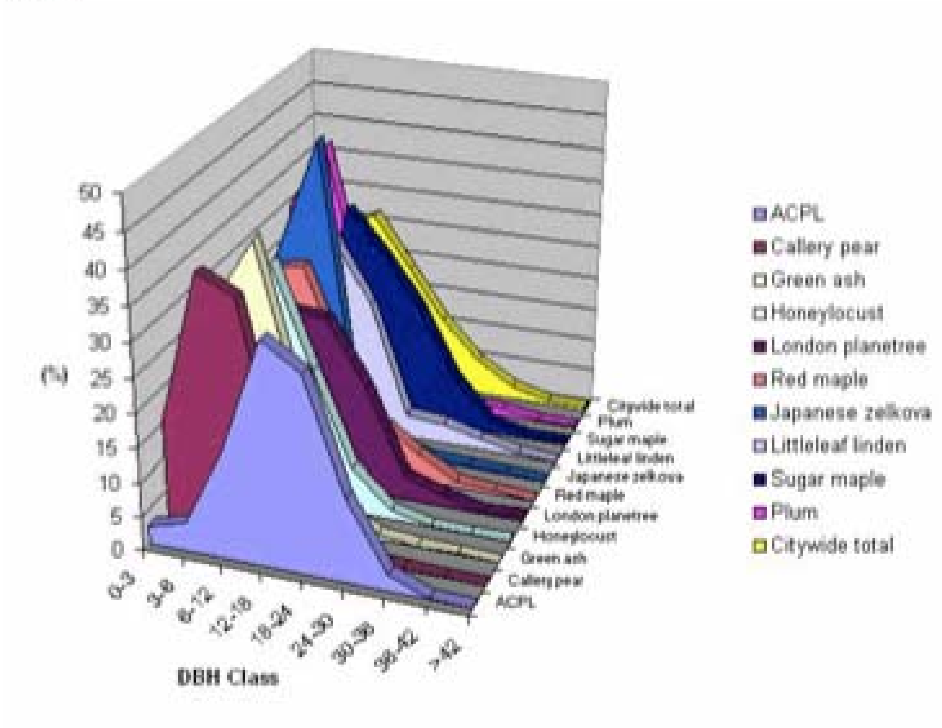
5/21/2007

Species	DBH Class (in) 0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total	Standard Error	% of Total
ACPL	19,841	89,562	1,007,855	4,945,183	8,449,638	6,315,584	1,875,929	291,111	53,411	23,048,116	(±0)	28.16
Callery pear	89,868	433,803	1,090,069	747,468	293,662	88,907	53,909	0	19,632	2,817,317	(±0)	3.44
Green ash	13,960	288,239	1,256,156	1,619,489	590,584	196,791	75,802	114,101	20,675	4,175,796	(±0)	5.10
Honeylocust	30,223	229,791	1,083,751	1,647,945	1,037,553	374,297	16,290	0	0	4,419,850	(±0)	5.40
London planetree	18,616	150,548	825,126	2,200,543	2,785,646	989,477	659,657	129,130	365,193	8,123,939	(±0)	9.92
Red maple	33,665	160,223	448,908	591,309	524,198	412,735	128,036	107,548	16,167	2,422,790	(±0)	2.96
Japanese zelkova	18,487	182,447	1,067,407	299,821	248,188	121,747	109,620	105,965	0	2,153,681	(±0)	2.63
Littleleaf linden	15,822	135,512	514,726	1,003,457	341,592	438,823	372,157	147,577	0	2,969,667	(±0)	3.63
Sugar maple	5,527	25,423	211,545	394,043	489,880	349,462	117,963	15,305	13,858	1,623,005	(±0)	1.98
Plum	28,013	104,138	136,552	178,456	214,873	63,672	97,177	26,212	24,121	873,215	(±0)	1.07
TI	5,176	78,116	176,110	602,194	470,641	331,456	212,688	0	38,948	1,915,328	(±0)	2.34
Northern red oak	1,744	26,541	60,837	216,193	731,669	2,526,766	2,729,660	1,235,258	818,868	8,347,536	(±0)	10.20
Pin oak	5,331	9,135	21,374	106,431	398,542	1,204,566	1,034,518	237,847	67,440	3,085,183	(±0)	3.77
Silver maple	3,618	22,004	122,355	181,321	241,687	273,318	342,528	266,596	473,699	1,927,126	(±0)	2.35
Crabapple	13,829	89,561	105,369	110,534	43,652	0	23,077	0	0	386,022	(±0)	0.47
Elm	17,657	64,088	66,769	31,891	28,543	38,072	72,095	12,409	53,121	384,645	(±0)	0.47
Kwanzan cherry	18,432	69,167	66,251	62,629	108,658	44,105	0	26,212	0	395,455	(±0)	0.48
Sweetgum	2,482	23,157	214,532	606,246	341,530	81,165	0	0	0	1,269,112	(±0)	1.55
Maple	5,005	23,351	90,744	164,307	237,054	192,300	46,120	52,425	124,051	935,356	(±0)	1.14
Ginkgo	2,968	44,012	157,552	128,908	151,228	14,323	0	0	0	498,991	(±0)	0.61
Crimson king maple	4,514	17,871	98,049	188,699	121,165	60,465	19,825	0	0	510,588	(±0)	0.62
American basswood	1,883	37,639	68,978	183,539	132,533	167,322	176,249	219,317	0	987,460	(±0)	1.21
BDL OTHER	211	2,429	223,375	234,439	220,258	8,833	50,460	39,161	38,112	817,277	(±0)	1.00
American elm	2,348	19,044	10,078	50,885	173,648	218,157	226,461	77,559	105,087	883,268	(±0)	1.08
Purpleleaf plum	11,069	31,184	34,976	17,090	8,306	0	0	0	0	102,625	(±0)	0.13
Japanese pagoda tree	1,005	13,989	191,049	20,038	82,054	0	30,279	39,161	0	377,574	(±0)	0.46
Oak	4,874	4,818	8,493	29,508	86,625	186,574	247,724	144,777	102,777	816,171	(±0)	1.00
BDS OTHER	15,767	11,368	0	0	0	0	0	0	0	27,134	(±0)	0.03
Flowering dogwood	4,184	17,747	34,201	48,430	56,674	0	0	0	0	161,237	(±0)	0.20
Chinese elm	3,386	20,593	11,465	9,637	4,647	9,194	0	0	0	58,922	(±0)	0.07
Sycamore maple	923	3,941	38,987	79,821	41,528	110,985	0	0	0	276,186	(±0)	0.34
American sycamore	1,962	1,081	41,500	104,548	38,069	65,908	0	24,596	54,985	332,649	(±0)	0.41
Columnare maple	157	10,389	56,582	41,685	0	11,868	0	0	0	120,681	(±0)	0.15
Tree of heaven	414	8,762	39,755	91,059	66,569	81,165	29,580	0	0	317,306	(±0)	0.39
American hornbeam	1,707	15,652	4,105	12,967	20,578	6,490	13,322	0	19,632	94,451	(±0)	0.12
BDM OTHER	628	20,855	3,185	2,453	0	0	0	0	0	27,121	(±0)	0.03
Northern hackberry	1,190	17,348	22,449	17,588	17,655	0	0	0	0	76,231	(±0)	0.09
Sawtooth oak	191	652	4,586	21,552	23,897	57,541	84,609	175,180	110,861	479,068	(±0)	0.59

City of Providence

Relative Age Distribution of Top 10 Public Tree Species (%)

5/21/2007



	DBH class (in)								
Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42
ACPL	2.7	4.3	16.3	32.5	28.9	12.4	2.4	0.3	0.0
Callery pear	15.6	37.5	34.7	9.6	2.1	0.4	0.1	0.0	0.0
Green ash	4.1	31.2	40.5	19.3	3.7	0.8	0.2	0.2	0.0
Honeylocust	11.4	25.1	35.1	20.4	6.6	1.4	0.1	0.0	0.0
London planetree	8.6	18.1	25.9	25.3	16.2	3.5	1.6	0.2	0.6
Red maple	11.6	28.9	29.8	16.2	8.0	4.0	0.9	0.5	0.1
Japanese zelkova	15.1	30.6	46.1	4.8	2.1	0.6	0.4	0.3	0.0
Littleleaf linden	12.7	28.7	29.4	20.4	3.6	3.1	1.6	0.5	0.0
Sugar maple	4.3	10.4	32.0	25.7	18.0	7.6	1.7	0.3	0.2
Plum	29.0	38.8	16.7	8.1	5.0	1.0	1.0	0.2	0.2
Citywide total	11.1	23.6	26.7	18.8	11.3	5.4	2.1	0.6	0.5

City of Providence

Total Annual Benefits of Public Trees by Species ($)

5/21/200

Species	Energy	CO_2	Air Quality	Stormwater	Aesthetic/Other	Total ($)	Standard Error	% of Total $
Norway maple	325,874	9,541	54,864	63,342	289,447	743,068	(±0)	25.3
Callery pear	79,383	1,414	11,415	16,722	135,349	244,282	(±0)	8.3
Green ash	95,521	1,614	14,782	17,225	90,977	220,119	(±0)	7.5
Honeylocust	99,533	1,810	15,307	17,161	109,882	243,693	(±0)	8.3
London planetree	101,104	1,938	15,057	19,775	78,855	216,728	(±0)	7.4
Red maple	54,852	1,112	8,185	11,402	52,705	128,255	(±0)	4.4
Japanese zelkova	55,693	927	7,268	6,970	75,648	146,507	(±0)	5.0
Littleleaf linden	31,857	709	4,888	6,461	49,823	93,738	(±0)	3.2
Sugar maple	35,754	749	5,452	7,871	30,044	79,871	(±0)	2.7
Flowering cherry	10,817	226	1,537	1,394	6,080	20,055	(±0)	0.7
Linden species	20,218	447	3,159	4,275	28,309	56,408	(±0)	1.9
Northern red oak	48,918	1,286	8,550	13,064	26,783	98,602	(±0)	3.4
Pin oak	42,303	1,372	7,776	12,005	36,050	99,506	(±0)	3.4
Silver maple	30,727	623	5,274	8,047	18,058	62,730	(±0)	2.1
Apple	6,365	103	926	870	4,777	13,041	(±0)	0.4
Elm	8,797	209	1,431	1,982	21,968	34,388	(±0)	1.2
Kwanzan cherry	5,660	117	798	713	3,459	10,747	(±0)	0.4
Sweetgum	14,750	247	1,622	2,523	13,187	32,329	(±0)	1.1
Maple	13,375	389	2,225	2,606	12,433	31,028	(±0)	1.1
Other street trees	147,160	3,308	23,816	30,535	152,817	357,636	(±0)	12.2
Citywide Total	1,228,661	28,143	194,334	244,945	1,236,649	2,932,731	(±0)	100.0

City of Providence

Annual Aesthetic/Other Benefits of Public Trees by Species

5/21/2007

Species	Total ($)	Standard Error	% of Total Trees	% of Total $	Avg. $/tree
Norway maple	289,447	(N/A)	19.0	23.4	61.56
Callery pear	135,349	(N/A)	11.7	10.9	46.66
Green ash	90,977	(N/A)	8.7	7.4	42.37
Honeylocust	109,882	(N/A)	7.5	8.9	59.40
London planetree	78,855	(N/A)	7.1	6.4	45.03
Red maple	52,705	(N/A)	5.7	4.3	37.35
Japanese zelkova	75,648	(N/A)	4.5	6.1	68.52
Littleleaf linden	49,823	(N/A)	3.8	4.0	52.84
Sugar maple	30,044	(N/A)	2.6	2.4	47.31
Flowering cherry	6,080	(N/A)	2.4	0.5	10.45
Linden species	28,309	(N/A)	2.0	2.3	57.19
Northern red oak	26,783	(N/A)	1.8	2.2	59.65
Pin oak	36,050	(N/A)	1.8	2.9	82.31
Silver maple	18,058	(N/A)	1.7	1.5	42.79
Apple	4,777	(N/A)	1.5	0.4	12.47
Elm	21,968	(N/A)	1.4	1.8	62.77
Kwanzan cherry	3,459	(N/A)	1.4	0.3	10.20
Sweetgum	13,187	(N/A)	1.2	1.1	42.95
Maple	12,433	(N/A)	1.1	1.0	45.54
Other street trees	152,817	(N/A)	13.4	12.4	45.97
Citywide total	1,236,649	(N/A)	100.0	100.0	49.85

City of Providence

Annual Air Quality Benefits of Public Trees by Species

5/21/2007

Species	Deposition (kg) O_3	Deposition (kg) NO_2	Deposition (kg) PM_{10}	Deposition (kg) SO_2	Total Depos. ($)	Avoided (kg) NO_2	Avoided (kg) PM_{10}	Avoided (kg) VOC	Avoided (kg) SO_2	Total Avoided ($)	BVOC Emissions (kg)	BVOC Emissions ($)	Total Emissions	Total ($)	Standard Error	% of Total Trees	Avg. $/tree
Norway maple	1,150.3	497.3	564.8	188.7	28,466	1,770.0	114.7	68.0	905.2	27,302	-177.6	-905	5,081.2	54,864	(N/A)	19.0	11.67
Callery pear	223.6	96.5	111.5	37.3	5,569	408.0	26.6	16.1	195.7	6,200	-69.5	-354	1,045.9	11,415	(N/A)	11.7	3.93
Green ash	289.9	121.9	139.7	44.5	7,068	504.0	32.8	19.6	249.5	7,714	0.0	0	1,401.9	14,782	(N/A)	8.7	6.89
Honeylocust	320.5	129.9	152.2	49.2	7,723	537.8	34.9	20.7	273.5	8,285	-137.6	-701	1,381.0	15,307	(N/A)	7.5	8.27
London planetree	343.6	144.4	165.6	52.8	8,377	550.1	35.6	21.1	281.9	8,490	-355.4	-1,810	1,239.8	15,057	(N/A)	7.1	8.60
Red maple	170.7	73.8	83.8	28.0	4,223	287.8	18.7	11.2	141.5	4,398	-85.8	-437	729.7	8,185	(N/A)	5.7	5.80
Japanese zelkova	117.2	49.2	56.5	18.0	2,856	289.4	18.9	11.3	140.7	4,412	0.0	0	701.2	7,268	(N/A)	4.5	6.58
Littleleaf linden	99.3	41.7	47.8	15.2	2,420	171.7	11.1	6.6	87.0	2,643	-34.3	-174	446.3	4,888	(N/A)	3.8	5.18
Sugar maple	115.2	49.8	56.5	18.9	2,850	189.7	12.3	7.4	94.5	2,908	-60.1	-306	484.2	5,452	(N/A)	2.6	8.59
Flowering cherry	29.6	12.8	14.5	4.9	733	53.6	3.5	2.1	24.5	805	-0.2	-1	145.4	1,537	(N/A)	2.3	2.64
Linden species	64.9	27.3	31.3	10.0	1,581	109.8	7.1	4.2	56.2	1,694	-22.9	-116	287.8	3,159	(N/A)	2.0	6.38
Northern red oak	211.0	91.1	105.3	35.2	5,256	276.3	17.8	10.4	147.2	4,304	-198.2	-1,009	696.1	8,550	(N/A)	1.8	19.04
Pin oak	194.1	83.8	96.8	32.4	4,834	243.6	15.7	9.1	132.4	3,814	-171.4	-873	636.5	7,776	(N/A)	1.8	17.75
Silver maple	116.7	50.5	57.3	19.2	2,889	167.6	10.9	6.4	86.2	2,589	-40.0	-204	474.8	5,274	(N/A)	1.7	12.50
Apple	18.4	8.0	9.0	3.1	455	31.4	2.1	1.3	14.3	472	-0.2	-1	87.3	926	(N/A)	1.5	2.42
Elm	28.9	11.7	13.7	4.4	697	47.7	3.1	1.8	24.3	735	0.0	0	135.7	1,431	(N/A)	1.4	4.09
Kwanzan cherry	15.4	6.6	7.5	2.5	380	27.9	1.8	1.1	12.6	418	-0.1	-1	75.4	798	(N/A)	1.4	2.35
Sweetgum	42.6	17.3	20.2	6.5	1,026	80.0	5.2	3.1	40.8	1,233	-125.1	-637	90.6	1,622	(N/A)	1.2	5.29
Maple	46.7	20.2	22.9	7.7	1,155	72.0	4.7	2.8	36.5	1,108	-7.4	-38	205.9	2,225	(N/A)	1.1	8.15
Other street trees	506.7	216.0	250.3	83.2	12,536	799.8	51.8	30.7	409.3	12,339	-208.2	-1,060	2,139.6	23,816	(N/A)	13.4	7.16
Citywide total	4,105.0	1,749.8	2,007.2	661.7	101,096	6,618.2	429.2	255.2	3,353.8		-1,694.0	-8,627	17,486.2	194,334	(N/A)	100.0	7.83

City of Providence

Annual CO_2 Benefits of Public Trees by Species

5/21/2007

Species	Sequestered (kg)	Sequestered ($)	Decomposition Release(kg)	Maintenance Release(kg)	Total Released ($)	Avoided (kg)	Avoided ($)	Net Total (kg)	Total Standard ($) Error	% of Total Trees	% of Total $	Avg. $/tree
Norway maple	813,657	5,991	-111,558	-27,523	-1,024	621,203	4,574	1,295,779	9,541 (N/A)	19.0	33.9	2.03
Callery pear	85,015	626	-20,156	-7,099	-201	134,206	988	191,966	1,414 (N/A)	11.7	5.0	0.49
Green ash	69,452	511	-14,535	-6,795	-157	171,126	1,260	219,248	1,614 (N/A)	8.7	5.7	0.75
Honeylocust	91,704	675	-27,574	-5,938	-247	187,667	1,382	245,859	1,810 (N/A)	7.5	6.4	0.98
London planetree	94,032	692	-16,872	-7,449	-179	193,460	1,425	263,172	1,938 (N/A)	7.1	6.9	1.11
Red maple	77,533	571	-18,754	-4,809	-174	97,063	715	151,032	1,112 (N/A)	5.7	4.0	0.79
Japanese zelkova	38,620	284	-6,468	-2,781	-68	96,505	711	125,876	927 (N/A)	4.5	3.3	0.84
Littleleaf linden	50,563	372	-10,952	-3,095	-103	59,726	440	96,243	709 (N/A)	3.8	2.5	0.75
Sugar maple	52,411	386	-12,470	-3,035	-114	64,828	477	101,734	749 (N/A)	2.6	2.7	1.18
Flowering cherry	19,559	144	-4,299	-1,296	-41	16,788	124	30,752	226 (N/A)	2.4	0.8	0.39
Linden species	32,292	238	-8,171	-1,897	-74	38,545	284	60,768	447 (N/A)	2.0	1.6	0.90
Northern red oak	92,725	683	-15,464	-3,614	-140	101,065	744	174,712	1,286 (N/A)	1.8	4.6	2.87
Pin oak	118,008	869	-19,111	-3,471	-166	90,899	669	186,325	1,372 (N/A)	1.8	4.9	3.13
Silver maple	39,220	289	-11,204	-2,538	-101	59,132	435	84,610	623 (N/A)	1.7	2.2	1.48
Apple	6,092	45	-1,201	-729	-14	9,792	72	13,954	103 (N/A)	1.5	0.4	0.27
Elm	15,052	111	-2,580	-777	-25	16,680	123	28,376	209 (N/A)	1.4	0.7	0.60
Kwanzan cherry	9,879	73	-1,957	-673	-19	8,664	64	15,913	117 (N/A)	1.4	0.4	0.35
Sweetgum	9,062	67	-2,369	-1,204	-26	28,015	206	33,504	247 (N/A)	1.2	0.9	0.80
Maple	33,860	249	-4,882	-1,182	-45	25,028	184	52,825	389 (N/A)	1.1	1.4	1.42
Other street trees	229,162	1,687	-48,975	-11,805	-448	280,906	2,068	449,288	3,308 (N/A)	13.4	11.8	1.00
Citywide total	1,977,898	14,564	-359,551	-97,709	-3,367		16,945	3,821,935	28,143 (N/A)	100.0	100.0	1.13

City of Providence

Annual Energy Benefits of Public Trees by Species

5/21/2007

Species	Total Electricity (GJ)	Electricity ($)	Total Natural Gas (GJ)	Natural Gas ($)	Total ($)	Standard Error	% of Total Trees	% of Total $	Avg. $/tree
Norway maple	1,636.8	54,563	17,669.6	271,311	325,874	(N/A)	19.0	26.5	69.31
Callery pear	353.6	11,788	4,402.2	67,595	79,383	(N/A)	11.7	6.5	27.36
Green ash	450.9	15,031	5,242.1	80,490	95,521	(N/A)	8.7	7.8	44.49
Honeylocust	494.5	16,484	5,408.8	83,050	99,533	(N/A)	7.5	8.1	53.80
London planetree	509.7	16,992	5,477.9	84,112	101,104	(N/A)	7.1	8.2	57.74
Red maple	255.7	8,525	3,017.1	46,326	54,852	(N/A)	5.7	4.5	38.87
Japanese zelkova	254.3	8,476	3,075.1	47,217	55,693	(N/A)	4.5	4.5	50.45
Littleleaf linden	157.4	5,246	1,733.1	26,611	31,857	(N/A)	3.8	2.6	33.78
Sugar maple	170.8	5,694	1,957.7	30,060	35,754	(N/A)	2.6	2.9	56.31
Flowering cherry	44.2	1,475	608.4	9,342	10,817	(N/A)	2.4	0.9	18.59
Linden species	101.6	3,386	1,096.2	16,832	20,218	(N/A)	2.0	1.7	40.84
Northern red oak	266.3	8,877	2,607.8	40,041	48,918	(N/A)	1.8	4.0	108.95
Pin oak	239.5	7,984	2,235.1	34,319	42,303	(N/A)	1.8	3.4	96.58
Silver maple	155.8	5,194	1,662.9	25,534	30,727	(N/A)	1.7	2.5	72.81
Apple	25.8	860	358.5	5,505	6,365	(N/A)	1.5	0.5	16.62
Elm	43.9	1,465	477.5	7,332	8,797	(N/A)	1.4	0.7	25.13
Kwanzan cherry	22.8	761	319.1	4,899	5,660	(N/A)	1.4	0.5	16.70
Sweetgum	73.8	2,461	800.3	12,289	14,750	(N/A)	1.2	1.2	48.04
Maple	65.9	2,198	727.9	11,176	13,375	(N/A)	1.1	1.1	48.99
Other street trees	740.1	24,673	7,977.2	122,487	147,161	(N/A)	13.4	12.0	44.27
Citywide total	6,063.5	202,132	66,854.7			(N/A)	100.0	100.0	49.53

City of Providence

Annual Stormwater Benefits of Public Trees by Species

5/21/2007

Species	Total rainfall interception (cu.m.)	Total ($)	Standard Error	% of Total Trees	% of Total $	Avg. $/tree
Norway maple	29,972	63,342	(N/A)	19.0	25.9	13.47
Callery pear	7,913	16,722	(N/A)	11.7	6.8	5.76
Green ash	8,150	17,225	(N/A)	8.7	7.0	8.02
Honeylocust	8,120	17,161	(N/A)	7.5	7.0	9.28
London planetree	9,357	19,775	(N/A)	7.1	8.1	11.29
Red maple	5,395	11,402	(N/A)	5.7	4.7	8.08
Japanese zelkova	3,298	6,970	(N/A)	4.5	2.9	6.31
Littleleaf linden	3,057	6,461	(N/A)	3.8	2.6	6.85
Sugar maple	3,724	7,871	(N/A)	2.6	3.2	12.40
Flowering cherry	660	1,394	(N/A)	2.4	0.6	2.40
Linden species	2,023	4,275	(N/A)	2.0	1.8	8.64
Northern red oak	6,181	13,064	(N/A)	1.8	5.3	29.10
Pin oak	5,681	12,005	(N/A)	1.8	4.9	27.41
Silver maple	3,808	8,047	(N/A)	1.7	3.3	19.07
Apple	412	870	(N/A)	1.5	0.4	2.27
Elm	938	1,982	(N/A)	1.4	0.8	5.66
Kwanzan cherry	338	713	(N/A)	1.4	0.3	2.10
Sweetgum	1,194	2,523	(N/A)	1.2	1.0	8.22
Maple	1,233	2,606	(N/A)	1.1	1.1	9.55
Other street trees	14,448	30,535	(N/A)	13.4	12.5	9.19
Citywide total	115,902	244,945	(N/A)	100.0	100.0	9.87

City of Providence

Stored CO2 Benefits of Public Trees by Species

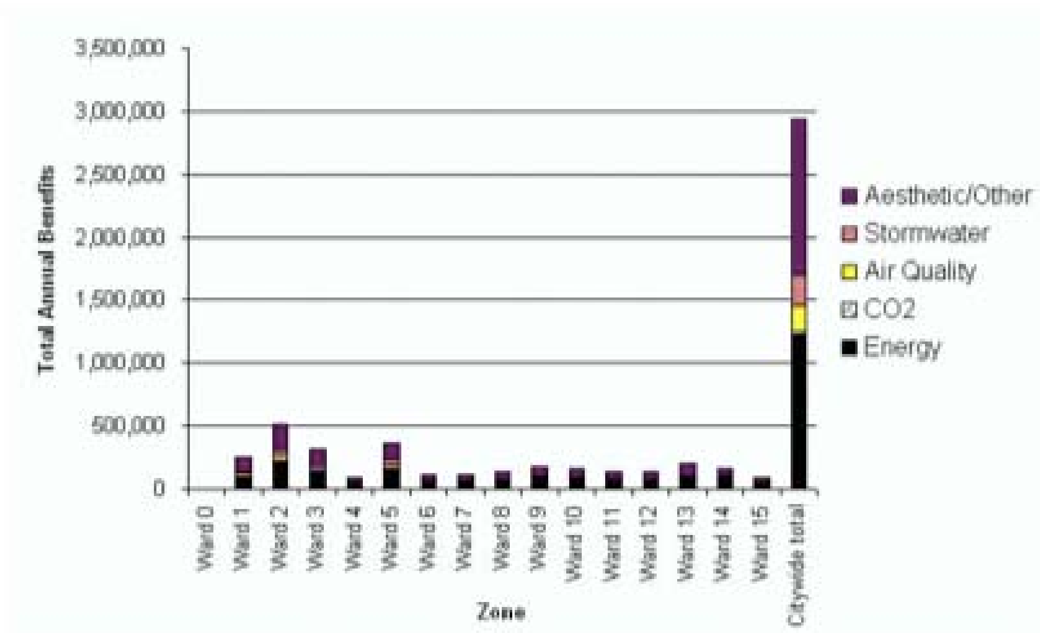
5/21/2007

Species	Total Stored CO2 (kg)	Total ($)	Standard Error	% of Total Trees	% of Total $	Avg. $/tree
Norway maple	13,042,405	96,037	(N/A)	19.0	36.0	20.42
Callery pear	958,836	7,060	(N/A)	11.7	2.7	2.43
Green ash	920,291	6,777	(N/A)	8.7	2.5	3.16
Honeylocust	1,345,973	9,911	(N/A)	7.5	3.7	5.36
London planetree	1,748,029	12,872	(N/A)	7.1	4.8	7.35
Red maple	1,656,631	12,199	(N/A)	5.7	4.6	8.65
Japanese zelkova	331,593	2,442	(N/A)	4.5	0.9	2.21
Littleleaf linden	746,516	5,497	(N/A)	3.8	2.1	5.83
Sugar maple	1,263,457	9,303	(N/A)	2.6	3.5	14.65
Flowering cherry	344,870	2,539	(N/A)	2.4	1.0	4.36
Linden species	528,738	3,893	(N/A)	2.0	1.5	7.87
Northern red oak	3,107,547	22,882	(N/A)	1.8	8.6	50.96
Pin oak	2,742,804	20,196	(N/A)	1.8	7.6	46.11
Silver maple	1,787,595	13,163	(N/A)	1.7	4.9	31.19
Apple	97,859	721	(N/A)	1.5	0.3	1.88
Elm	211,529	1,558	(N/A)	1.4	0.6	4.45
Kwanzan cherry	158,508	1,167	(N/A)	1.4	0.4	3.44
Sweetgum	155,565	1,145	(N/A)	1.2	0.4	3.73
Maple	556,928	4,101	(N/A)	1.1	1.5	15.02
Other street trees	2,036,799	33,065	(N/A)	13.4	12.4	9.95
Citywide total	36,196,041	266,527	(N/A)	100.0	100.0	10.74

City of Providence

Total Annual Benefits of Public Trees by Zone ($)

5/21/200



Zone	Energy	CO_2	Air Quality	Stormwater	Aesthetic/Other	Total ($)	Standard Error	% of Total $
Ward 0	819	20	133	154	821	1,947	(N/A)	0.1
Ward 1	102,575	2,166	15,827	19,711	107,358	247,637	(N/A)	8.4
Ward 2	218,602	5,145	34,877	43,840	205,821	508,285	(N/A)	17.3
Ward 3	129,283	3,087	20,633	25,477	132,133	310,612	(N/A)	10.6
Ward 4	35,323	811	5,621	7,139	35,068	83,962	(N/A)	2.9
Ward 5	160,501	3,967	26,545	34,852	144,018	369,883	(N/A)	12.6
Ward 6	43,892	1,006	6,820	8,395	46,858	106,971	(N/A)	3.6
Ward 7	49,289	1,032	7,682	9,494	43,850	111,346	(N/A)	3.8
Ward 8	56,996	1,414	9,350	11,939	54,066	133,765	(N/A)	4.6
Ward 9	72,881	1,627	11,240	13,478	79,770	178,995	(N/A)	6.1
Ward 10	67,499	1,578	10,782	14,046	66,170	160,076	(N/A)	5.5
Ward 11	53,024	1,080	7,906	9,688	69,332	141,030	(N/A)	4.8
Ward 12	53,359	1,125	8,197	10,283	59,653	132,616	(N/A)	4.5
Ward 13	78,184	1,484	11,390	13,499	91,083	195,640	(N/A)	6.7
Ward 14	71,266	1,873	12,004	16,338	59,614	161,095	(N/A)	5.5
Ward 15	35,168	727	5,329	6,614	41,034	88,872	(N/A)	3.0
Citywide total	1,228,661	28,143	194,334	244,945	1,236,649	2,932,731	(N/A)	100.0