CUFR-2

Benefit-Cost Analysis of Fort Collins' Municipal Forest

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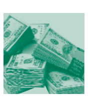
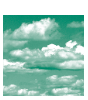
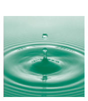
Center for
Urban Forest Research

Areas of Research:

 Investment Value

 Energy Conservation

 Air Quality

 Water Quality

 Firewise Landscapes

Mission Statement

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

United States
Department of
Agriculture

Forest Service

Pacific Southwest
Research Station

Center for Urban
Forest Research

Internal Report
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Content

Executive Summary
Benefit-Cost Analysis of Fort Collins' Municipal Forest

"You can gauge a country's wealth, its real wealth, by its tree cover."
--- Dr. Richard St. Barbe Baker, *Man of the Trees*

The primary purpose of this report is to answer the question: *Do the accrued benefits from Fort Collins' urban forest justify an annual municipal budget that is nearly $1 million?* Our results indicate that the 31,000 streets and park trees in Fort Collins produce substantial benefits. Net annual benefits total $1.17 million ($38/tree, $9/capita). For every $1 invested in tree management, residents receive $2.18 in benefits for increased property values, reduced stormwater runoff, cleaner air, energy conservation, and reduced atmospheric carbon dioxide. Over the years Fort Collins has invested millions in its municipal forest. Citizens are now receiving a relatively large return on that investment. Continued investment in management is critical to insuring that residents receive a greater return on investment in the future.

Other important findings:

- Fort Collins' municipal forest is healthy and well-stocked. Seventy-five percent of the trees are in excellent or good condition, 20% are in fair condition, and 5% are poor, dying, or dead. Approximately 66% of all streetside planting sites are filled with trees.

- Benefits total $2.17 million ($70/tree) with greatest value for aesthetic benefits/increased property values ($1.6 million, $52/tree) and reduced stormwater runoff ($404,000, $13/tree). Building shade, cooler summertime temperatures, and decreased winter winds attributed to street and park trees produce energy savings valued at $112,000 ($4/tree). Smaller benefits result from atmospheric carbon dioxide reduction ($25,000, $2/tree) and improved air quality ($18,000, $1/tree).

- These findings indicate that the City's trees are providing important aesthetic, health, and environmental benefits to residents.

- Costs total $997,000 ($32/tree) with 41% of this amount for pruning ($405,000). Mature tree care accounts for 70% of total costs.

- Green ash is the most abundant street tree species. It accounts for 22% of all street trees and produces 17% of all street tree benefits. Other important species by virtue of their size and numbers are Honeylocust, American elm, Hackberry, Siberian elm, Littleleaf linden, and Silver maple.

- Large, old trees (> 24 inch dbh) account for 11% of the population and produce 22% of all benefits ($144/tree). American elms on streets alone account for 23% of total annual benefits from old trees. Siberian elm, Silver maple, and Plains cottonwood along streets together account for another 31% of the remaining benefits. Although these dominant species have proven to be relatively long-lived, they are being phased-out of the population. Insect and disease problems, brittle wood and intensive pruning requirements make them unsuitable for planting in large numbers. Intensive inspection and maintenance are necessary to insure that these problems do not jeopardize tree health, public safety, and the sizable benefits that these trees produce.

- The City is planting a myriad of large-stature trees that are more suitable than the species they replace. These new plantings include varieties of White ash, Oak, Maple, and Linden. As a result, the forest is becoming more diverse, and ultimately, more stable.

Chapter I. Introduction

"I think that I shall never see heat pump lovely as a tree."

--- Adapted from Joyce Kilmer

Fort Collins' Forestry Division manages approximately 16,400 trees along streets and 14, 500 trees in parks. The Division believes that the public's investment in stewardship of Fort Collins' urban forest produces benefits that are particularly relevant to the community. Fort Collins needs to maintain a vigorous local economy, while retaining the quality of life for which it is known. Research indicates that healthy city trees can mitigate impacts of development on air quality, climate, energy for heating and cooling buildings, and stormwater runoff. Healthy street trees increase real estate values, provide neighborhoods with a sense of place, and foster psychological well-being. Street and park trees are associated with other intangibles such as increased community attractiveness and recreational opportunities that make Fort Collins a more enjoyable place to work and play. Fort Collins' urban forest creates a setting that helps attract tourism and retain businesses and residents.

However, in an era of dwindling public funds and rising expenditures elected officials often scrutinize expenditures that are considered "non-essential" such as planting and management of the municipal forest. Although the current program has demonstrated its economic efficiency, questions remain regarding the need for the level of service presently provided. Hence, the primary question that this study asks is:

Do the accrued benefits from Fort Collins' urban forest justify an annual municipal budget of nearly $1.0 million?

In answering this question our purpose is to:

- Assist decision-makers assess and justify the degree of funding and type of management program appropriate for this city's urban forest.
- Provide critical baseline information for the evaluation of program cost-efficiency, alternative pruning cycles, and alternative management structures.
- Highlight the relevance and relationship of Fort Collins' urban forest to local quality of life issues such as environmental health, economic development, and psychological well-being.
- Provide quantifiable data to assist in developing alternative funding sources through utility purveyors, air quality districts, federal or state agencies, legislative initiatives, or local assessment fees.

This report consists of 7 Chapters.

Chapter I.	**Introduction** - Describes the purpose of this study.
Chapter II.	**Fort Collins' Urban Forest** - Describes the current species composition, structure, and health of the street and park tree population.
Chapter III.	**Costs of Managing Fort Collins' Urban Forest** - Details management expenditures.
Chapter IV.	**Benefits Produced by Fort Collins' Urban Forest** - Quantifies the estimated value of tangible benefits, describes intangible benefits, and calculates net benefits and a benefit-cost ratio.
Chapter V.	**Conclusions** – Summarizes results, evaluates relevancy of the current program, and identifies future management challenges and opportunities.
Chapter VI.	**Acknowledgments and References** - Lists publications cited in the study and the contributions made by various participants not cited as authors.
Chapter VII.	**Appendices** - Contain detailed information on the municipal tree population in Fort Collins and methods used to conduct the study.

Chapter II. Fort Collins' Urban Forest

"We all know what trees are, of course – and certainly we know what they look like, and how and where they live, how big or small they can be, how old, how fast, or slowly they grow – we know all about trees. Hah! What pompous pipsqueaks we humans can be at times."-
--- Russ Kinne

History and Current Management

Tree planting began in the City of Fort Collins soon after settlement. Early developers planted many trees. For example, Elms that stand today on the Oval at Colorado State were planted in the 1880s. This tree planting tradition has left a valuable arboreal legacy in Fort Collins.

The City of Fort Collins has one of the most comprehensive and highly regarded tree programs in the nation. This spring the City of Fort Collins received recognition as a Tree City USA for the 25th year. Tim Buchanan, the City Forester has served in state and regional leadership positions for professional organizations such as the Rocky Mountain Chapter, International Society of Arboriculture and the Front Range Urban Forestry Council. He is frequently requested to share expertise and success stories with other professionals and communities wishing to take their programs to a higher level. The City of Fort Collins has a proud tradition of excellence in urban and community forestry.

In 2003 the tree program employed 11 full time staff to maintain approximately 31,000 street and park trees. The City plants, prunes, preserves, removes, and replaces dying and diseased trees to protect public safety and perpetuate net benefits from a healthy tree population. A street tree inventory was updated in 2002. Approximately 3,500 street trees are pruned each year. Street trees are in one of three different trim cycles, depending on size. Large trees (>40 ft) are pruned every 12 years. Medium trees (20-40 ft) are pruned every 7 years. Small trees are trimmed every 8 years for structure and form. Monitoring to detect pest problems is performed regularly, and treatments are applied as needed. Storm damage clean-up, root pruning, and other emergency activities are performed on an as-needed basis.

Approximately 400 trees are removed from City streets and parks each year. About 500 trees are planted annually following guidelines documented in several brochures that can be obtained from the city web-site. Removed trees are replaced, usually with 1 3/4" balled and burlapped (B&B) trees, 15 gallon stock, or transplants moved with a tree spade. Trees are selected to fit the available space and match other growing conditions. A diverse mix of species are planted to protect against catastrophic loss.

Species Composition, Structure, Condition of Existing Trees

Tree Numbers and Species Composition

There are approximately 30,942 street and park trees in Fort Collins. Street trees account for 53% (16,408) of the total, while park trees comprise the remaining 47% (14,534). Assuming Fort Collins' human population is 135,000 (personal correspondence, Tim Buchanan, Oct. 10, 2002), there is about one public tree for every four residents. Fort Collins' ratio of street trees per capita is 0.12, somewhat less than the mean ratio of 0.37 reported for 22 U.S. street tree populations (McPherson and Rowntree 1989).

Full stocking of street tree populations has been defined as having all vacant sites planted. This equates to an average spacing between trees of about 50 ft (15 m) on average (McPherson and Rowntree 1989). There are approximately 25,000 street tree planting sites in Fort Collins, and about 8,500 are estimated to be vacant. Hence, 66% of all planting sites are filled with trees. This finding indicates that Fort Collins' streets are relatively well-treed. Park tree densities average 22.4 trees/ac (55.3/ha), slightly greater than 14 and 21 trees/ac in Modesto and Santa Monica, CA (McPherson and Simpson 2002).

Large-stature trees comprise 86% and 64% of the street and park tree populations, respectively. Parks contain relatively more medium-stature trees than streets (26% to 4%), while small trees make up 10% of both populations **(Table 1)**. Conifers account for 34% of all park trees, but only 4% of all street trees. Fort Collins is likely to receive substantial benefits from its trees now and into the future because 76% of all street trees have a large mature size. The distribution of all street trees by mature size class and life form is shown in **Table 1**.

There are 95 different species of trees in the street tree inventory database. The mean number of species recorded for 22 U.S. street tree populations was 53, but Los Angeles and La Canada Flintridge, CA and Eugene, OR contained 77, 77, and 63 tree species, respectively (McPherson and Rowntree 1989). Compared to these cities, Fort Collins has a relatively rich assemblage of trees species along its streets.

Green ash (*Fraxinus pennsylvanica*) is the most common street tree species, with 3,551 trees accounting for 22% of the population (**Table 2**). Honey locust (*Gleditsia triacanthos*) accounts for 10.2% all trees. These percentages exceed the customary guideline that no single species should exceed 10% of the population. However, these species seem relatively well-suited to growing conditions in Fort Collins and are not likely to fail in large numbers. The next most abundant species are Littleleaf linden, 7% (*Tilia cordata*), Burr oak, 6% (*Quercus macrocarpa*), Hackberry, 6% (*Celtis occidentalis*), and Apple/crabapples, 5% (*Malus spp.*).

Importance and Age Structure

The importance of Green ash as the dominant component of the City's street tree population is illustrated in Table 2. They account for 21% of all street tree canopy cover, 20% of all leaf area, and 22% of all trees. Many of the benefits and costs associated with Fort Collins' municipal urban forest are associated with this species. Although relatively few in numbers (4%), American elm (*Ulmus americana*) accounts for 19% of total canopy cover due to its large mature crown size. Other relatively important species include Honey locust, Siberian elm (*Ulmus pumila*), Hackberry, Silver maple (*Acer saccharinum*), Plains cottonwood (*Populus sargentii*), and Norway maple (*Acer platanoides*). Some species are very abundant but relatively unimportant. For example, Littleleaf linden make up 7% of the population but only 2% of the total canopy cover because many are recently planted.

The distribution of ages within a tree population influences present and future costs as well as the flow of benefits. An uneven-aged population allows managers to allocate annual maintenance costs uniformly over many years and assure continuity in overall tree canopy cover (Miller 1997). An "ideal" distribution has a high proportion of new transplants (40%) and the percentage of trees in the older classes progressively declines (30% maturing, 20% mature, 10% old) (Richards 1982/83). Younger trees tend to have the highest loss rates, so are needed in greatest numbers.

The age structure for all trees in Fort Collins is well distributed among size classes **(Figure 1)**. Young trees less than 6" diameter at breast height (dbh) account for 53% of the population compared to the "ideal" of 40%, and old trees (> 24" dbh) make up 6% of the population compared to the "ideal" of 10%. Maturing trees match the "ideal" 30%, but Fort Collins has a deficit of mature trees (18-30" dbh), only 11% compared to the "ideal" 20%. These trees would have been planted from 1950-1975. The park tree population contains relatively more maturing and mature trees than does the street tree population (Appendix A).

Table 1. Percentage of each tree type by mature size class and location (Large = >40 ft tall, Mod. = 25-40 ft, Small = <25 ft).

	Street				Park				Total			
Tree Type	Large	Mod	Small	Total	Large	Mod	Small	Total	Large	Mod	Small	Total
Brdleaf Decid.	85.9	2.3	8.3	96.5	47.2	11.8	6.7	65.7	67.7	6.7	7.6	82.0
Conifer	0.3	1.8	1.4	3.5	17.2	13.7	3.4	34.3	8.2	7.4	2.4	18.0

Table 2. Tree numbers, leaf area (LA), canopy cover (CC), and importance value (IV) of Fort Collins' street trees.

Species	Tree No.	% Total	LA	% Total	CC	% Total	IV
Green ash	3,552	21.6	9,636	20.1	2,147	20.8	20.9
American elm	715	4.4	8,721	18.2	1,906	18.5	13.7
Honey locust	1,674	10.2	4,202	8.8	1,065	10.3	9.8
Siberian elm	467	2.9	5,482	11.5	982	9.5	7.9
Hackberry	916	5.6	2,781	5.8	551	5.3	5.6
Silver maple	298	1.8	3,351	7.0	657	6.4	5.1
Plains cottonwood	233	1.4	2,424	5.1	491	4.8	3.7
Norway maple	484	2.9	1,813	3.8	430	4.2	3.6
Burr oak	1,080	6.6	603	1.3	149	1.4	3.1
American linden	390	2.4	640	1.3	94	0.9	1.5
White ash	279	1.7	365	0.8	62	0.6	1.0
Pear spp.	163	2.3	100	0.2	35	0.3	0.9
Austrian pine	201	1.2	291	0.6	64	0.6	0.8
Kentucky coffee tree	176	1.1	260	0.5	78	0.8	0.8
Cherry/plum spp.	158	1.5	18	0.0	8	0.1	0.5
Austrian pine	100	0.6	183	0.4	38	0.4	0.5
Colorado spruce	159	0.3	100	0.2	17	0.2	0.2
Other street trees	5,363	31.5	6,856	14.3	1,537	14.9	20.3
	16,408	100.0	47,827	100.0	10,311	100.0	100.0

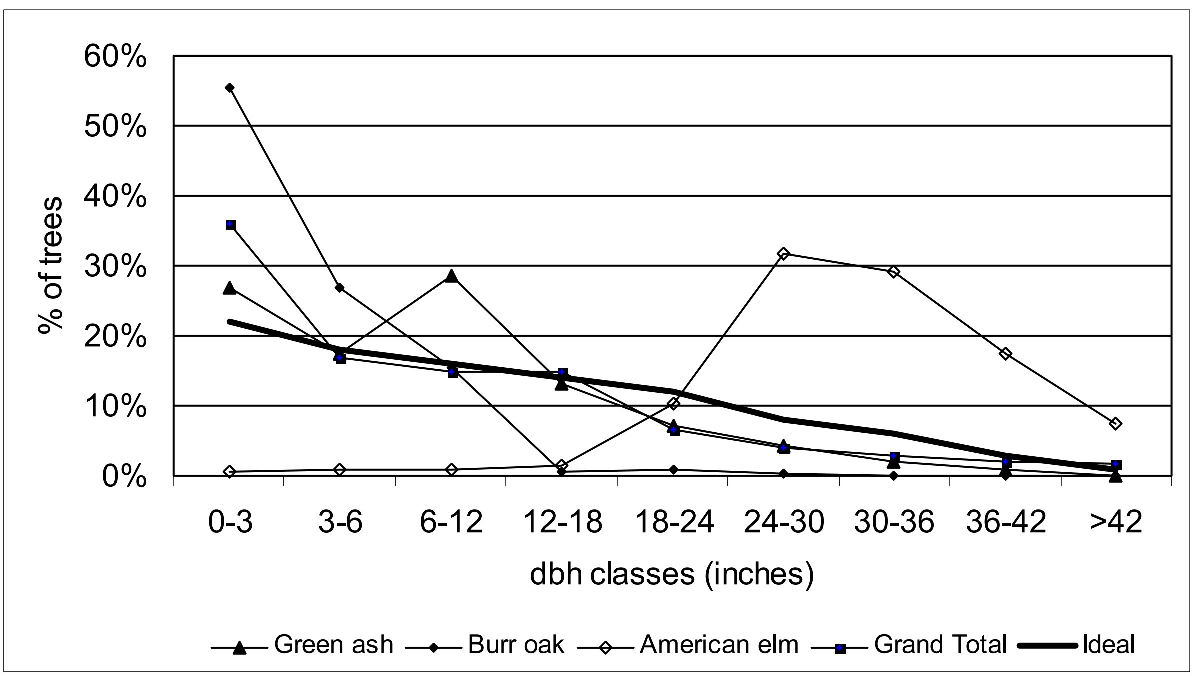

Figure 1. Age structure of selected species, all trees, and an "ideal" distribution that allows for higher mortality rates for younger trees.

Age curves for different tree species help explain their relative importance and suggest how tree management needs may change as these species grow older. Many of Fort Collins' American elm, Plains cottonwood, and Siberian elm are greater than 50 years old and require intensive care. These trees have provided benefits over a long period of time. The relatively large percentage of older trees suggests that future benefits will be closely linked to their health. On the other hand, most of the Burr oak and Littleleaf linden are young trees. Training these trees for structure and form while young will reduce later costs for pruning and storm clean-up.

Tree Canopy Cover

We estimate that the street tree canopy covers almost 1 million sq ft (8.9 ha). Given City area of 49.4 sq miles (128 km^2), street tree canopy covers 22 ac or 0.07% of the entire City. Fort Collins' street trees shade approximately 0.5% of all street paving. This calculation assumes that 40% of all street tree canopy cover is shading street surfaces, there are 436 miles (702 km) of street, and the average curb-to-curb distance is 35 ft (10.7 m).

Condition of Existing Trees

We infer from our sample of 847 street trees to the entire municipal tree population to evaluate the condition of existing trees. Overall, the municipal urban forest appears healthy. Fifteen percent of the trees are in excellent condition, 60% are in good condition, and 20% are in fair condition **(Figure 2)**. About 5% of the trees are in poor condition, dying, or dead. During our field work we found very few trees that were candidates for immediate removal.

The relative performance index (RPI) of each species provides an indication of their suitability to local growing conditions, as well as their performance. It is calculated for each species by dividing its proportion of all trees rated as good or excellent by the percentage of all trees rated as good or excellent. For example, the RPI for Green ash is 1.15 because 86% were good or excellent compared to 74.7% of all trees rated good or excellent (0.86/0.747 = 1.15). Species with RPIs greater than 1.0 have proportionately more individuals classified as good or excellent. Such trees are likely to provide greater benefits at less cost than species with RPIs less than 1.0. Species with the highest RPI are the Littleleaf and American linden (*Tilia americana*), White ash *(Fraxinus americana*), Apple/crabapple species, Kentucky coffee tree (*Gymnocladus diocus*), Hackberry, Green ash, and Burr oak **(Table 3).** These species are widely adapted to growing conditions throughout the City. Species with the lowest RPIs are the elms, Plains cottonwood, Silver maple, and Colorado spruce (*Picea pungens*). The elm and cottonwood populations largely consist of older trees.

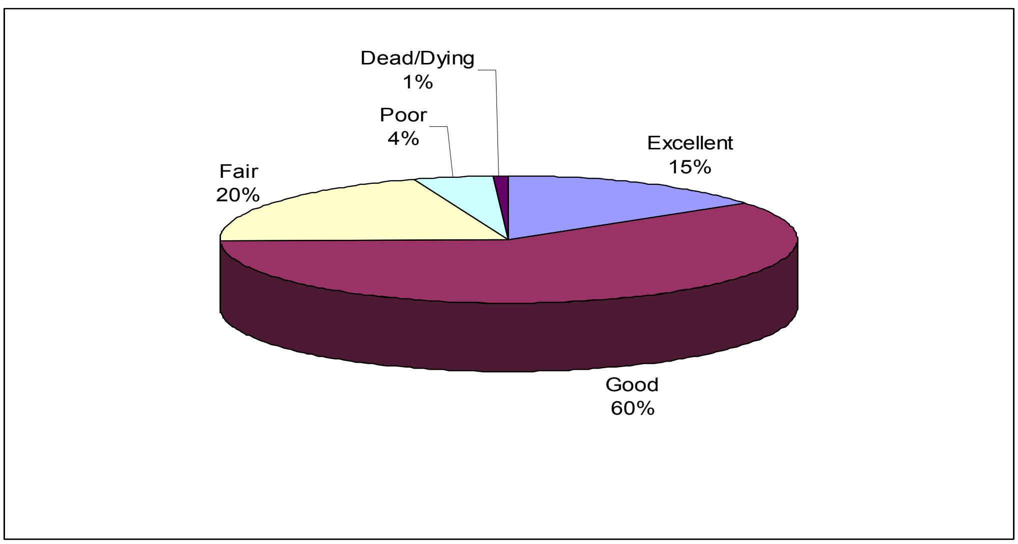

Figure 2. Distribution of street trees by condition class.

Table 3. Relative performance index (RPI) for street tree species in Fort Collins.

Species	RPI
Littleleaf linden	1.30
American linden	1.30
White ash	1.29
Apple/crabapple species	1.29
Kentucky coffee tree	1.25
Hackberry	1.16
Green ash	1.15
Burr oak	1.14
Cherry/plum species	1.12
Pear species	1.10
Austrian pine	1.09
Sugar maple	1.08
Norway maple	1.07
Ponderosa pine	1.03
Honeylocust	1.02
Colorado spruce	0.97
Silver maple	0.93
Siberian elm	0.70
Plains cottonwood	0.48
American elm	0.42

Location and Other Features

From the street tree sample we found that 76% of all trees were in planting strips, 12% in front yards, 11% in medians, and 1% in cutouts. The majority of trees were adjacent to single family residential land uses (59%), and others were on commercial/industrial (12%), multi-family residential (11%), and other land uses (18%).

Roots from 23% of the trees had heaved sidewalks. Thirty-one percent of all trees shaded cars in streetside parking spaces and driveways. Tree shade reduces the potential release of evaporative hydrocarbons from parked vehicles that are precursors to ozone formation (Scott et al. 1999).

Chapter III. Costs of Managing Fort Collins' Urban Forest

They took all the trees and put them in a tree museum... And they charged all the people a dollar and a half just to see 'em... Don't it always seem to go that you don't know what you've got... Till it's gone … They've paved paradise and put up a parking lot."
--- Joni Mitchell

Program Expenditures

Costs were based on a review of expenditures during fiscal years 2002 and 2003, as well as budgets for fiscal year 2004. The FY 2004 operating budget for the Forestry Division of the Parks and Recreation Department is approximately $925,438 (personal communication, Tim Buchanan, City of Fort Collins, October, 2002). This amount represents 0.3% of the City's total operating budget ($343.7 million in FY2004) and $6.86 per person (135,000 pop.). Assuming our figure of 30,942 street and park trees, the Forestry Division spends $29.91/tree on average during the fiscal year. The Forestry Division's per tree expenditure is greater than the 1997 mean value of $19/tree reported for 256 California cities (Thompson and Ahern 2000). We estimate that an additional $72,200 is spent on tree-related matters by other city departments. These external expenditures involve hardscape repair and legal issues. Overall, $997,638 is spent on management of Fort Collins' municipal urban forest ($7.39/capita, $32.19/tree). Forestry Division expenditures fall into three categories: tree planting and establishment, mature tree care, and administration.

Tree Planting and Establishment

The production of quality nursery stock, its planting, and follow-up care are critical to perpetuation of a healthy urban forest. The city plants and establishes about 500 trees each year, 60% at new sites and 40% as replacements for removed trees. Costs are typically about $150/tree for planting (1 ¾ " caliper B&B), $60 for watering, and an additional $160 for concrete cutting when needed. These activities consume 12% of the tree program budget, or $111,052. Approximately 600 young trees are pruned annually for structure and form at an average cost of $35/tree. During summer street trees are watered bi-weekly by truck for the first three years after planting at a cost of $3/tree per watering. Park trees are watered by in-ground irrigation (drip or sprinkler) systems. Total annual watering costs are $38,868.

Mature Tree Care

Fort Collins' urban forest contains many mature and old trees so it is not surprising that about 70% ($670,000) of the tree program's budget is spent keeping these trees healthy and safe. Pruning, tree removal, and inspection accounts for most of this amount. Approximately $405,344 is spent for programmed pruning, as well as service request pruning and low pruning to lift branches overhanging sidewalks and streets. The Division removes about 400 trees each year at a cost of $130,487 (includes stump removal). Approximately 15% of the tree removal and pruning work is contracted. Inspection time for answering service requests, public education, and plan review adds up to $53,675 annually.

Pest infestations can pose a serious threat to the health and survival of susceptible tree species, and drip from insects is a nuisance to residents. Expenditures for pest and disease control total $21,285, with $4,000 for monitoring, $9,635 for cultural treatments (e.g., watering, fertilization, aeration) aimed at improving tree health, and $7,650 for treatments to control spider mites, ash borers, elm scale, and other pests. Clean-up after storms occurs on a periodic basis. Approximately $40,526 is spent annually, based on a 10-year average. Another $15,000 is regularly expended for street-related tree clean-up.

Administration

Approximately 12% of all program expenditures are for administration, totaling $109,201. This item accounts for salaries and benefits of supervisory staff who perform planning and management functions, as well as contract development and supervision.

Other Tree-Related Expenditures External to the Community Forestry Program

Tree-related expenses accrue to the City that were not captured in the Community Forestry Program's budget. These expenditures include sidewalk and curb repair and legal claims.

Sidewalk and Curb Repair

Shallow roots that heave sidewalks, crack curbs, and damage driveways are an important aspect of mature tree care. Once problems occur, the city attempts to remediate the problem without removing the tree. Strategies include ramping the sidewalk over the root, meandering or narrowing the sidewalk, replacing concrete with more flexible materials like unit pavers, and root pruning. In total, $60,000 is spent on these measures. The largest expenditure, $33,000, is for repair of damaged sidewalks, curbs, and gutters.

Property and Personal Claims

Although the Forestry Division has an excellent service record, damage occasionally occurs to private property due to limb failure, inaccurately located irrigation or sewer lines, or conflicting landscaping. Payments are occasionally made for trip and fall accidents. The annual expenditure for claims and legal services is $12,200.

Total Expenditures

Total annual expenditures for street and park tree management are $997,638 **(Table 4)**. Program costs are responsible for 93% of the total, while external expenditures accounted for the remaining 7%. The average annual costs per tree and per capita are $32.19 and $7.39, respectively.

Table 4. Fort Collins' annual expenditures

Program Expenditures	
Planting	111,052
Pruning	405,344
Removals	130,487
Inspection	53,675
Storm/Litter Clean-Up	55,526
Irrigation	38,868
Pest & Disease Control	21,285
Administration	109,201
Total Program	925,438
Non-Program Expenditures	
Hardscape repair	60,000
Claims and legal	12,200
Total Non-Program	72,200
Grand Total Expenditures	997,638

Chapter IV. Benefits Produced by Fort Collins' Urban Forest

"You can gauge a country's wealth, its real wealth, by its tree cover."
--- Dr. Richard St. Barbe Baker, *Man of the Trees*

Introduction

In this chapter we present estimated benefits provided by Fort Collins' street and park trees. Our estimates of benefits are initial approximations. The state of knowledge about the physical processes at work and their interactions vary, and is being added to all the time. Therefore, these estimates are not meant to be accurate to the penny, but rather provide a general understanding of the benefits provided by Fort Collins' public trees over the course of one year. Methods used to quantify and price these benefits are described in Appendix B.

Environmental Benefits

Energy Savings

Urban forests modify climate and conserve building energy use through 1) shading, which reduces the amount of radiant energy absorbed and stored by built surfaces, 2) evapotranspiration, which converts liquid water in plants to vapor, thereby cooling the air, and 3) wind speed reduction, which reduces the infiltration of outside air into interior spaces (Simpson 1998). Trees and other greenspace within individual building sites may lower air temperatures 5°F (3°C) compared to outside the greenspace. At the larger scale of urban climate (6 miles or 10 km^2), temperature differences of more than 9°F (5°C) have been observed between city centers and more vegetated suburban areas.

Electricity and Natural Gas Results. Electricity saved annually from both shading and climate effects totaled 1,020 MWh, for a total retail savings of $58,160 (1.88/tree). Savings for park trees ($1.57/tree) are less than for street trees ($2.15/tree), reflecting the fact that park trees provide only climate benefits, while street trees provide both shade and climate benefits.

Total annual savings for natural gas are nearly $53,885. This reduction in heating costs results from winter savings from wind speed reduction (a climate effect). Park trees produce a greater net heating savings than street trees ($2.10/tree vs. $1.42/tree). Only climate effects are attributed to them, and they don't provide shade in winter that increases heating demand.

Net Energy Savings. Net energy savings **(Table 5)** are nearly evenly split between reduced winter heating and summer air conditioning. Total savings are 19,184 MBtu, valued at $112,045. Average savings per tree are $3.72, and exceed $10/tree for larger varieties (e.g., elms, Silver maple).

Atmospheric Carbon Dioxide Reductions

Urban forests can reduce atmospheric CO_2 in two ways: 1) trees directly sequester CO_2 as woody and foliar biomass while they grow, and 2) trees near buildings can reduce the demand for heating and air conditioning, thereby reducing emissions associated with electric power production. On the other hand, CO_2 is released by vehicles, chain saws, chippers, and other equipment during the process of planting and maintaining trees. Eventually, all trees die and most of the CO_2 that has accumulated in their woody biomass is released into the atmosphere through decomposition.

Sequestered, Released and Avoided CO_2 Result. Sequestration less releases due to decomposition and maintenance (net sequestration) resulted in total savings of 1,785 short tons (1,619 metric tonnes or t) of CO_2, with an implied value of $26,776. Average annual net sequestration /tree is 115 lb (52 kg) and saves $0.87 per tree. Green ash accounts for 26% of total net CO_2 sequestered by street trees.

Net avoided emissions total 1,127 tons (1,023 t) with an average value of $0.55/tree. Net sequestration is 1.6 times greater than avoided CO_2. Avoided emissions are important in Fort Collins because the primary fuel is coal. Coal has a relatively high CO_2 emission factor.

Table 5. Net energy savings for all street and park trees.

Tree Species	Total MBtu	Total $	% of Total $	Avg. $/tree
Green ash	2,130	12,386	21.1	3.49
Honey locust	1,085	6,315	10.8	3.77
Littleleaf linden	162	944	1.6	0.86
Burr oak	141	819	1.4	0.76
Hackberry	540	3,139	5.4	3.43
Apple/crabapple spp.	211	1,232	2.1	1.60
American elm	1,838	10,705	18.3	14.97
Norway maple	423	2,460	4.2	5.08
Siberian elm	903	5,239	8.9	11.22
American linden	91	531	0.9	1.36
Silver maple	579	3,357	5.7	11.26
White ash	60	351	0.6	1.26
Plains cottonwood	454	2,633	4.5	11.30
Austrian pine	82	478	0.8	2.38
Kentucky coffee tree	79	459	0.8	2.61
Pear spp.	13	78	0.1	0.48
Cherry/plum spp.	25	144	0.2	0.91
Colorado spruce	63	368	0.6	2.31
Sugar maple	40	231	0.4	1.55
Ponderosa pine	40	234	0.4	1.72
Other Street Trees	1,126	6,546	11.2	2.86
Street Tree Total	10,084	58,649	52.3	3.75
Park Tree Total	9,100	53,396	47.7	3.67
Grand Total	19,184	112,045		3.72

Table 6. Net CO_2 reductions for all street and park trees.

Tree Species	Total lb	Total $	% of Total $	Avg. $/tree
Green ash	811,229	6,084	24.2	1.71
Honey locust	333,160	2,499	10.0	1.49
Littleleaf linden	52,134	391	1.6	0.35
Burr oak	61,060	458	1.8	0.42
Hackberry	141,479	1,061	4.2	1.16
Apple/crabapple spp.	60,051	450	1.8	0.59
American elm	456,511	3,424	13.6	4.79
Norway maple	145,462	1,091	4.3	2.25
Siberian elm	348,971	2,617	10.4	5.60
American linden	36,079	271	1.1	0.69
Silver maple	236,696	1,775	7.1	5.96
White ash	24,467	183	0.7	0.66
Plains cottonwood	140,722	1,055	4.2	4.53
Austrian pine	20,030	150	0.6	0.75
Kentucky coffee tree	20,960	157	0.6	0.89
Pear spp.	5,830	44	0.2	0.27
Cherry/plum spp.	5,627	42	0.2	0.27
Colorado spruce	26,305	197	0.8	1.24
Sugar maple	15,058	113	0.4	0.76
Ponderosa pine	8,691	65	0.3	0.48
Other Street Trees	396,791	2,976	11.9	0.90
Street Tree Total	3,347,315	25,105	57.5	1.53
Park Tree Total	2,477,545	18,581	42.5	1.28
Grand Total	5,824,860	43,686		1.41

Net Atmospheric CO_2 Reductions. Net CO_2 reduction, the sum of avoided and net sequestration, is 2,912 tons (2,642 t), with a value of $43,686 **()**. This is an average benefit of $1.41/tree, with a maximum of $6/tree. Green ash (24%), American elm (14%), and Siberian elm, and Honey locust (both 10%) are responsible for the largest percentages of net atmospheric CO_2 reductions by street trees.

Air Quality Improvement

Urban trees provide air quality benefits by 1) absorbing gaseous pollutants (ozone, nitrogen oxides) through leaf surfaces, 2) intercepting particulate matter (e.g., dust, ash, pollen, smoke), 3) releasing oxygen through photosynthesis, and 4) and transpiring water and shading surfaces, which lowers local air temperatures, thereby reducing ozone levels. In the absence of the cooling effects of trees, higher air temperatures contribute to ozone formation. Most trees emit various biogenic volatile organic compounds (BVOCs) such as isoprenes and monoterpenes that can contribute to ozone formation. The ozone forming potential of different tree species varies considerably (Benjamin and Winer 1998). High emitters of BVOCs (> 10 ug/g/hr) in Fort Collins are Plains cottonwood, Colorado spruce (*Picea pungens*), and Burr oak (*Quercus macrocapa*).

Research in the Sacramento, CA region quantified the effectiveness of trees for air quality improvement and has relevance to Fort Collins. Scott et al. (1998) found that the total value of annual air pollutant uptake produced by Sacramento County's six million trees was $28.7 million, nearly $5 /tree on average. The urban forest removed approximately 1,606 tons) (1,457 t) of air pollutant annually. Trees were most effective at removing ozone and particulate matter (PM_{10}). Daily uptake of NO_2 and PM_{10} represented 1 to 2% of emission inventories for the county. Pollutant uptake rates were highest for residential and institutional land uses.

Trees in a Davis CA parking lot were found to benefit air quality by reducing air temperatures 0.5-1.5°C (1-3°F) (Scott et al. 1999). By shading asphalt surfaces and parked vehicles the trees reduce hydrocarbon emissions from gasoline that evaporates out of leaky fuel tanks and worn hoses. These evaporative emissions are a principal component of smog, and parked vehicles are a primary source. Initial calculations indicate that planting trees in parking lots throughout the region could reduce hydrocarbon emissions comparable to the levels achieved through the local air quality district's currently funded programs (e.g., graphic arts, waste burning, vehicle scrappage).

Deposition and Interception Result. Pollutant uptake by tree foliage (pollutant deposition and particulate interception) is 4.4 ton (4.0 t) of combined uptake. The total value of this benefit is $18,500, or $0.60 /tree. Ozone and NO_2 uptake account for 75% and 19% of the savings, respectively.

Avoided Pollutants and BVOC Emissions Result. Annual avoided pollutant emissions at power plants plus BVOC emissions total 734 lb (333 kg). Although trees provide substantial reductions of power plant emissions due to energy savings, their release of more highly priced BVOCs result in a net cost of $29. Street trees produce a net benefit of $0.29/tree, while the higher BVOC emitting conifers in parks produce an average cost of $0.33/tree. Colorado spruce (-$5/tree), Plains cottonwood (-$4/tree), and Austrian pine (*Pinus nigra*) (-$1/tree) are street tree species responsible for the greatest BVOC emissions. American ($2/tree) and Siberian elms ($1/tree) produce the greatest net benefits on average due to avoided emissions.

Net Air Quality Improvement. Fort Collins' public trees produce annual air quality benefits valued at $18,472 ($0.60/tree) by removing 6 tons (5.5 t) of pollutants from the atmosphere. Net air quality savings **(**Error! Reference source not found.**)** are primarily due to pollutant uptake ($0.60/tree, especially for street trees. However, higher BVOC emissions for park trees offsets some of the pollutant uptake benefit. Annual savings exceed $5 for elms and -$4 for Colorado spruce.

Table 7. Net air quality benefits for all street and park trees.

Tree Species	Total lb	Total $	% of Total $	Avg. $/tree
Green ash	1,971	3,478	22.0	0.98
Honey locust	726	1,123	7.1	0.67
Littleleaf linden	120	197	1.2	0.18
Burr oak	-12	-100	(0.6)	-0.09
Hackberry	527	936	5.9	1.02
Apple/crabapple spp.	151	253	1.6	0.33
American elm	2,298	4,325	27.4	6.05
Norway maple	373	632	4.0	1.31
Siberian elm	1,273	2,388	15.1	5.11
American linden	61	90	0.6	0.23
Silver maple	686	1,216	7.7	4.08
White ash	52	92	0.6	0.33
Plains cottonwood	96	-111	(0.7)	-0.47
Austrian pine	3	-47	(0.3)	-0.23
Kentucky coffee tree	51	81	0.5	0.46
Pear spp.	8	13	0.1	0.08
Cherry/plum spp.	21	39	0.2	0.25
Colorado spruce	-255	-662	(4.2)	-4.17
Sugar maple	36	62	0.4	0.41
Ponderosa pine	-2	-28	(0.2)	-0.21
Other Street Trees	1,061	1,825	11.5	0.55
Street Tree Total	9,243	15,801	85.5	0.96
Park Tree Total	2,866	2,670	14.5	0.18
Grand Total	12,110	18,472		0.60

Stormwater Runoff Reductions

Urban stormwater runoff is a major source of pollution entering local rivers. A healthy urban forest can reduce the amount of runoff and pollutant loading in receiving waters. Trees intercept and store rainfall on leaves and branch surfaces, thereby reducing runoff volumes and delaying the onset of peak flows. Root growth and decomposition increase the capacity and rate of soil infiltration by rainfall and reduce overland flow. Urban forest canopy cover reduces soil erosion by diminishing the impact of raindrops on barren surfaces, as well as runoff.

Studies that have simulated urban forest impacts on stormwater report annual runoff reductions of 2-7%. For example, annual interception of rainfall by Sacramento's urban forest for the urbanized area was only about 2% due to the winter rainfall pattern and predominance of non-evergreen species (Xiao et al. 1998). However, average interception loss for the land with tree canopy cover ranged from 6 to 13% (150 gal/tree on average), close to values reported for rural forests. Trees are less effective for flood control than water quality protection because canopy storage is exceeded well before peak flows occur. Trees can delay the time of peak runoff because it often takes 10-20 minutes for the tree crown to become saturated and flow to begin from stems and trunk to the ground. By reducing runoff from small storms, which are responsible for most annual pollutant washoff, trees can protect water quality.

Result. Fort Collins' street and park trees are estimated to reduce annual runoff by 49,956 Ccf (141,461 m^3) with an implied value of $403,597 **(Table 8)**. On average, each tree reduces stormwater runoff by 1,208 gal (4.57 m^3) annually, and the value of this benefit is $13.04. Street tree species that produced the greatest annual benefits /tree were Siberian elm ($89), Silver maple ($43), Plains cottonwood ($43), and American elm ($36).

Table 8. Stormwater runoff reduction benefit (Ccf or 100 Cubic Feet) for all street and park trees.

Tree Species	Total Ccf	Total $	% of Total $	Avg. $/tree
Green ash	4,830	39,023	17.6%	10.98
Honey locust	2,432	19,647	8.8%	11.74
Littleleaf linden	479	3,869	1.7%	3.51
Burr oak	311	2,511	1.1%	2.32
Hackberry	2,230	18,014	8.1%	19.67
Apple/crabapple spp.	146	1,179	0.5%	1.53
American elm	3,210	25,934	11.7%	36.27
Norway maple	1,038	8,385	3.8%	17.32
Siberian elm	5,140	41,523	18.7%	88.92
American linden	301	2,430	1.1%	6.23
Silver maple	1,594	12,877	5.8%	43.21
White ash	154	1,248	0.6%	4.47
Plains cottonwood	1,235	9,981	4.5%	42.84
Austrian pine	438	3,539	1.6%	17.61
Kentucky coffee tree	195	1,576	0.7%	8.95
Pear spp.	39	314	0.1%	1.92
Cherry/plum spp.	52	418	0.2%	2.65
Colorado spruce	521	4,212	1.9%	26.49
Sugar maple	96	779	0.4%	5.23
Ponderosa pine	196	1,581	0.7%	11.63
Other Street Trees	2,881	23,277	10.5%	7.04
Street Tree Total	27,518	222,317	55%	13.55
Park Tree Total	22,438	181,280	45%	12.47
Grand Total	49,957	403,597		13.04

Property Value Increases and Other Benefits

Trees provide a host of social, economic, and health benefits that should be described and monetized in this benefit-cost analysis. Environmental benefits from trees not accounted for previously include noise abatement and wildlife habitat. Although these types of environmental benefits are more difficult to quantify than those previously described, they can be important. Another important benefit from street tree shade is money saved for repaving because shaded streets do not deteriorate as fast as unshaded streets.

The social and psychological benefits provided by Fort Collins' urban forest improve human well-being. Research indicates that views of vegetation and nature bring relaxation and sharpen concentration. Hospitalized patients with views of nature and time spent outdoors needed less medication, slept better, and were happier than patients without these connections to nature (Ulrich et al.1985). Trees reduce exposure to ultraviolet light, thereby lowering the risk of harmful health effects from skin cancer and cataracts. Other research shows that humans derive substantial pleasure from trees, whether it be feelings of relaxation, connection to nature, or religious joy (Dwyer et al.1992). Trees provide important settings for recreation in and near Fort Collins. Research on the aesthetic quality of residential streets has shown that street trees are the single strongest positive influence on scenic quality. Just the act of planting trees has social value in that new bonds between people often result. Also, urban and community forestry provides educational opportunities for residents who want to learn about nature through first-hand experience.

Research comparing sales prices of residential properties with different tree resources suggests that people are willing to pay 3 -7% more for properties with ample tree resources versus few or no trees. One of the most comprehensive studies of the influence of trees on residential propertyvalues was based on actual sales prices for 844 single family homes in Athens, Georgia (Anderson and Cordell 1988). Using regression analysis, each large front-yard tree was found to be associated with about a 1% increase in sales price ($336 in 1985 dollars). This increase in property value resulted in an estimated increase of $100,000 (1978 dollars) in the city's property tax revenues. A much greater value of 9% ($15,000) was determined in a U.S. Tax Court case for the loss of a large black oak on a property valued at $164,500 (Neely 1988).

Result. The estimated total annual benefit associated with property value increase and other less tangible benefits is $1.6 million, or $52/tree on average **(Table 9).** Street trees are responsible for 70% of this benefit because they are assumed to have greater impact on property values than park trees. Tree species adding the largest amount of leaf area over the course of a year tend to produce the highest average annual benefit: Silver maple ($113/tree), White ash (*Fraxinus americana*) ($110/tree), American elm ($107/tree), and Siberian elm ($105/tree).

Table 9. Aesthetic and property value benefits (LSA or leaf surface area) for all street and park trees.

Tree Species	Total LSA ft2	Total $	% of Total $	Avg. $/tree
Green ash	525,292	307,147	27.5%	86.45
Honey locust	257,385	150,497	13.5%	89.90
Littleleaf linden	89,729	52,466	4.7%	47.61
Burr oak	55,333	32,354	2.9%	29.96
Hackberry	132,946	77,736	7.0%	84.86
Apple/crabapple spp.	41,123	24,045	2.2%	31.31
American elm	130,306	76,192	6.8%	106.56
Norway maple	59,649	34,878	3.1%	72.06
Siberian elm	84,003	49,118	4.4%	105.18
American linden	44,059	25,762	2.3%	66.06
Silver maple	57,838	33,819	3.0%	113.49
White ash	52,257	30,556	2.7%	109.52
Plains cottonwood	30,972	18,110	1.6%	77.72
Austrian pine	17,861	10,444	0.9%	51.96
Kentucky coffee tree	20,336	11,891	1.1%	67.56
Pear spp.	4,834	2,826	0.3%	17.34
Cherry/plum spp.	9,479	5,543	0.5%	35.08
Colorado spruce	17,064	9,978	0.9%	62.75
Sugar maple	11,918	6,969	0.6%	46.77
Ponderosa pine	10,085	5,897	0.5%	43.36
Other Street Trees	256,441	149,945	13.4%	45.33
Street Tree Total	1,908,911	1,116,173	70%	68.02
Park Tree Total	1,381,967	480,074	30%	33.03
Grand Total	3,290,878	1,596,247		51.59

Total Benefits

It is impossible to quantify all the benefits and costs that tree's produce. For example, property owners with large street trees can receive benefits from increased property values, but they may also benefit directly from improved human health (i.e., reduced exposure to cancer-causing UV radiation) and greater psychological well-being through visual and direct contact with trees. On the cost side, increased health care costs may be incurred because of nearby trees, as with allergies and respiratory ailments related to pollen. The value of many of these benefits and costs are difficult to determine. We assume that some of these intangible benefits and costs are reflected in what we term "property value and other benefits." Other types of benefits we can only describe, such as the social, educational, and employment/training benefits associated with the urban forestry program. To some extent, connecting people with their trees reduces costs for health care, welfare, crime prevention, and other social service programs.

Fort Collins residents can obtain additional economic benefits from street and park trees depending on tree location and condition. For example, street trees can provide air conditioning savings by shading buildings and pavement. This benefit can extend to the neighborhood, as the aggregate effect of many street trees is to reduce air temperatures and lower cooling costs. Neighborhood property values can be influenced by the extent of tree canopy cover on streets and in nearby parks. The community benefits from cleaner air and water and reduced local flooding. Reductions in atmospheric CO_2 concentrations due to trees can have global benefits. To capture the value of all annual benefits we sum each type of benefit.

Total benefits produced by Fort Collins' street and park trees are estimated to have a value of $2.17 million **(Table 10)**, about $16/resident and $70/tree. Street trees produce benefits valued at $1.4 million ($88/tree, $10.65/capita), while park tree benefits are valued at $736,000 ($51/tree, $5.45/capita). Street trees account for 66% of total benefits and park trees produced the remaining 34%. Urban forest effects on property values and other intangible benefits account for 74% of total benefits ($52/tree). Stormwater runoff reduction benefits are second in importance (19% of total benefits, $13/tree). Benefits associated with energy savings represent 5% ($4/tree) of total benefits. Carbon dioxide reductions and air quality benefits account for the remaining 2% of estimated total annual benefits.

Average annual benefits increase from $30/tree for small trees to $175/tree for large trees **(Figure 3)**. Property value/other benefits are most important for young trees because the result is influenced by growth rate. Stormwater runoff reduction benefits are greatest for older trees because leaf area and crown diameter influence rainfall interception.

Table 11 shows the distribution of annual benefits by species and size class. Green ash, which make up 22% of all street trees and 28% of all leaf area, account for 17% of all street tree benefits **(Figure 4)**. Over 50% of this species are less than 12-inch dbh. Other broadleaf deciduous large trees account for 14% of all street trees and 28% of total benefits by virtue of their relatively large size. Honey locust (8%), American elm (6%), Siberian elm (5%), and Hackberry (5%) are also important producers of benefits

Annual benefits from small, young trees (< 6", 15 cm dbh) average $31/tree and account for 23% of total benefits, although the trees make up 53% of the population. Over 14% of these benefits are from Green ash along streets (about 18% of small trees) and 11% are from Honey locust **(Figure 5).**

Table 10. Total annual benefits in dollars and resource units (RU) for all street and park trees.

	Total $	$/tree	Total RU	RU/tree
Energy (MBtu)	112,045	3.62	19,184	0.62
Carbon dioxide (lb)	43,686	1.41	5,824,613	188.24
Air quality (lb)	18,472	0.60	12,110	0.39
Stormwater (Ccf & gal)	403,597	13.04	49,956	1,207
Property/Other	1,596,247	51.59		
Total	2,174,047	70.26		

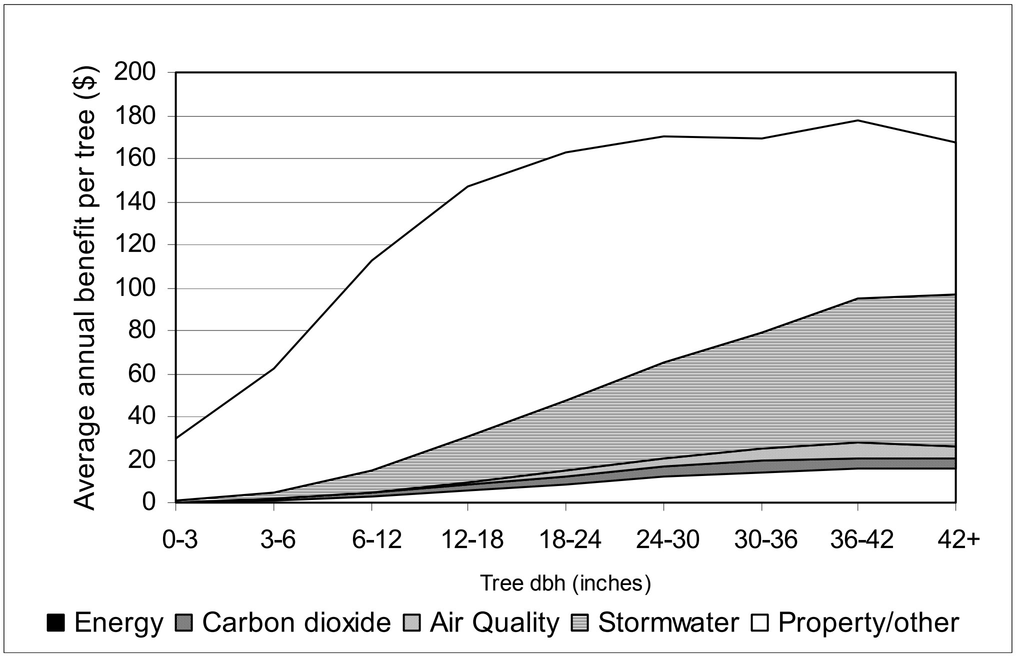

Figure 3. Average annual benefits per tree by dbh size classes.

Annual benefits from maturing trees (6-18", 15-45 cm dbh) account for 43% of total benefits, while the size class accounts for 30% of all trees. Benefits are less evenly distributed among species than they are for young trees, with 23% attributed to Green ash along streets. The average benefit is $101/tree. Other maturing street tree species producing substantial benefits are Honey locust, Siberian elm, and Norway maple.

Mature trees, those between 18-30" dbh (45-75 cm), make up 11% of the tree population and are responsible for 21% of total benefits. The average annual benefit averages $136/tree. Green ash produces 16% of total benefits and accounts for 12% of the mature street tree population. The magnitude of future benefits depend on the extent to which species such as Green ash, Norway maple, Hackberry, Honey locust, and Silver maple continue to grow older and larger.

Large old trees, those greater than 30" dbh (75 cm), are 6% of the population and produce 13% of all benefits. Their average annual benefit is $144/tree. American elms on streets alone account for 23% of total annual benefits from old trees. Siberian elm, Silver maple, and Plains cottonwood along streets together account for another 37% of the remaining benefits. Other broadleaf deciduous large trees, primarily in parks, account for 25% of total benefits from old trees.

Relying on relatively few species (i.e., Green ash, Honey locust, American elm) for such a large portion of total benefits (30%) is risky. Commonly, relatively few species come to dominate urban forests by virtue of their ability to survive the tests of time. Critical to the benefit-cost equation is the suitability of the dominant species. Although American elm, Honey locust, and Siberian elm have proven to be relatively long-lived, they are being phased-out of the population. Insect and disease problems, brittle wood, and intensive pruning requirements make them unsuitable for planting in large numbers. Intensive inspection and maintenance are necessary to insure that these problems do not jeopardize tree health, public safety, and the sizable benefits that these trees produce. Similar conclusions were drawn for Fremont poplar (*Populus fremontii*) and Siberian elm in Albuquerque, NM and Silver maple in many Midwestern cities (McPherson and Rowntree 1989).

However, as these species are phased-out the city is replacing them with a myriad of large-stature trees that are more suitable. These replacements include varieties of White ash, Oak, Maple, and Linden. As a result, the forest is becoming more diverse, and ultimately, more stable.

Table 11. Average annual benefits ($) by species and size class (dbh in inches) for all street and park trees.

	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	42+	Total	% Total
Green ash	24,574	43,761	131,827	81,984	46,476	25,918	10,494	2,845	238	368,118	16.9
Honey locust	29,272	26,735	48,311	42,563	18,218	10,743	3,043	882	314	180,081	8.3
Littleleaf linden	15,519	14,865	19,006	7,473	852	51	0	0	101	57,867	2.7
Burr oak	8,594	4,672	19,303	1,116	1,717	327	164	150	0	36,042	1.7
Hackberry	11,723	12,246	28,806	13,125	14,844	15,122	3,029	1,230	760	100,886	4.6
Apple/crabapple spp.	9,083	3,698	6,782	5,072	1,448	760	105	211	0	27,159	1.2
American elm	477	927	829	1,479	10,288	34,505	36,680	24,189	11,205	120,579	5.5
Norway maple	2,842	2,412	9,210	13,901	13,666	3,733	1,232	449	0	47,446	2.2
Siberian elm	3,665	5,414	4,716	4,581	7,563	16,899	18,720	22,440	16,887	100,885	4.6
American linden	2,110	8,483	9,122	3,853	3,703	1,316	330	0	167	29,085	1.3
Silver maple	118	308	2,392	10,958	8,355	11,937	8,342	6,546	4,086	53,043	2.4
White ash	15,899	10,209	4,436	452	479	802	154	0	0	32,431	1.5
Plains cottonwood	0	522	774	1,132	831	1,055	2,827	6,124	18,405	31,669	1.5
Austrian pine	137	1,359	5,045	5,790	2,073	0	159	0	0	14,564	0.7
Kentucky coffee tree	363	4,397	8,483	790	0	131	0	0	0	14,165	0.7
Pear spp.	1,411	1,298	430	49	60	26	0	0	0	3,274	0.2
Cherry/plum spp.	4,457	1,187	377	144	22	0	0	0	0	6,186	0.3
Colorado spruce	315	1,043	3,868	3,898	3,487	1,234	123	0	124	14,093	0.6
Sugar maple	5,518	163	370	301	760	302	350	391	0	8,154	0.4
Ponderosa pine	64	811	3,386	3,198	168	123	0	0	0	7,749	0.4
BDL OTHER	73,123	75,902	74,539	171,152	95,985	50,907	32,137	16,596	21,147	611,487	28.1
BDM OTHER	6,675	7,386	5,731	7,452	4,309	1,882	1,249	856	792	36,330	1.7
BDS OTHER	15,256	5,804	4,511	4,400	1,223	217	0	0	0	31,411	1.4
CEL OTHER	9,516	12,082	22,514	58,687	17,387	3,654	2,202	1,528	1,415	128,985	5.9
CEM OTHER	5,203	7,146	16,616	45,653	12,785	1,934	1,224	839	777	92,178	4.2
CES OTHER	1,355	3,921	4,334	7,496	2,217	383	204	140	129	20,180	0.9
Total	247,270	256,750	435,719	496,700	268,917	183,960	122,767	85,415	76,548	2,174,047	100.0
% Total	11.4	11.8	20.0	22.8	12.4	8.5	5.6	3.9	3.5	100.0	
$/tree	22.13	49.20	94.32	106.67	130.66	147.80	144.58	146.60	142.12	70.26	

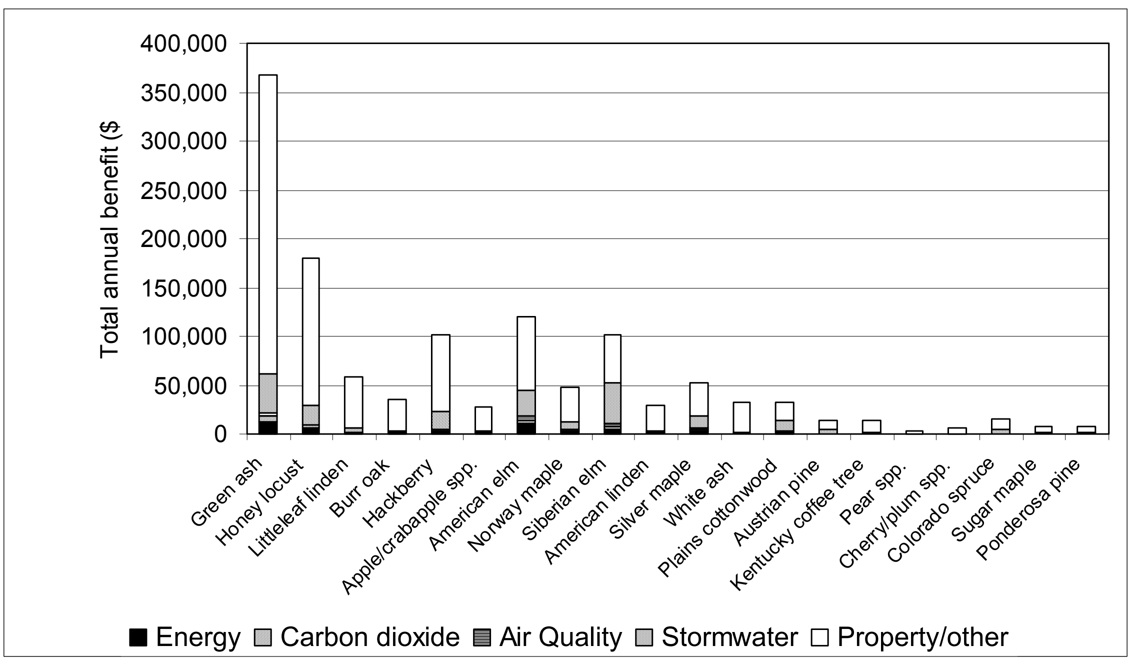

Figure 4. Green ash account for 22% of the street tree population and produce 17% of total street tree benefits. Because of their relatively rapid growth they make a substantial contribution to property value/other benefits.

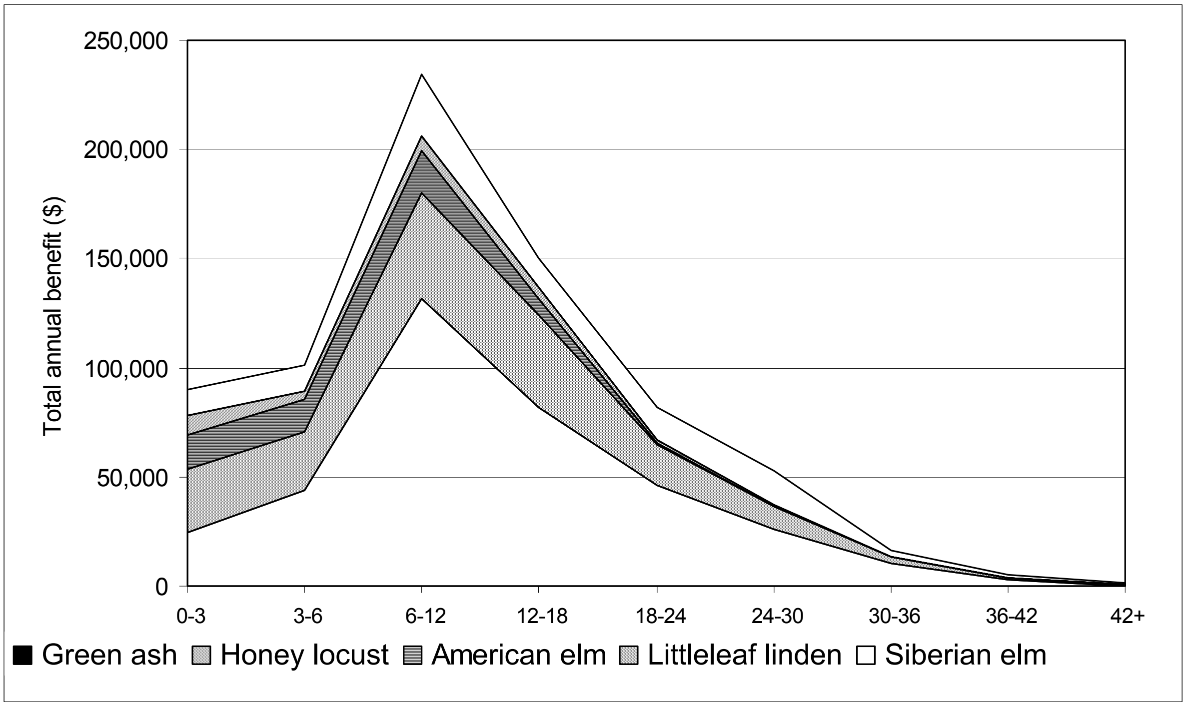

Figure 5. The magnitude of benefits from five street tree species varies due to the number of trees in each size class. Benefits from American and Siberian elm are predominately from older, large trees. Benefits from Green ash and Honey locust are largely from small and mid-sized trees. Benefits from Littleleaf linden are from trees in the smaller size classes.

Net Benefits and Benefit-Cost Ratio

Total fiscal benefits of $2,174,047, less net expenditures of $997,638 result in a net annual benefit of $1,170,229 **(Table 12)**. Average annual net benefits per resident and /tree are $9 and $38, respectively. The benefit-cost ratio is 2.18:1, meaning that for each $1 in net expenditures for urban forest management, benefits valued at $2.18 are returned to the residents of Fort Collins.

Limitations and Uncertainty

We have greater certainty in our estimates of expenditures than benefits. Our uncertainty is greatest in estimating the amount of air pollutant uptake by trees, the value of BVOC emissions, and property value/other benefits. Although our estimates of air pollutant uptake are in good agreement with results from urban forestry studies for Chicago, Sacramento, Modesto, and Santa Monica, it should be noted that our ability to accurately estimate the extent to which shade trees produce air quality benefits is impaired by uncertainties regarding rates of pollutant deposition and release. We used canopy resistance values for rural forests because data are lacking for urban trees. We expect that urban trees might have lower canopy resistance values than trees in rural forests due to lower levels of water stress and higher gas exchange rates. If this is the case, pollutant uptake rates will be greater than we estimate here. BVOC release may be overvalued if emissions are not converted into ozone and thus, do not become a health hazard. Although we have used the best information currently available, application of new research results or different modeling techniques could alter these findings.

Estimating the property value/other benefits associated with public trees is open to debate because little research has examined this question. Given that the total property value and other benefits from park trees was $480,000 of the $1.6 million, reducing or increasing the park tree reduction factor from 0.5 could alter results of this analysis. Further research is needed to better understand relations between trees and these benefits.

Table 12. Net benefits and benefit-cost ratio for all street and park trees.

Benefit Category	$/year	$/tree	$/capita
Energy	112,045	3.62	0.83
Carbon dioxide	43,686	1.41	0.32
Air quality	18,472	0.60	0.14
Stormwater	403,597	13.04	2.99
Property/Other	1,596,247	51.59	11.82
Total Benefits	2,174,047	70.26	16.10
Program Expenditures			
Planting	111,052	3.59	0.82
Pruning	405,344	13.10	3.00
Removals	130,487	4.22	0.97
Other	169,354	5.47	1.25
Administration	109,201	3.53	0.81
Total Program	925,438	29.91	6.86
Non-Program Expenditures			
Hardscape repair	60,000	1.94	0.44
Leaf clean-up	0		
Claims and legal	12,200	0.39	0.09
Total Non-Program	72,200	2.33	0.53
Revenues	-		
Net Expenditures	997,638	32.24	7.39
Net Benefits	1,170,229	37.82	8.67
Benefit-Cost Ratio	2.18		

Chapter V. Conclusions

"We forget that we owe our existence to the presence of trees and as far as forest cover goes, we have never been in such a vulnerable position as we are today. The only answer is to plant more trees, to plant for our lives."
--- Dr. Richard St. Barbe Baker, *Man of the Trees*

Fort Collins' municipal urban forest reflects the values, lifestyles, preferences, and aspirations of current and past residents. It is a dynamic legacy, on one hand dominated by trees planted over 40 years ago and at the same time constantly changing as new trees are planted and others mature. Although this study provides a "snapshot" in time of Fort Collins' urban forest, it also serves as an opportunity to speculate about the future. Given the current status of Fort Collins' street and park tree population, what future trends are likely and what management challenges will need to be met?

Fort Collins' existing municipal forest is extensive. Approximately 31,000 trees create a canopy over the City. There is approximately one public tree for every four residents. The street tree stocking level is 66%, indicating that relative to other cities, Fort Collins' streets are well stocked. Nevertheless, opportunities for planting trees to extend the canopy cover do exist. We estimate that the existing street and park tree canopy covers 1% of the City and shades 5% of all street surfaces.

Although 95 different species of trees have been planted along streets, Green ash is the dominant tree. It accounts for 22% of all street trees, 28% of total leaf area and 17% of all annual benefits. Honey locust, American elm, Siberian elm, and Hackberry are other important tree species, producing 8%, 6% and 5% of all benefits, respectively. The Fort Collins tree population has a relatively diverse age structure, with many young, replacement trees and quite a few large, old trees. Given this age structure, it is not surprising that expenditures for mature tree care comprise 70% of tree program expenditures. Additional funds are spent addressing other mature tree-related issues such as sidewalk repair and trip and fall claims. When considering total expenditures, Fort Collins spends nearly $1 million annually for urban forestry ($7/resident, $32/tree). Keeping old trees healthy, perpetuating the forest through planting, and providing a safe and attractive environment for the public comes with a price.

We estimate that total annual benefits from Fort Collins' urban forest are $2.17 million ($16/resident, $70/tree). Net benefits (total benefits less costs) for are $1.17 million ($9/resident, $38/tree). For each $1 invested in urban forest management, benefits valued at $2.18 are returned to the residents of Fort Collins.

Fort Collins' municipal trees provide substantial benefits. As trees grow they increase the value of nearby properties, enhance scenic beauty, and produce other benefits with an estimated annual value of $1.6 million ($52/tree). The net annual stormwater runoff reduction benefit is valued at $403,597 ($13/tree). Building shade, cooler summertime temperatures, and decreased winter winds attributed to street and park trees produce energy savings valued at $112,045 ($4/tree). Smaller benefits result from air quality benefits ($13,091 or $1/tree) and atmospheric carbon dioxide ($25,105 or $2/tree). These findings indicate that the City's trees are providing important health and environmental benefits to residents.

Fort Collins' investment in urban forestry is providing significant benefits to property owners in terms of increased sales prices. Increased property values benefit the city through increased property tax revenues. Public trees are producing tangible air quality, flood control, energy conservation, and CO_2 reduction benefits. Those who benefit from these "environmental services" are potential new partners in urban forest management. The local air quality district, stormwater management agency, electric utility, and industries interested in offsetting carbon dioxide emissions could view Fort Collins' urban forest as an asset to their programs. As air pollution trading markets develop, there is potential for the City to claim credits for these benefits. Urban forestry credits could be applied against municipal emissions or sold to local emitters. Money obtained from the sale of credits could help finance the tree program. Pollution trading markets exist for several criteria pollutants (PM_{10}, NO_2, VOCs), and have been proposed for CO_2.

At the outset of this report we stated our primary question: *Do the accrued benefits from Fort Collins' urban forest justify an annual municipal budget of $1 million?* Our results indicate that the benefits residents obtain from Fort Collins' urban forest do exceed management costs by a factor of 2.18. Over the years Fort Collins has invested millions in its municipal forest. Citizens are now receiving a relatively large return on that investment. Continued investment in management is critical to insuring that residents continue to receive a healthy return on investment. Furthermore, because of the existing forest's reliance on benefits from older trees such as the American elm, Siberian elm, and Plain's cottonwood, spending less on management at this time could jeopardize the future stream of net benefits.

Appearances can be deceiving. Although Fort Collins' municipal forest is well maintained and appears to be as permanent as streets and homes, it is a rather fragile resource. Without the intensive maintenance that is needed to keep many older trees healthy and safe, these trees would be producing fewer benefits and creating greater costs. Already predisposed to health problems because of their age, future stress from disease, pests, drought, and repeated root pruning could decimate many old trees. Combating health problems, removing dead trees, and replanting could require an enormous expenditure by the city. Moreover, large-scale tree canopy cover reduction translates into substantial loss of benefits. This scenario has played out in other U.S. communities that lost large numbers of American elms to Dutch Elm Disease within a few years. Although the Elms are not as dominant in Fort Collins as American elms were in many Midwestern communities, the peril is evident. From our perspective, it seems prudent to continue investing in intensive management that will create a more stable forest over the next 20 years, rather than risking a catastrophic loss in tree cover and large emergency expenditures to obtain short term budget savings.

Looking toward the future, by planting a diverse mix of large-stature trees, the City is on-track to maintain the high level of net benefits produced today by Fort Collins' municipal forest, while at the same time increasing its stability. Creating a more stable forest will result from the movement of younger trees into the mature age classes. Through wise planning that has resulted in a population that is diverse in terms of species and age structure, Fort Collins' urban forest is well-positioned to maximize net benefits and reduce the risk of catastrophic loss in the years ahead. With continued investment in tree care, achieving a more stable forest should not be difficult because of the forest's current species composition and structure.

VI. Acknowledgments and References

"Isolation is a blind alley...Nothing on the planet grows except by convergence."
--- Pierre Teilhard de Chardin, Priest and author

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VII. Appendices

The wrongs done to trees, wrongs of every sort, are done in the darkness of ignorance and unbelief, for when light comes, the heart of people is always right.
--- John Muir, Naturalist

Appendix A – Tree Distribution

Table A-1. Tree numbers by size class (diameter at breast height [dbh] in inches) for all street and park trees. Tree types are BDL, BDM, and BDS for broadleaf deciduous large, medium, and small, CEL, CEM, CES for coniferous evergreen large, medium, and small.

Tree Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total	%Total
Green ash	953	618	1,013	471	249	148	72	26	2	3,552	21.7
Honey locust	480	311	406	281	107	62	19	6	2	1,674	10.2
Littleleaf linden	689	199	146	55	10	1	-	-	2	1,102	6.7
Burr oak	600	291	168	7	10	2	1	1	-	1,080	6.6
Hackberry	275	164	234	76	73	70	14	6	4	916	5.6
Apple/crabapple spp.	406	133	143	61	15	7	1	2	-	768	4.7
American elm	4	7	7	12	75	222	210	125	53	715	4.4
Norway maple	43	35	115	138	112	28	10	3	-	484	2.9
Siberian elm	11	17	19	24	44	96	95	98	63	467	2.8
American linden	133	118	79	26	23	8	2	-	1	390	2.4
Silver maple	1	2	13	52	39	59	48	47	37	298	1.8
White ash	148	86	33	3	3	5	1	-	-	279	1.7
Plains cottonwood	-	7	9	11	7	8	20	42	129	233	1.4
Austrian pine	10	37	72	60	20	-	2	-	-	201	1.2
Kentucky coffee tree	15	76	79	5	-	1	-	-	-	176	1.1
Pear spp.	105	42	11	2	2	1	-	-	-	163	1.0
Cherry/plum spp.	90	40	21	6	1	-	-	-	-	158	1.0
Colorado spruce	16	20	46	36	29	10	1	-	1	159	1.0
Sugar maple	126	3	5	3	6	2	2	2	-	149	0.9
Ponderosa pine	4	37	65	28	1	1	-	-	-	136	0.8
BDL OTHER	1,363	353	154	121	99	64	54	21	56	2,285	13.9
BDM OTHER	125	51	29	-	3	1	-	-	-	209	1.3
BDS OTHER	329	31	43	27	10	2	-	-	-	442	2.7
CEL OTHER	10	1	14	15	4	4	-	-	-	48	0.3
CEM OTHER	2	6	30	51	11	-	-	-	-	100	0.6
CES OTHER	54	113	41	11	4	1	-	-	-	224	1.4
Street Tree Total	5,992	2,798	2,995	1,583	957	803	552	379	350	16,408	53.0
Total Park Trees	5,183	2,420	1,625	3,073	1,101	442	297	204	189	14,534	47.0
Grand Total	11,175	5,218	4,620	4,656	2,058	1,245	849	583	539	30,942	100.0

APPENDIX B - Methodology

Sampling and Tree Growth

Fort Collins' tree database contained information on approximately 16,500 street trees, including species and size. Park tree data consisted of estimated numbers by size classes (DBH) and type (i.e., shade, conifer, ornamental) for park, cemetery, golf course, stormwater basins, and special garden (xeriscape/native plant) locations. We grouped these data to fit our street tree DBH classes and tree type categories. Because park tree numbers by species were not available, we present total park tree benefits, while results for street trees are reported by species.

A stratified random sample of 847 street trees was inventoried to establish relations between tree age, size, leaf area and biomass. In turn, estimates for determining the magnitude of annual benefits and costs were derived. Estimated to account for 87% of the total municipal street tree population, the sample was composed of the 20 most abundant species, and was used to infer growth rates to all street and park trees.

To obtain information spanning the life cycle of each species, the sample was stratified into 9 diameter at breast height (DBH) classes: 0-3 in, 3-6 in, 6-12 in, 12-18 in, 18-24 in, 24-30 in, 30-36 in, 36-42 in, and 42+ in. Thirty-five to 70 randomly selected trees of each species were selected to survey, along with an equal number of alternative trees. Tree metrics sampled included DBH (to nearest 0.1 cm by tape), tree crown and bole height (to nearest 0.5m by altimeter), crown diameter in two directions (parallel and perpendicular to adjacent street, to nearest 0.5m by tape), tree condition and location, and crown pruning level (percentage of crown removed by pruning). Replacement trees were sampled when trees from the original sample population could not be located. Tim Buchanan and Ralph Zentz (City of Fort Collins) determined tree age based on historical planting records. Field work was conducted June through July, 2002.

Crown volume and leaf area (LA) were estimated from computer processing of tree crown images obtained 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).

Nonlinear regression was used to fit predictive growth models—DBH as a function of age—for each of the 20 sampled species. Predictions of leaf surface area (LSA), crown diameter, and height metrics were modeled as a function of DBH using best-fit models (Peper et al. 2001).

Calculating Benefits

Annual benefits for Fort Collins' street and park trees were estimated for the year 2003. Growth rate modeling information was used to perform computer-simulated growth of the existing tree population for one year and account for the associated annual benefits. This "snapshot" analysis assumed that no trees were added to, or removed from, the existing population during the year. The approach directly connects benefits with tree size variables such as DBH and LSA. Many functional benefits of trees are related to leaf-atmosphere processes (e.g., interception, transpiration, photosynthesis), and, therefore, benefits increase as tree canopy cover and leaf surface area increase

Prices were assigned to each benefit (e.g., heating/cooling energy savings, air pollution absorption, stormwater runoff reduction) and cost (e.g., planting, pruning, removal, irrigation, infrastructure repair, liability) through direct estimation and implied valuation as environmental externalities. Implied valuation is used to price society's willingness to pay for the air quality and stormwater runoff benefits trees produce. For example, air quality benefits are estimated using control costs, which reflect the typical cost for reducing emissions from stationary sources. If a corporation is willing to pay $1 per pound to install technologies that reduce emissions, then the air pollution mitigation value of a tree that absorbs or intercepts 1 lb of air pollution should be $1.

Energy Savings

Calculating annual building energy use per residential unit (Unit Energy Consumption [UEC]) was based on computer simulations that incorporate building, climate and shading effects, following methods outlined by McPherson and Simpson (1999). Changes in UECs from trees (ΔUECs) were calculated on a /tree basis by comparing results before and after adding trees. Building characteristics (e.g., cooling and heating equipment saturations, floor area, number of stories, insulation, window area, etc.) were differentiated by a building's vintage, or age of construction: pre-1950, 1950-1980 and post-1980.

Typical meteorological year (TMY) weather data for Denver International Airport were used. Shading effects for each tree species measured were simulated at 3 tree-building distances, 8 orientations, and 9 tree sizes.

Shading coefficients for tree crowns in leaf were based on a photographic method for measured species, which estimates visual density. These techniques have been shown to give good estimates of light attenuation for trees in leaf (Wilkinson 1991). Visual density was calculated as the ratio of crown area computed with and without included gaps. Crown areas were obtained from digital images isolated from background features using the method of Peper and McPherson (2003). Values for trees not measured, and for all trees not in leaf, were based on published values where available (McPherson 1984, Hammond et al. 1980). Values for remaining species were assigned based on taxonomic considerations (trees of the same genus assigned the same value) or observed similarity in the field to known species. Foliation periods for deciduous trees were obtained from the literature (McPherson 1984, Hammond et al. 1980) or based on consultation with local arborists and city tree managers.

Tree distribution by location (e.g. frequency of occurrence at each location) specific to Fort Collins was determined to calculate average energy savings as a function of distance and direction from a building. Distance between trees and buildings (setbacks), and tree orientation with respect to buildings, were based on the field measurements of street trees. Setbacks were assigned to four distance classes: 0-20 ft, 20-40 ft, 40-60 ft and >60 ft. It was assumed that street trees within 60 ft of buildings provided direct shade on walls and windows. Savings at each location were multiplied by tree distribution to determine location-weighted savings per tree for each species and DBH class that was independent of location. Location-weighted savings per tree were multiplied by number of trees in each species/DBH class and then summed to find total savings for the city. Land use (single family, residential, multifamily residential, commercial/industrial, other) was based on field measurements. The same tree distribution was used for all land uses.

Three prototype buildings were used in the simulations to represent pre-1950, 1950 and post-1980 construction practices for Fort Collins (Ritschard et al. 1992). Building footprints were square, which was found to be reflective of average impacts for large building populations (Simpson 2002). Buildings were simulated with 1.5-ft overhangs. Blinds had a visual density of 37%, and were assumed closed when the air conditioner is operating. Summer and winter thermostat settings were 78° F and 68° F during the day, respectively, and 60° F at night. UECs were adjusted to account for saturation of central air conditioners, room air conditioners, and evaporative coolers **(Table B-1)**.

UECs for simulated single-family residential buildings were adjusted for type and saturation of heating and cooling equipment, and for various factors that modified the effects of shade and climate modifications on heating and cooling loads, using the expression,

$$\Delta UEC_x = \Delta UEC^{sh}_{SFD} \times F_{sh} + \Delta UEC^{cl}_{SFD} \times F_{cl}$$

where $F_{sh} = F_{equipment} \times APSF \times F_{adjacent\ shade} \times F_{multiple\ tree}$

$F_{cl} = F_{equipment} \times PCF$

and $F_{equipment} = Sat_{CAC} + Sat_{window} \times 0.25 + Sat_{evap} \times (0.33$ for cooling or 1.0 for heating$)$. [1]

Total change in energy use for a particular district and land use was found by multiplying change in UEC per tree by the number of trees (N):

Total change = $N \times \Delta UEC_x$. [2]

Table B-1.Saturation adjustments for cooling.

	Equipment Factors	Equipment Adjusted Saturations pre-1950	1950-1980	post-1980
Central air/heat pump	100%	38%	56%	72%
Evaporative cooler	33%	0%	0%	0%
Wall/window unit	25%	37%	23%	25%
None	0%	25%	23%	10%
		47%	62%	78%

Saturations based on data for climate zone 2 (EIA 1993), adjustments on Sarkovich (1996).

Subscript *x* refers to residential structures with 1, 2-4 or 5 or more units, SFD to single family detached structures which were simulated, and *sh* to shade and *cl* to climate effects. Unit energy density (UED)—sometimes referred to as unit energy use intensity—is defined as UEC/CFA. Unit energy density and CFA (conditioned floor area) data were taken from EIA (1993) for climate zone 2. Similar adjustments were used to account for UEC and CFA differences between single-family detached residences for which simulations were done, and attached residences and mobile homes. Average potential shade factors (APSF) and potential climate factors (PCF) were 1.0 for single-family residential buildings.

Estimated shade savings for all residential structures were adjusted by factors that accounted for shading of neighboring buildings, and reductions in shading from overlapping trees. Homes adjacent to those with shade trees may benefit from their shade. For example, 23% of the trees planted for the Sacramento Shade program shaded neighboring homes, resulting in an estimated energy savings equal to 15% of that found for program participants. This value is used here ($F_{adjacent\ shade}$ = 1.15). In addition, shade from multiple trees may overlap, resulting in less building shade from an added tree than would result if there were no existing trees. Simpson (2002) estimated that the fractional reduction in average cooling and heating energy use per tree were approximately 6% and 5% percent, respectively, for each tree added after the first. Simpson (1998) also found an average of 2.5 to 3.4 existing trees per residence in Sacramento. A multiple tree reduction factor of 85% was used here, equivalent to approximately 3 existing trees per residence.

In addition to localized shade effects, which were assumed to accrue only to street trees within 18-60 ft of buildings, lowered air temperatures and wind speeds from neighborhood tree cover (referred to as climate effects) produce a net decrease in demand for summer cooling (reduced wind speeds by themselves may increase or decrease cooling demand, depending on the circumstances) and winter heating. To estimate climate effects on energy use, air temperature and wind speed reductions as a function of neighborhood canopy cover were estimated from published values following McPherson and Simpson (1999), then used as input for building energy use simulations described earlier. Peak summer air temperatures were assumed to be reduced by 0.4 °F for each percentage increase in canopy cover. Wind speed reductions were based on the canopy cover resulting from the addition of the particular tree being simulated to that of the building plus other trees. Lot size used was 10,000 ft^2.

Dollar value of electrical energy savings (City of Fort Collins 2003) and natural gas savings (Public Service Company of Colorado 2003) were based on electricity and natural gas prices of $0.057 per kWh and $0.60 per therm, respectively. Cooling and heating effects were reduced based on the type and saturation of air conditioning) **(Table B-1)** or heating **(Table B-2)** equipment by vintage. Equipment factors of 33% and 25% were assigned to homes with evaporative coolers and room air conditioners, respectively. These factors were combined with equipment saturations to account for reduced energy use and savings compared to those simulated for homes with central air conditioning ($F_{equipment}$). Building vintage distribution was combined with adjusted saturations to compute combined vintage/saturation factors for air conditioning **(Table B-3)**. Heating loads were converted to fuel use based on efficiencies in **(Table B-3)**. The "other" and "fuel oil" heating equipment types were assumed to be natural gas for the purpose of this analysis. Building vintage distributions were combined with adjusted saturations to compute combined vintage/saturation factors for natural gas and electric heating **(Table B-3)**.

Unit energy consumptions from shade for multi-family residences (MFRs) were calculated from single-family residential UECs adjusted by APSFs to account for reduced shade resulting from common walls and multi-story construction. Average potential shade factors were estimated from potential shade factors (PSFs), defined as ratios of exposed wall or roof (ceiling) surface area to total surface area, where total surface area includes common walls and ceilings between attached units in addition to exposed surfaces (Simpson 1998). Potential shade factor=1 indicates that all exterior walls and roof are exposed and could be shaded by a tree, while PSF=0 indicates that no shading is possible (i.e., the common wall between duplex units). Potential shade factors were estimated separately for walls and roofs for both single and multi-story structures. Average potential shade factors were 0.74 for land use MFR 2-4 units and 0.41 for MFR 5+ units.

Unit energy consumptions were also adjusted for climate effects to account for the reduced sensitivity of multi-family buildings with common walls to outdoor temperature changes with respect to single family detached residences. Since estimates for these PCFs were unavailable for multi-family structures, a multi-family PCF value of 0.80 was selected (less than single family detached PCF of 1.0 and greater than small commercial PCF of 0.40; see next section).

Table B-2 Saturation adjustments for heating.

a. Electric heating:		Equipment efficiencies		
		Pre-1950	1950-1980	post-1980
Natural gas	AFUE[a]	0.75	0.78	0.78
Heat pump	HSPF[b]	6.8	6.8	8
Electric resistance	HSPF	3.412	3.412	3.412
	Equipment factors	Saturation factors		
Electric resistance	100%	2%	10%	21%
Heat pump	100%	0%	2%	4%
Adj. elec. heat saturations		0.4%	2.5%	5.2%

[a]Annual Fuel Utilization Efficiency, a measure of space heating equipment efficiency defined as the fraction of energy output/energy input

[b]Heating Seasonal Performance Factor, the ratio of heating output to power consumption.

Electric heat saturations are adjusted to convert natural gas results that were simulated to kWh

b. NG and other heating[c]:				
Natural gas	100%	69%	61%	50%
Oil	100%	18%	19%	0%
Other	100%	10%	8%	25%
NG Heat saturations:		97%	88%	75%

[c.] Oil and "Other" heating categories treated as natural gas; all residences assumed to be heated

Table B-3. Residential building vintage distribution and combined vintage/saturation factors for heating and air conditioning.

Distributions of vintage or building type and trees	Single family residential			Multi-family residential			Commercial/ Industrial		Institutional/ Transportation
	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	Post-1980	Small	Large	
Vintage distribution[a]	43%	48%	10%	43%	48%	10%	100%	100%	100%
Tree distribution	25.5%	28.4%	5.9%	4.6%	5.1%	1.1%	9.4%	9.0%	11.7%
Combined vintage, equipment saturation factors for cooling									
Cooling factor: shade	12.9%	17.0%	4.5%	1.0%	1.5%	0.4%	2.2%	1.0%	1.4%
Cooling factor: climate	13.3%	17.6%	4.6%	1.7%	2.5%	0.7%	2.5%	1.8%	1.6%
Combined vintage, equipment saturation factors for heating									
Heating factor: nat. gas	23.9%	24.2%	4.3%	2.1%	2.1%	0.4%	2.5%	1.2%	1.5%
Heating factor: electric	1.2%	0.7%	0.3%	0.01%	0.06%	0.03%	0.2%	0.1%	0.1%

[a] EIA (1993)

Converts kBtu natural gas heat to kWh electricity used for heat based on heat pump and electric resistance saturation values, and AFUE and SEER by vintage.

Unit energy consumptions for C/I and I/T land uses due to presence of trees were determined in a manner similar to that used for multi-family land uses. Potential shade factors of 0.40 were assumed for small C/I, and 0.0 for large C/I. No energy impacts were ascribed to large C/I structures since they are expected to have surface to volume ratios an order of magnitude larger than smaller buildings and less extensive glazed area. Average potential shade factors for I/T structures were estimated to lie between these extremes; a value of 0.15 was used here. A multiple tree reduction factor of 0.85 was used and no benefit was assigned for shading of buildings on adjacent lots.

Potential climate factors of 0.40, 0.25 and 0.20 were used for small C/I, large C/I and I/T, respectively. These values are based on estimates by Akbari and others (1990), who observed that commercial buildings are less sensitive to outdoor temperatures than houses.

Change in UECs due to shade tend to increase with CFA for typical residential structures. As building surface area increases so does the area shaded. This occurs up to a certain point because the projected crown area of a mature tree (approximately 700 to 3,500 ft^2) is often larger than the building surface areas being shaded. Consequently, more area is shaded with increased surface area. However, for larger buildings, a point is reached at which no additional area is shaded as surface area increases. Therefore, ΔUECs will approach a constant value as CFA increases. Since information on the precise relationships between change in UEC, CFA, and tree size are not known, it was conservatively assumed that ΔUECs don't change in Equation 1 for C/I and I/T land uses.

Atmospheric Carbon Dioxide Reduction

Sequestration, the net rate of CO_2 storage in above- and below-ground biomass over the course of one growing season, is calculated by species using tree growth equations for DBH and height described above to calculate tree volume with equations from Pillsbury et. al (1998) and Ter-Mikaelian and Karzukhin (1997) (see McPherson and Simpson [1999] for additional information). Fresh weight (kg/m^3) and specific gravity ratios from Alden (1995) were applied to convert volume to biomass.

Carbon dioxide released through decomposition of dead woody biomass varies with characteristics of the wood itself, fate of the wood (e.g., left standing, chipped, burned), and local soil and climatic conditions. Recycling of urban waste is now prevalent, and we assume here that most material is chipped and applied as landscape mulch. Our calculations are conservative because they assume that dead trees are removed and mulched in the year that death occurs, and that 80% of their stored carbon is released to the atmosphere as CO_2 in the same year. Total annual decomposition is based on the number of trees in each species and age class that die in a given year and their biomass. Tree survival rate is the principal factor influencing decomposition. Tree mortality was reported to average 3.0% annually in the first 5 years after planting, then 0.77% annually (Buchanan 2002).

Finally, CO_2 released from tree maintenance is estimated to be 13.4 lb CO_2/tree based on carbon dioxide equivalent annual release of 220,500 lb (11,677 gallons of gasoline, propane, and diesel fuel use) and average tree diameter of 10 inches (Buchanan 2002).

Reductions in building energy use result in reduced emissions of CO_2. Emissions were calculated as the product of energy use and CO_2 emission factors for electricity and heating. Heating fuel is largely natural gas and electricity in Fort Collins (Error! Reference source not found.). The overall fuel mix for electricity is approximately 14% natural gas and 86% coal (U.S. EPA 2003). Emissions factors for electricity (lb/MWh) and natural gas (lb/MBtu) weighted by the appropriate fuel mixes are given in Table B-4. Implied value of avoided CO_2 was \$0.008/lb based on average high and low estimates for emerging carbon trading markets in the U.S. (CO2e.com 2002) **(Table B-4)**.

Improving Air Quality

Reductions in building-energy use result in reduced emissions of air pollutants from power plants and space heating equipment. Volatile organic hydrocarbons (VOCs) and nitrogen dioxide (NO_2)—both precursors of ozone formation—as well as sulfur dioxide (SO_2) and particulate matter of <10 micron diameter (PM_{10}) were considered. Changes in average annual emissions and their offset values were calculated in the same way as for CO_2, using utility-specific emission factors for electricity and heating fuels (Ottinger et al. 1990; US EPA 1998). The price of emissions savings was derived from models that calculate the marginal cost of controlling different pollutants to meet air quality standards (Wang and Santini 1995). Air pollutant concentrations were obtained from

U.S. EPA (2002), and population estimates from the U.S. Census Bureau (2003).

Trees also remove pollutants from the atmosphere. The modeling method we applied was developed by Scott et al. (1998). It calculates hourly pollutant dry deposition per tree expressed as the product of a deposition velocity ($V_d = 1/[R_a+R_b+R_c]$), a pollutant concentration (C), a canopy projection area (CP), and a time step. Hourly deposition velocities for each pollutant were calculated during the growing season using estimates for the resistances (R_a, R_b, and R_c) for each hour throughout the year. Hourly concentrations for NO_2, SO_2, O_3, and PM_{10} and hourly meteorological data (i.e., air temperature, wind speed, solar radiation) for 1999 were obtained from the Colorado Department of Public Health and Environment. We used implied values based on the work of Wang and Santini (1995) to price pollutant uptake by trees **(Table B-4).** The implied value of NO_2 was used for ozone.

Annual emissions of biogenic volatile organic compounds (BVOCs) were estimated for each tree species using the algorithms of Guenther et al. (1991; 1993). BVOCs were expressed as a product of a base emission rate (μg-C g^{-1} dry foliar biomass hr^{-1}), adjusted for sunlight (isoprene and monoterpenes) and temperature (monoterpenes) and the amount of dry, foliar biomass present in the tree. Annual dry foliar biomass was derived from field data collected in Fort Collins, CO during summer 2002. Hourly air temperature and solar radiation data from the Denver area for 1999 were used as model input. This year was chosen because data were available and it closely approximated long-term, regional climate records. Base emission rates were based on values reported in the literature (Benjamin and Winer 1998). Hourly emissions were summed to get monthly and annual emissions. The cost of these emissions is priced at $2.39/lb **(Table B-4).**

Net air quality benefits were calculated by subtracting the costs associated with BVOC emissions from benefits due to pollutant uptake and avoided power plant emissions. This is a conservative approach, since we do not account for the benefit associated with lowered summertime air temperatures and the resulting reduced hydrocarbon emissions from biogenic as well as anthropogenic sources. Simulation results from Los Angeles indicate that ozone reduction benefits of tree planting with “low-emitting” species exceeded costs associated with their BVOC emissions (Taha 1996).

Reducing Stormwater Runoff

A numerical simulation model was used to estimate annual rainfall interception (Xiao et al. 1998). The interception model accounts for water intercepted by the tree, as well as throughfall and stem flow. Intercepted water is stored temporarily on canopy leaf and bark surfaces. Once the leaf is saturated, water drips from the leaf surface and flows down the stem surface to the ground, or evaporates. Tree canopy parameters include species, leaf surface area, shade coefficient (visual density of the crown), and tree dimensions (i.e., height, crown height, crown diameter, LSA, and DBH). Tree height data are used to estimate wind speed at different heights above the ground and resulting rates of evaporation.

The volume of water stored in the tree crown was calculated from crown projection area (area under tree dripline), leaf area indices (LAI, the ratio of leaf surface area to crown projection area), and the depth of water captured by the canopy surface. Species-specific shade coefficients and tree surface saturation values influence the amount of projected throughfall.

Table B-4. Emissions factors and prices for air pollutants

	—Emission Factor—		
	Electricity (lbs/MWh)	Natural gas (lbs/Mbtu)	Price[1] ($/lb)
CO_2	2,210	118	0.008
NO_2	3.650	0.0922	2.54
SO_2	5.650	0.0006	0.90
PM10	0.903	0.0075	0.45
VOC's	0.861	0.0054	2.39

1 $15/ton for CO2 from CO2e.com (2001), values for all other pollutants are based on methods of Wang and Santini (1995) using emissions concentrations from U.S. EPA (1998) and population estimates from the U.S. Census Bureau (2003).

Hourly meteorological and rainfall data for 1998 from Colorado Agricultural Meteorological network (station ID: FTC01. Station name: Fort Collins AERC) were used for this simulation. Annual precipitation during 1998 was 18.0 inches (458 mm), close to the recent 10-year average annual precipitation of 17.8 inches (452 mm). Storm events less than one-tenth (2.54 mm) inch were assumed to not produce runoff and dropped from the analysis. More complete descriptions of the interception model can be found in Xiao et al. (1998, 2000).

To estimate the value of rainfall intercepted by urban trees, stormwater management control costs were based on construction and operation costs for a recently built detention/retention basin in Fort Collins, CO. The drainage area was 660 acres (267 ha). The basin was designed to hold 17.2 acre feet (21,216 m^3) of runoff and cost $1.04 million to construct (McBride 2002). With operating and maintenance costs of $700/month for 20 years, the total project costs were $1.21 million. Assuming that the basin filled once annually for 20 years, the control cost was $0.0108/gal ($0.000041/m^3).

Aesthetic And Other Benefits

Many benefits attributed to urban trees are difficult to translate into economic terms. Beautification, privacy, shade that increases human comfort, wildlife habitat, sense of place and well-being are products that are difficult to price. However, the value of some of these benefits may be captured in the property values for the land on which trees stand. To estimate the value of these "other" benefits, results of research that compares differences in sales prices of houses are used to statistically quantify the difference associated with trees. The amount of difference in sales price reflects the willingness of buyers to pay for the benefits and costs associated with the trees. This approach has the virtue of capturing what buyers perceive to be as both the benefits and costs of trees in the sales price. Some limitations to using this approach in Fort Collins include the difficulty associated with 1) determining the value of individual trees adjacent to private properties, 2) the need to extrapolate results from studies done years ago in the east and south to California, and 3) the need to extrapolate results from front yard trees on residential properties to street trees in various locations (e.g., commercial vs. residential).
In an Athens, GA study (Anderson and Cordell 1988), a large front yard tree was found to be associated with a 0.88% increase in average home resale values. Along with identifying the LSA of a typical mature large tree (40-year old plane tree) in Fort Collins (2,943 ft^2) and using the average annual change in LSA (ft^2) for trees within each DBH class as a resource unit, this increase was the basis for valuing a tree's capacity to increase property value.

Assuming the 0.88% increase in property value held true for Fort Collins, each large tree would be worth $1,870 based on the median single-family home resale price in Fort Collins of $212,000 (Mills 2002). However, not all trees are as effective as front yard residential trees in increasing property values. For example, street trees adjacent to multifamily housing units will not increase the property value at the same rate as trees in front of a single-family home. Therefore, a citywide reduction factor (0.84) was applied to prorate a tree's value based on the assumption that trees adjacent to differing land-use—single home residential, multi-home residential, commercial/industrial, vacant, park and institutional—were valued at 100%, 75%, 50%, 25%, 50%, and 50%, respectively, or to 0.84*1870, or $1571 of the full $1,870 (McPherson et al. 2001). Based on limited literature (Hammer et al. 1974, More et al. 1988) the adjustment for park trees was 50%.

Given these assumptions, a typical large street tree was estimated to increase property values by $0.58/$ft^2$ of LSA. For example, it was estimated that a single Pear adds about 20 ft^2 of LSA per year when growing in the DBH range of 12-18 in. During this period of growth, therefore, Pear trees effectively added $11.60, annually, to the value of an adjacent home, condominium, or business property.

Total Benefits

Defined as resource units, the absolute value of the benefits of Fort Collins' street and park trees—electricity (kWh/tree) and natural gas savings (kBtu/tree), net atmospheric CO_2 reductions (lbs/tree), net air quality improvement (lbs/tree), stormwater runoff reductions (precipitation interception [ft^3/tree]) and property value increases (Δ LSA [ft^2/tree])—were assigned prices through methods described above for model trees (Maco and McPherson 2003).

Estimating the magnitude of benefits (resource units) produced by all street trees in Fort Collins required four procedures: 1) categorizing street trees by species and DBH based on results of the sample inventory, 2) matching significant species with those from the 20 modeled species 3) grouping remaining "other" trees by type, and 4) applying resource units to each tree.

The first step in accomplishing this task involved categorizing the estimated total number of public and private street trees by relative age (DBH class). Results of the sample inventory were used to group trees—both citywide and by districts—using the following classes:

1) 0-3 in
2) 3-6 in
3) 6-12 in
4) 12-18 in
5) 18-24 in
6) 24-30 in
7) 30-36 in
8) 36-42 in
9) >42 in

Because DBH classes represented a range, the mid-point value for each DBH class was utilized as a single value representing all trees encompassed in each class. Linear interpolation was used to estimate resource unit values (Y-value) for each of the 20 modeled species for the 9 midpoints (X-value) corresponding to each of the DBH classes assigned to the city's street and park trees.

Once categorized, the interpolated resource unit values were matched on a one-for-one basis. For example, the sample inventory results suggested that out of an estimated 3,552 Green ash street trees citywide, 1,013 were within the 6-12 in DBH class size. The interpolated electricity resource unit value for the class size midpoint (9 in) was 32.8 kWh/tree. Therefore, multiplying the size class resource unit by 3,551 equals the magnitude of annual cooling benefits produced by this segment of the population: 33.2 MWh in electricity saved.

To infer from the 20 municipal species modeled for growth to the entire public tree population, each species representing over one percent of the population citywide were matched directly with corresponding model species or, where there was no corresponding tree, the best match was determined by identifying which of the 20 species was most similar in size, leaf shape/type, habit, and tree type. For example, the 20 species we sampled accounted for all species representing 1% or more of the population, with the exception of Hawthorn (*Crataegus spp.*), which was matched with the next closest species: Apple/crabapple.

The species that were less than 1% of the population were labeled "other" and were categorized according to tree type classes based on tree type (one of four life forms and three mature sizes):

- Broadleaf deciduous - large (BDL), medium (BDM), and small (BDS).
- Conifer - large (CL), medium (CM), and small (CS).

Large, medium, and small trees measured < 25 ft, 25-40 ft, and >40 ft in mature height. A typical tree was chosen for each of the above 6 categories to obtain growth curves for "other" trees falling into each of the categories:

BDL Other = Norway maple
BDM Other = Ornamental pear
BDS Other = Apple/Crabapple
CEL Other = Colorado spruce
CEM Other = Austrian pine
CES Other = Scaled @ 2/3 Austrian pine

Where modeled species did not exist for a specific category—CES Other—a larger-stature species was scaled-down in size metrics to be used as a surrogate for other trees falling into the category.

Calculating Costs

Expenditures associated with public trees were evaluated based on data provided by Buchanan (2003) for Fiscal Year 2003-2004. Cost data were specific to public street and park trees, and included costs for sidewalk repair by Public Works and trip and fall legal costs.

Calculating Net Benefits and Benefit-Cost Ratios

To assess the total value of annual benefits (B) for each tree (i) benefits were summed.

$$B = \sum_{1}^{n} (\sum_{1}^{n} i(e_i + a_i + c_i + h_i + p_i) \qquad [3]$$

where

e = price of net annual energy savings = annual natural gas savings + annual electricity savings

a = price of annual net air quality improvement = PM_{10} interception = No_2 and O_3 absorption = avoided power plant emissions – BVOC emissions

c = price of annual carbon dioxide reductions = CO_2 sequestered less releases + CO_2 avoided from reduced energy use

h = price of annual stormwater runoff reductions = effective rainfall interception

p = price of aesthetics = annual increase in property value

Total net expenditures were calculated based on all identifiable internal and external costs associated with the annual management of public and private street trees citywide. Annual costs for public trees (*C*) were summed:

$$C + p + t + r + d + e + s + c + l + a + q \qquad [4]$$

where

p = annual planting expenditure

t = annual pruning expenditure

r = annual tree and stump removal and disposal expenditure

d = annual pest and disease control expenditures

e = annual establishment/irrigation expenditure

s = annual price of repair/mitigation of infrastructure damage

c = annual price of litter/storm clean-up

l = average annual litigation and settlements expenditures due to tree – related claims

a = annual expenditure for program administration

q = annual expenditures for inspection/answer service requests

Total citywide annual net benefits as well as the benefit–cost ratio (BCR) were calculated using the sums of benefits and costs:

$$\text{Citywide Net Benefits} = B\text{-}C \qquad [5]$$

$$\text{BCR} = {}^{B}\!/_{C} \qquad [6]$$

APPENDIX C – Tree Species List

Tree species listed in the street tree inventory and tree type (BDL, BDM, and BDS for broadleaf deciduous large, medium, and small, CEL, CEM, CES for coniferous evergreen large, medium, and small). Species with "Other" were not among the top 20 species.

Botanical Name	Common name	Type
Abies concolor	white fir	CEL Other
Acer freemanii	Freeman maple	DL Other
Acer glabrum	Rocky Mountain maple	BDS Other
Acer negundo	boxelder maple	DL Other
Acer platanoides	Norway maple	DL
Acer saccharum	sugar maple	DL
Acer sacharinum	silver maple	DL
Acer spp.	maple other	DL Other
Aesculus glabra	Ohio buckeye	DM Other
Aesculus hippocastanum	horsechestnut	DM Other
Amelanchier spp.	serviceberry	DS Other
Betula spp.	birch other	DM Other
Carpinus betulus	hornbeam	DM Other
Carya ovata	shagbark hickory	DL Other
Carya spp.	hickory/chestnut	DL Other
Catalpa spp.	catalpa	DL Other
Celtis occidentalis	hackberry	DL
Cercis canadensis	redbud	DS Other
Cornus spp.	dogwood shrub/other	DS Other
Corylus colurna	Turkish filbert	DM Other
Crateagus spp.	hawthorn	DS Other
Eleagnus angustifolia	Russian olive	DS Other
Fagus spp.	beech	DL Other
Fagus sylvatica	European beech	DL Other
Fraxinus americana	white ash	DL
Fraxinus pennsylvanica	green ash	DL
Fraxinus spp.	ash other	DL Other
Ginkgo biloba	gingko	DL Other
Gleditisia triancanthos	honeylocust	DL
Gymnocladus dioicus	Kentucky coffee tree	DL
Juglans cinerea	butternut	DL Other
Juglans nigra	black walnut	DL Other
Juniperous spp.	juniper species	CES Other
Juniperous virginana	Eastern red cedar	CES Other
Juniperus communis	common juniper	CES Other
Juniperus monosperma	oneseed juniper	CES Other
Juniperus scopulorum	Rocky Mountain juniper	CES Other
Liquidambar styraciflua	sweetgum	DL Other
Liriodendron tulipifera	tulip tree	DL Other
Lonicera spp.	honeysuckle	DS Other
Malus spp.	apple/crabapple species	DS
Metasequoia glyptostroboides	dawn redwood	DL Other
Picea engelmannii	Engelmann spruce	CEL Other
Picea glauca	white spruce	CEL Other
Picea mariana	black spruce	CEL Other
Picea pungens	blue spruce	CEL
Picea rubens	red spruce	CEL Other
Picea spp.	spruce other	CEL Other
Pinus cembroides	Mexican pinyon pine	CES Other
Pinus contorta	lodgepole	CEM Other
Pinus edulis	pinyon pine	CES Other
Pinus mugo	Mugo pine	CES Other
Pinus nigra	Austrian pine	CEM Other
Pinus ponderosa	ponderosa pine	CEL
Pinus strobiformis	southwestern white pine	CES Other
Pinus sylvestris	Scotch pine	CEM Other
Populus acuminata	lanceleaf cottonwood	DL Other
Populus alba	white poplar	DL Other
Populus angustifolia	narrowleaf cottonwood	DL Other
Populus boleana	Bolean poplar	DL Other
Populus caroliniana	Carolina poplar	DL Other
Populus sargentii	Plains cottonwood	DL
Populus spp.	cottonwood/poplar other	DL Other
Populus tremuloides	aspen	DM Other
Prunus padus	Mayday tree	DS Other
Prunus spp.	cherry/plum tree	DS
Prunus virginiana	chokecherry	DS Other
Pseudotsuga menziesii	Douglas fir	CEL Other
Pyrus spp.	pear species	DM
Quercus bicolor	swamp white oak	DL Other
Quercus coccinea	scarlet oak	DL Other
Quercus macrocarpa	burr oak	DL
Quercus muhlenbergii	chinkapin oak	DL Other
Quercus palustris	pin oak	DL Other

Quercus rober	English oak	DL Other
Quercus rubra	red oak	DL Other
Quercus shumardii	Shumard oak	DL Other
Quercus spp.	oak species	DL Other
Rhus spp.	sumac species	DS Other
Rhus typhina	staghorn sumac	DS Other
Robinia pseudoacacia	black locust	DL Other
Salix alba	white willow	DL Other
Salix discolor	pussy willow	DS Other
Salix fragilis	crack willow	DL Other
Salix spp.	willow species	DL Other
Sorbus spp.	mountain ash	DS Other
Syringa reticulata	Japanese tree lilac	DS Other
Syringa spp.	lilac other	DS Other
Thuja plicata	Western red cedar	CEL Other
Thuja spp.	arborvitae	CEL Other
Tilia americana	American linden	DL
Tilia cordata	littleleaf linden	DL
Tilia spp.	linden other	DL Other
Ulmus americana	American elm	DL
Ulmus pumila	Siberian elm	DL
Ulmus spp.	elm other	DL Other

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