City of Bismarck, North Dakota
Street Tree Resource Analysis

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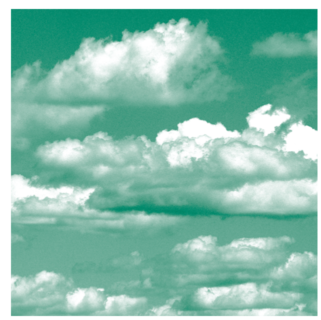
Technical Report to:

Mr. Paul Blumhardt, City Forester
Bismarck Forestry Department
Bismarck, ND 58506-5503

-- November 2004 --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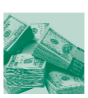
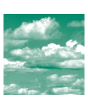
Areas of Research:


Investment Value


Energy Conservation


Air Quality


Water Quality


Firewise Landscapes

Mission Statement

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

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This report relied on data obtained from other organizations and has not been subjected to the peer-review process.

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Executive Summary

City of Bismarck, North Dakota Street Tree Resource Analysis

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Street trees in Bismarck are managed by the city's Forestry Department (BFD). They are maintained by both the BFD and private property owners. Over the years Bismarck has invested millions in its municipal forest. The primary question that this study asks is *whether the accrued benefits from Bismarck's street trees justify the annual expenditures?*

This analysis combines results of a 2002 citywide inventory with benefit-cost modeling data to produce four types of information:

1. Resource structure (species composition, diversity, age distribution, condition, etc.)
2. Resource function (magnitude of environmental and aesthetic benefits)
3. Resource value (dollar value of benefits realized)
4. Resource management recommendations (sustainability, pruning, planting)

Resource Structure

- Based on the 2002 BFD inventory there were of 17,821 municipal street trees in Bismarck. About 200 trees are removed from city streets each year, but the Department estimates an annual planting rate of at least 600 trees. In 2002, 725 trees were planted.
- There are many opportunities to increase the street tree resource. Approximately 24,000 sites—57.5% of all street tree- planting sites—were unplanted. This includes nearly 9,000 sites suitable for planting large trees, 7,300 for medium-stature trees, and 7,900 for small trees.
- Bismarck's ratio of street trees per capita is 0.31, slightly lower than the mean ratio of 0.37 reported for 22 U.S. street tree populations.
- Citywide, the resource represented 93 different tree species, a notable number considering climate restrictions. However, because the majority were newer introductions to the city and few in number, overall diversity was low.
- Over 47% of the street trees were in good to excellent condition with an additional 49% in fair condition. Over 50% of the trees in core areas (Zones, 3, 4, 5), where the predominant species was America elm, were in good or better condition.
- Abundant species having the best performance overall were Green ash, American elm, Chokecherry, and Hackberry.
- Having the most leaf area, Green ash and American elm were the most important street tree species in Bismarck, contributing over 82% of the total tree leaf area and 74% of the total basal area.
- The tree population is predominantly characterized by young and small trees, which should eventually produce many benefits. These trees represent a focused effort in recent years to increase tree

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numbers and species diversity, eventually enabling the community to reduce its current reliance on a single mature species – American elm – for benefit production

Resource Function And Value

- The ability of Bismarck's municipal trees to intercept rain—thereby avoiding stormwater runoff—was estimated at 953,528 cubic feet annually, providing the largest environmental benefit to the community. The total value of this benefit was $496,227. Citywide, the average street tree intercepted 400 gallons, valued at $27.85, annually.

- Because of Bismarck's winter wind conditions, energy savings from trees are higher than those that would be found in more sheltered locations. Electricity and natural gas saved annually from shading, wind shelter and other climate effects, totaled 651 MWh and 6,242 Mbtu, respectively, for a total retail savings of $84,332 ($4.73/tree).

- Citywide, municipal trees sequestered 952 tons of the greenhouse gas carbon dioxide. The same trees offset an additional 866 tons through reductions in energy plant emissions. The combination of these savings was valued at $27,269 ($1.53/tree) annually.

  Annual air pollutant uptake by trees (pollutant deposition and particulate interception) was 2.2 tons combined. The total value of this benefit for all street trees was $3,022, or about $0.17/tree.

- Energy savings associated with less fossil fuel consumption (due to the shade and climate effects of the trees) minus biogenic volatile organic compound emissions (BVOC) resulted in a net benefit of $1,491 or $0.08/tree. Only one species that accounted for more than 1% of the street tree population had a high BVOC emission rate – Boxelder maple – and there were only 198 trees.

- The estimated total annual benefit associated with property value increases and other less tangible benefits was $367,536 or $20.62/tree on average. Elm ($27/tree), and Hackberry ($25/tree) were on the high end, while Bur oak ($8/tree) and Common chokecherry ($7/tree) averaged the least benefits (the latter being new introductions and, therefore, still small in size).

- Overall, annual benefits were determined largely by tree size, where large-stature trees typically produced greater benefits. For example, average small or young trees produced $18/tree in benefits, maturing medium-sized trees produced $52/tree, mature large trees produced $123/tree, and large old trees produced annual benefits of $209/tree. The high values of the last two categories are attributable predominantly to American elm.

- The municipal tree resource of Bismarck is a valuable asset, providing approximately $979,877 ($55/tree) in total annual benefits to the community. The city currently spends approximately $18/tree on their care. Over the years Bismarck has invested millions in its municipal forest. Citizens are now receiving a relatively large return on that investment – receiving $3.09 in benefits for every $1 spent on tree care. Continued investment in management is critical to insuring that the community maintains or increases its return on investment into the future.

Resource Management Recommendations

- Use the street tree inventory as a tool for assessing long-term adaptability of new species, particularly large-stature species, through regular re-evaluations of tree condition and relative performance. This will assist in determining which species to include in a long-term planting program.

- Develop a long-term plan to achieve resource sustainability. This requires increasing diversity of the street tree population by balancing new plantings of proven, long-lived species with successful, newer introductions. This plan should address:

  – tree removal and replacement for senescent populations.

  – planting available large sites first, followed by those allowing medium and small trees.

- maximizing available growth space (24,000 sites) to provide for the largest amount of leaf area and canopy coverage as the trees mature.
- focusing planting efforts along streets and in zones where stocking levels are lowest to improve the distribution of benefits provided to all neighborhoods.

- Pruning needs for street trees were substantial. Within current budget constraints, the BFD re-allocated resources to reduce a 7-year rotational pruning cycle to a 5-year cycle for training smaller trees and a 6-year cycle for the contract pruning of larger trees. Tree health (the key to tree functionality and longevity) would improve by further reducing the inspection and pruning cycle to 2-3 years for smaller trees (<10" DBH) and 5 years for the larger trees.

Bismarck's street trees are a dynamic resource. Managers of this resource and the community alike can delight in knowing that street trees do improve the quality of life in Bismarck, but they are also faced with a fragile resource in need of constant care to maximize and sustain these benefits through the foreseeable future. The challenge will be to maximize net benefits from available growth space over the long-term, providing a resource that is both highly functional and sustainable.

Chapter One—Introduction

City of Bismarck, North Dakota
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Bismarck's Forestry Department (BFD) manages approximately 17,800 street trees in nine tree management zones located throughout the city. Street trees are identified as those growing in the City right-of-way area behind the curb. The trees are managed entirely by the Department but maintained by both the Department and adjacent property owners. The BFD believes that the public's investment in stewardship of Bismarck's urban forest produces benefits that outweigh the costs to the community. Bismarck, the state capital and second largest city in North Dakota, is an active economic, cultural and political center for the state. The population has grown by 1.2% over the past ten years to 56,234 citizens. Current community goals include maintaining and enhancing the integrity of community neighborhoods and business districts, as well as focusing on improvement through community investment in redevelopment zones. 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 health. Street trees are associated with other intangibles such as increased community attractiveness and recreational opportunities that make Bismarck a more enjoyable place to work and play. Bismarck's 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, residents and 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 whether the accrued benefits from Bismarck's street trees justify the annual expenditures?

In answering this question, information is provided to:

1. Assist decision-makers to assess and justify the degree of funding and type of management program appropriate for this city's urban forest.
2. Provide critical baseline information for the evaluation of program cost-efficiency and alternative management structures.
3. Highlight the relevance and relationship of Bismarck's municipal tree resource to local quality of life issues such as environmental health, economic development, and psychological health.
4. 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 seven chapters and five appendices:

Chapter One—Introduction: Describes purpose of the study.

Chapter Two—Bismarck's Street Tree Resource: Describes the current structure of the street tree resource.

Chapter Three—Costs of Managing Bismarck's Street Trees: Details management expenditures for publicly and privately managed trees.

Chapter Four—Benefits of Bismarck Municipal Trees: Quantifies estimated value of tangible benefits and calculates net benefits and a benefit-cost ratio for each population segment.

Chapter Five—Management Implications: Evaluates relevancy of this analysis to current programs and posits management challenges with goals of street tree management.

Chapter Six—Conclusion: Final word on the use of this analysis.

Chapter Seven—References: Lists publications cited in the study and the contributions made by various participants not cited as authors.

Appendix A—Methodology and Procedures

Appendix B—Tree Population Summary

Appendix C—Tree Population Summary by Zone

Appendix D—Condition and Relative Performance Index for All Species

Appendix E—Maintenance Tasks Citywide by Type, Zone and Species

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History And Current Management

Initially established as the western terminus of the Northern Pacific's Railroad in 1873, the city was named after German chancellor Otto von Bismarck. Gold was discovered shortly thereafter, increasing the growing city's population. Located in the rolling hills and valley along the Missouri River, Bismarck today is referred to as the "Jewel of North Dakota." It is ranked the least stressful city in America (Sperling 2004) and in 1997 received All American City designation (National Civic League 1997).

Bismarck is 574.4 m (1653 ft.) above sea level at latitude 46 o 46' and longitude 100 o 45'. It is located along the Missouri River where natural flooding used to occur annually and associated soils are predominantly a deep Mandan silt loam. Thirty-year average minimum and maximum temperatures range from 10.1°F to 70.3°F (-12.2°C to 21.3°C), respectively, with extremes from -0.6°F to 84.5°F (-18.1°C to 29.2°C). The city receives 15.4 inches (391.2 mm) of precipitation annually with winds averaging 10.2 mph (17.3 km/hr).

Bismarck has an active tree management program that promotes tree planting and stewardship throughout the community. It has received Tree City USA recognition annually since 1978. In 2003 the Bismarck Forestry Department employed 6 full time staff to manage and maintain municipal trees. The Department is responsible for the management and maintenance of all street trees and all other woody vegetation on all public properties. Although tree maintenance on street right-of-way (ROW) is conducted on a rotation by BFD and contract crews, adjacent property owners may apply for permission to prune and remove trees between rotation cycles. Additionally, the Department provides education programs and other information for citizens, conducts tree inspections on residential lots, licenses and regulates commercial arborists within the city, and provides planning and planting advice for new tree installations. The BFD also provides citizens with information on Bismarck trees, tree care, ordinances, and current issues affecting the urban forest on a website (http://www.bismarck.org/city_departments/department/default.asp?dID=12).

For this report, analysis was conducted on street trees only. Street trees are defined as those trees on city rights-of-way, behind street curbing in planting strips and/or lawns.

The Forestry Department maintains an active inventory of all street trees, updating it with condition, maintenance and removal information. Approximately 2,930 street trees were pruned in 2002, a year selected for this study because it represents normal maintenance trends. The goal of the BFD is to prune every tree at least once every 6 years, with a training pruning cycle of once every 5 years for smaller trees. When trees grow and develop clearance problems between rotation cycles, property owners are responsible for pruning the trees to established clearance standards. They are referred to commercial arborists licensed by the city.

On average, about 200 trees are removed from city streets each year. However, over 725 street trees were planted in 2002 and the Department estimates an annual planting rate of at least 600 trees. Property owners may obtain free permits for planting and participate in a tree planting grant program that partially defrays tree purchase and planting costs. In recent years the BFD has focused on increasing species diversity to increase protection against catastrophic loss.

Bismarck has 9 major tree management zones, with all but zones 6 and 9 subdivided into 3 to 7 sub-zones. The zones are:

- Zones 1 and 2 = developed in early 1980s
- Zones 3, 4, 5 = downtown core area; region of oldest development

- Zone 6 = development began in 1960s and 70s but 50% growth since 1980s
- Zones 7, 8 = developed late 1960s and early 1970s
- Zone 9 = predominantly industrial, including airport

The information reported in this chapter is based upon data provided in the 2002 Bismarck street tree inventory.

Tree Numbers And Stocking

There are approximately 17,821 street trees in Bismarck (Table 1). Zones 3, 4, and 5, constitute the majority of the city's core area where 55% of all street trees citywide are planted. Assuming Bismarck's human population is 56,234 (City-data.com 2004), there is about one street tree for every three residents. Calculations of street trees per capita are important in determining how well forested a city is. The more residents and greater housing density a city possesses, the more need for trees to provide benefits. Bismarck's ratio of street trees per capita is 0.31, slightly lower than the mean ratio of 0.37 reported for 22 U.S. street tree populations (McPherson and Rowntree 1989). There are 24,150 available planting sites; thus, 57.5% of all street tree planting sites are unplanted, ranging from 45.2% to 81.2% among zones. Approximately 37% of these sites could accommodate large trees, with 33% and 30% available for small and medium trees, respectively.

Table 1. Street right-of-way tree numbers by zone.

Zone	# of trees	# of APS	Total # of Sites	Stocking %
1	2,195	1,814	4,009	54.8
2	1,406	1,568	2,974	47.3
3	1,981	3,007	4,988	39.7
4	3,077	3,377	6,454	47.7
5	4,133	5,445	9,578	43.2
6	666	2,274	2,940	22.7
7	1,553	1,999	3,552	43.7
8	2,679	4,099	6,778	39.5
9	131	567	698	18.8
Citywide total	17,821	24,150	41,971	42.5

Large-stature coniferous and broadleaf trees (0-25 ft, 0-7.6m tall) composed 84% of Bismarck's street tree population with large-stature broadleaf deciduous trees the most prevalent tree type citywide (Table 2). They accounted for 82% of the trees. Only 3% of all trees planted were conifers. Medium-stature trees (25-40 ft or 7.6-12.2 m) were the least abundant (2.8%) in both tree type categories. Appendix B lists all tree species and their relative size at maturity as small (<25 ft tall; 7.6 m), medium (25-40 ft; 7.6-12.2 m), and large (>40 ft or 12.2 m).

Table 2. Citywide street tree numbers by mature size class and tree type.

Tree Type	Large	Med	Small	Total
Broadleaf Decid.	82.0	1.5	13.7	97.2
Conifer	1.6	0.6	0.6	2.8

Species Composition And Richness

The predominant street tree species (Table 3) were Green ash (Fraxinus pennsylvanica) and American elm (Ulmus americana), representing 51.4% of all trees (31.7 and 19.7%, respectively). These percentages exceed the customary guideline that no single species should exceed 10% of the population. However, both are also native to the area and well-

Table 3. Species predominance (listed in order by percent of total trees) and importance values calculated as the mean of tree numbers, leaf and basal area proportions.

Species	# of trees	% of Total Trees	Leaf Area (ft2)	% of Total Leaf Area	Basal Area (ft2)	% of Total Basal Area	IV
Green ash	5,644	31.7	11,697,020	27.9	2,978	18.1	25.9
American elm	3,506	19.7	19,804,960	47.3	9,135	55.7	40.9
American linden	1,342	7.5	1,141,286	2.7	137	0.8	3.7
Common chokecherry	744	4.2	394,175	0.9	185	1.1	2.1
Black ash	637	3.6	360,365	0.9	66	0.4	1.6
Littleleaf linden	539	3.0	448,294	1.1	137	0.8	1.6
Amur maple	506	2.8	181,791	0.4	65	0.4	1.2
Hackberry	476	2.7	617,467	1.5	131	0.8	1.6
Crabapple	384	2.2	151,023	0.4	60	0.4	1.0
Manchurian ash	324	1.8	147,887	0.4	19	0.1	0.8
Siberian elm	219	1.2	1,472,907	3.5	635	3.9	2.9
Bur oak	212	1.2	51,944	0.1	11	0.1	0.5
White/silver poplar	208	1.2	1,504,711	3.6	1,106	6.7	3.8
Norway maple	205	1.2	145,014	0.3	13	0.1	0.5
Boxelder maple	198	1.1	1,187,620	2.8	447	2.7	2.2
Totals	15,144	85.0	39,306,460	93.9	15,125	92.2	90.4

adapted. In all nine tree zones, Green ash or American elm were the most prevalent species (Table 4). American elm remains dominant in the older downtown areas (Zones 3, 4, and 5), with Green ash representing from 32 to 46% of the population in the remaining zones. The next most abundant species are American linden, 7.5% (Tilia americana), Common chokecherry, 4.2% (Prunus virginiana), and Black ash, 3.6% (Fraxinus nigra).

There were a total of 93 different tree species in the street tree inventory database. This is roughly double the mean of 53 species reported by McPherson and Rowntree (1989) in their nationwide survey. The majority of these species represent a conscious effort in recent years by the BFD to improve upon species diversity. They are new plantings of relatively few trees per species. An effort to select among the higher performing 10 or 12 new species should be encouraged.

Importance Value

Importance values are particularly meaningful to managers because they suggest a community's reliance on the functional capacity of particular species. In other words, importance value (IV) provides meaningful interpretation with respect to the degree a city might depend on particular urban trees insofar as their environmental benefits are concerned. This evaluation takes into account not only total numbers, but their basal and leaf area, providing a useful comparison to the total population distribution.

As a mean of three relative values, importance values (IVs), in theory, can range between 0 and 100; where an IV of 100 suggests total reliance on one species and an IV of 0 suggests no reliance. The 15 species listed in Table 3 constituted 85% of the street tree population in Bismarck, 94% of the leaf area, and 92% of the basal area. Therefore, the remaining 78 species combined accounted for only 15% of the trees, 6% of the leaf area and 8% of the basal area. Importance values ranged from 0.5 for Bur oak (Quercus macrocarpa) and Norway maple (Acer platanoides) to 40.9 for American elm.

American elms accounted for about one-fifth of all trees (3,506), but reliance on this species for benefit production was much higher than tree numbers alone indicate; these elms produced over one-quarter of all the leaf area and nearly 56% of the basal area. The importance values indicate that Bismarck is heavily reliant on their elms and also on a second species – Green ash – for the majority of the environmental benefits associated with municipal trees. Green ash accounted for 32% of the street tree population and produced nearly 28% of the leaf area, but only 18% of the basal area. In contrast, American linden accounted for a relatively small percentage of total leaf area (2.7%) and basal area (3.7%) despite being among the most abundant trees. This is because the majority of lindens are still small and young – over 90% are less than 12 in. (30.5 cm) DBH. As these trees grow, their importance will increase within the community.

Age Structure

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. An "ideal" distribution has a high proportion of new transplants to offset establishment-related mortality, while the percentage of older trees declines with age (Richards 1982/83).

Age curves for different tree species help explain their relative importance and suggest how tree management needs may change as the populations continue to age. Figure 1 compares the "ideal" age distribution with Bismarck's age structure for all species citywide, as well as the 10 predominant species. What stands out is how few older, large-diameter trees were present. With the exception of American elm, the Bismarck street tree population

Table 4. Top five species listed in order by percent (in parentheses) of total zone tree numbers.

Zone	Total	1st	2nd	3rd	4th	5th
1	1,509	Green ash (41.2)	American linden (8.5)	Black ash (7)	Common chokecherry (6.8)	Amur maple (5.3)
2	1,036	Green ash (45.9)	American linden (9.5)	Black ash (8.9)	Common chokecherry (5.3)	Littleleaf linden (4.1)
3	1,377	American elm (29.4)	Green ash (25.1)	American linden (8.6)	Hackberry (3.5)	Amur maple (2.9)
4	2,474	American elm (45.2)	Green ash (24.2)	American linden (5.8)	Littleleaf linden (3.6)	Crabapple (1.7)
5	3,008	American elm (33)	Green ash (27.6)	American linden (5.5)	White/silver poplar (3.5)	Common chokecherry (3.2)
6	444	Green ash (40.2)	American linden (14.6)	Black ash (4.1)	Common chokecherry (4.1)	Littleleaf linden (3.8)
7	835	Green ash (31.6)	Common chokecherry (8)	American linden (6.4)	Dogwood (5.9)	Crabapple (4.4)
8	1,575	Green ash (33.9)	American linden (9.2)	Common chokecherry (6.1)	American elm (5.3)	Amur maple (4.3)
9	90	Green ash (36.6)	Hackberry (9.9)	Crabapple (8.4)	Freeman maple (6.9)	Ponderosa pine (6.9)
Total	11,873	Green ash (31.7)	American elm (19.7)	American linden (7.5)	Common chokecherry (4.2)	Black ash (3.6)

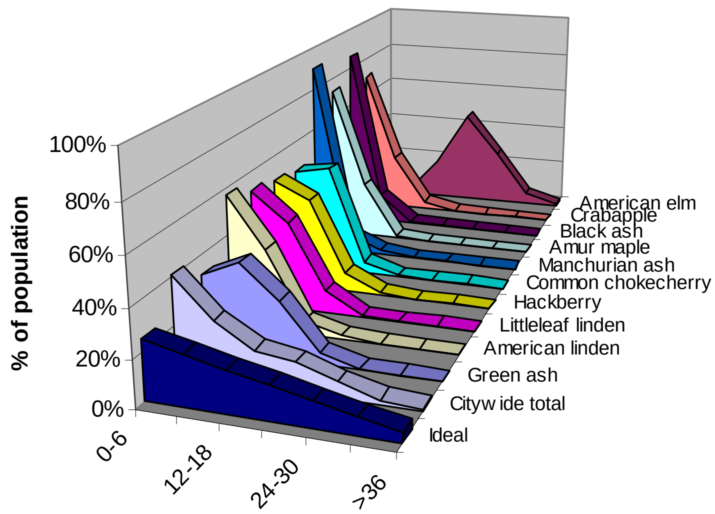

Figure 1. Relative age distribution for Bismarck's 10 predominant street tree species and all species citywide compared to "ideal" distribution.

predominantly consisted of relatively young and small trees. The age structure of street trees in Bismarck differed from the ideal in having 4% fewer mature or older trees. However, American elm accounted for nearly 75% of all mature trees citywide. Clearly, the continued health and welfare of this species is vital to the city's ability to maintain a flow of benefits into the future. These trees have provided benefits over a long period of time and, because of their size, are particularly important to maintain. Similarly, continued planting of successful newer introductions is important to developing a more diverse and sustainable municipal forest that has less possibility of suffering catastrophic loss due to the dominance of one or two species.

Although nearly 84% of the street trees are large-growing, the majority are still young with nearly 65% under 12 in. (30.5 cm). The intensity of newer plantings of large-stature trees – American and Littleleaf linden, Hackberry (Celtis occidentalis), Black ash, Green ash, Manchurian ash (Fraxinus mandshurica) – will contribute to a growing stream of future benefits as they mature. Amur maple (Acer ginnala) and Common chokecherry, although planted in large numbers in recent years, are small-stature trees and produce significantly less leaf area and fewer benefits than large-growing species. However, these are good selections for planting sites restricted by overhead utilities or limited soil volume. The challenge will be finding the best large-stature trees for planting and increase functional benefits over the long term.

Tree Condition

Tree condition indicates both how well trees are managed and their relative performance given site-specific conditions. Over 47% of the street trees were in good to excellent condition with an additional 49% in fair condition (Fig. 2 and Table 5). Over 50 % of the trees in core areas (Zones 3, 4, 5), where the predominant species was American elm, were in good or better condition. While street trees appeared healthy overall, there were some areas of localized concern. For example, 1.5% of the trees in Zone 9 were dead or dying, about 3 times the amount of any other zone. This zone was primarily industrial rather than residential and trees may not have received irrigation or care as consistently as those growing in boulevards with adjacent to homes, particularly during establishment. Additionally, nearly 7% of the trees in Zone 1 were in poor or worse condition, with the fewest trees in good or better condition. This zone was characterized by ongoing development and many newly-planted, young trees. It was also located where the prevailing winter winds and weather made new tree establishment more challenging than in other portions of the community. Soil conditions associated with the hills here were also not as favorable as the silty loams adjacent to the Missouri River.

Relative Performance Index

Typically, 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

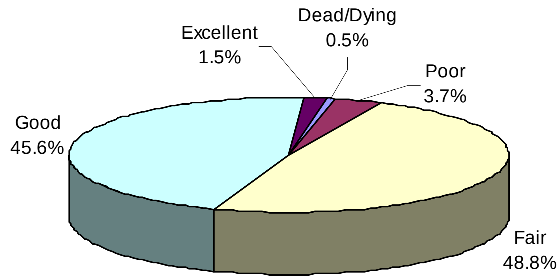

Figure 2. Citywide distribution of street trees by condition class.

dividing its proportion of all trees rated as good or excellent by the percentage of all trees citywide rated as good or excellent. For example, the RPI for Green ash was 1.13 because 53.1% were good or excellent compared to 47% of all trees citywide rated good or excellent (53.1/47 = 1.13). Species with RPIs greater than 1.0 have proportionately more individuals classified as good or excellent (Table 5). Species with larger percentages of trees in good condition are likely to be better adapted to Bismarck's climate and site conditions, requiring fewer inputs of money and management.

Abundant species rated as having the best performance, overall, were Green ash, American elm, Chokecherry, Hackberry, and Siberian elm (Ulmus pumila). For the most part, these species were widely adapted to growing conditions throughout the city. However, Siberian elm is increasingly suffering from canker disease that is causing higher mortality and removal rates. Nearly 13% of these trees were rated in poor condition. Similarly, Boxelder maple (Acer negundo) had a higher percentage of poor performers compared to other species.

Predominant species with the lowest RPI based on number of trees in good or better condition included Norway maple, Manchurian ash, Black ash, and Bur oak. It is important to note that the majority of these "low performers" were likely experiencing a transplant and adjustment period when their condition was rated. Each represents a newer introduction to the city's planting palette. Appendix D lists the condition RPI for all species included in the street tree inventory. Since the majority of Bismarck's street tree population is relatively young, we recommend that the RPI list be reviewed in conjunction with the population summary list (Appendix B) to better evaluate whether the RPI is based upon established tree selections or new

Table 5. Condition (%) and relative performance index (RPI) of Bismarck's street tree population (See Appendix for entire list).

	% of Trees in Each Condition Class							
Common Name	Dead	Poor	Fair	Good	Excellent	RPI	No. of Trees	% of Total Population
Green ash	0.3	4.5	42.0	52.4	0.7	1.13	5,644	31.7
American elm	0.1	2.0	30.9	64.2	2.9	1.42	3,506	19.7
American linden	1.1	4.2	60.3	32.5	1.9	0.73	1,342	7.5
Common chokecherry	-	1.6	34.3	61.6	2.4	1.36	744	4.2
Black ash	0.3	1.3	80.7	17.4	0.3	0.38	637	3.6
Littleleaf linden	1.3	3.9	53.2	39.3	2.2	0.88	539	3.0
Amur maple	0.8	2.6	59.1	36.6	1.0	0.80	506	2.8
Hackberry	0.6	3.8	48.5	44.3	2.5	1.00	476	2.7
Crabapple	-	1.8	64.3	33.6	-	0.71	384	2.2
Manchurian ash	0.9	4.0	80.9	13.3	0.9	0.30	324	1.8
Siberian elm	-	12.8	40.2	45.7	1.4	1.00	219	1.2
Bur oak	1.4	1.9	78.3	14.2	4.2	0.39	212	1.2
White/silver poplar	0.5	5.8	50.5	41.3	1.9	0.92	208	1.2
Norway maple	-	6.3	83.9	8.8	-	0.19	205	1.2
Boxelder maple	0.5	11.1	49.0	37.9	1.5	0.84	198	1.1
Citywide Street Tree Total	0.5	3.6	48.7	45.5	1.5		17,821	100

introductions that have not yet had time to prove or disprove their suitability as a species.

Location

The majority of the 17,821 street trees in Bismarck were located in planting strips ranging from 4 to 12 ft wide. Our sample estimated that 71% of these trees were adjacent to single family residential land uses and others were on commercial/industrial (10%), multi-home residential (9%), and other land uses (10%, institutional, vacant, or agricultural use).

Maintenance Needs

Understanding species distribution, age structure, and tree condition may aid in determining proper pruning cycle length, but it is important to understand the actual pruning and maintenance needs of the city trees on a species basis. Not only will this provide clues to whether or not the pruning is adequate, but what level of risk and liability is associated with the city's street tree population. Appendix E provides a complete list of maintenance tasks citywide by type, zone, and species.

Maintenance tasks (Table 6) recommended for Bismarck street trees included planting, training, pruning (levels 1-3), removal (levels 1-3), and routine maintenance. Nearly all inventoried trees (99%) were assigned maintenance tasks. The majority of these – over 95% -- required either routine pruning (57.2%) or training (38.5%). Over 10,200 trees (57%) required routine maintenance – either re-inspection or routine pruning. American elm and Green ash accounted for the majority of these trees – 7,192 or 70% of all trees requiring routine maintenance. American linden (5.6%), Common chokecherry (3.8%), and Littleleaf linden (2.4%) were the next most common species requiring routine pruning on a citywide basis.

Recently planted and immature trees that are still small should be pruned to correct or eliminate weak, interfering or objectionable branches to reduce future maintenance requirements and improve overall tree health and longevity. In Bismarck, 6,854 street trees required training. This accounted for 38% of the street tree population, not surprising considering the large number of young trees in Bismarck. Over 54% of those trees requiring training were Green ash (23%), American linden (11%), Black ash (8%), Common chokecherry, and Amur maple (5% each).

A safety prune implies remedy for hazardous tree conditions. Trees requiring removal indicate severe problems, although these are not necessarily related to safety hazards. Numbers may simply reflect dead or dying newly planted trees, or they may reflect unmanageable tree defects and hazards. Regardless, trees classified as needing removal and replacement detract from aesthetic appearance at best, and represent substantial costs or public safety hazards at worst. Only 2.8% of all Bismarck street trees required safety pruning (Pruning 1-3) or removal as hazardous trees. Nearly three-quarters of these 502 trees consisted of these five species: American elm (143; 28.5%), Green ash (111; 22.1%), Boxelder maple (Acer negundo, 60; 12.0%), Siberian elm (33; 6.6%) and White spruce (Picea glauca, 15; 3.0%). Zones 4 and 5 accounted for 57% of all required hazard tree removals and safety prunes. These zones are core downtown areas with more potential "targets" – vehicles and people – for hazardous trees.

Table 6. The number of trees requiring recommended maintenance by task for each DBH size class.

Task	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total	% of total population
Plant	5	11	-	-	-	-	-	-	-	16	0.1
Pruning 1	-	-	-	1	2	-	-	-	-	3	0.0
Pruning 2	-	1	-	1	5	2	-	-	1	10	0.1
Pruning 3	-	-	6	5	9	2	-	-	-	22	0.1
Removal 1	1	1	-	3	4	4	2	-	-	15	0.1
Removal 2	10	8	45	35	48	22	6	2	3	179	1.0
Removal 3	14	37	47	67	64	30	8	5	1	273	1.5
Routine	84	959	3,371	2,395	1,977	1,045	269	65	37	10,202	57.2
Train	4,240	1,811	781	21	-	-	-	-	1	6,854	38.5
Totals	4,354	2,828	4,250	2,528	2,109	1,105	285	72	43	17,574	98.6

City of Bismarck, North Dakota
Street Tree Resource Analysis

Paula J. Peper, E. Gregory McPherson, James R. Simpson, Scott E. Maco, Qingfu Xiao

Fiscal Year 2001-2002 Program Expenditures

Costs of Managing Public Trees

Costs were based on a review of expenditures during fiscal year 2001. The 2001 operating budget for the Bismarck Forestry Department for street and park tree management was $504,723 (Blumhardt 2002; 2004). The amount spent on the street tree program alone was $273,212, or 54% of the entire budget. This amount represented 0.68% of the city's total 2001 operating budget ($40,135,848). An additional $43,428 was spent on tree-related matters by other city departments for infrastructure repair associated with tree root damage and a wood-waste salvage program. Overall, $316,640, or $5.63 per capita, was spent on management of Bismarck's street trees. This is roughly equivalent to the regional (Northern Tier Region) average annual tree management expenditures of $309,392 reported by Tschantz and Sacamano (1994). The total number of street trees was 17,821 with expenditures per tree of $17.77 (Table 7). Forestry Department expenditures fell into three categories: tree planting and establishment, mature tree care, and administration.

Table 7. Bismarck annual expenditures in 2001.

Program Expenditures	Total	$/tree	$/capita
Contract & BFD Pruning	94,850	5.32	1.69
Tree & Stump Removal	50,061	2.81	0.89
Pest Management	17,429	0.98	0.31
Irrigation	7,200	0.40	0.13
Inspection/Service	17,011	0.95	0.30
Litter Clean-up	9,103	0.51	0.16
Purchasing Trees and Planting	5,880	0.33	0.10
Administration	71,678	4.02	1.27
Other Cost	-	-	-
Program subtotal	273,212	15.33	4.86
External expenditures			
Infrastructure Repairs	21,490	1.21	0.38
Wood Waste Program	21,938	1.23	0.39
Total External Expenditures	43,428	2.44	0.77
Grand total	316,640	17.77	5.63

Tree Planting and Establishment

The production of quality nursery stock, its subsequent planting, and follow-up care are critical to perpetuation of a healthy urban forest for Bismarck. The city plants and establishes an average 600 street trees per year. Community-minded sponsors have partnered with the city to provide funds to assist homeowners in purchasing and planting trees. Typically, homeowners obtain a free permit from the BFD after a forester conducts an on-site visit to determine tree placement and a provide advice on a selection of possible species. The program provides homeowners 50% of the cost to purchase and plant a tree with an annual maximum of $40/tree or $500/property. Trees are typically purchased from local nurseries. Direct costs to the city for tree planting in 2001 were $5,880 for tree planting. Remaining costs were absorbed by homeowners and sponsors in the Partners in Planting program.

Approximately 2,000 young trees are pruned annually for structure and form at an average cost of $32/tree. The BFD has been able to reduce their training pruning cycle to 5 years for the small (<10" DBH) trees pruned by their forestry staff. This was accomplished by increasing the number of trees pruned per hour and lengthening the amount of time spent pruning each year.

During summer, street trees are watered by truck for the first three years after planting at a cost of $8/tree per watering. Total annual watering costs are $7,200. Tree planting and irrigation costs account for about 4% of total tree expenditures by the city.

Mature Tree Care

Over 20% of Bismarck's street trees are over 18 inches DBH and predominantly American elm. This represents many mature and old trees so it is not surprising that about 60% ($188,454) of the 2001 tree program's budget was spent keeping these and other trees healthy and safe. Pruning, tree removal, and pest management accounted for most of this amount. Approximately $94,850 was spent for contract and BFD pruning combined. Pruning accounts for the largest cost for tree management in the city, accounting for 30% ($5.32) of the total per tree expenditures ($17.77). The Department removes about 200 street trees each year (based on the past 5 years) at a cost of $50,061 (includes stump removal). This is the second largest per tree expenditure at $2.81.

Mature tree care for street trees is dependent upon both the city and adjacent property owners. Mature trees are predominantly pruned under contract with licensed commercial arborists that the BFD monitors. These trees are currently pruned on a 6-year rotation, but it is sometimes necessary that homeowners prune trees between rotation pruning cycles. Citizens contact the BFD to request an inspection of their trees and obtain a free street tree pruning permit. The BFD provides property owners with a list of commercial arborists licensed by the city. Inspection time for answering service requests, public education, and plan review adds up to $17,011 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. Bismarck has an extensive American elm street tree population and an aggressive Dutch Elm Disease (DED) monitoring program that has been very successful in preserving the overall health of the species. Considering the species' importance to the city, maintaining the health and vigor of this population is vital. The 2001 pest and disease control expenditures totaled $17,429 for treatments to control DED, spider mites, elm scale, and other pests associated with the street tree population. Expenditures to cleanup tree litter were $9,103 or $0.51/tree annually.

Administration

Approximately 23% of all program expenditures were for administration, totaling $71,678. This item accounted for salaries and benefits of supervisory staff that performed planning and management functions, as well as contract development and supervision.

Other Tree-Related Expenditures External To The City Forestry Program

Tree-related expenses accrued to the city that were not captured in the Forestry Department's budget. These expenditures included sidewalk and curb repair and a wood waste program.

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 resolve the problem without removing the tree. The BFD air-excavates the tree roots to determine whether they are the cause of the damage and, if so, which specific roots need pruning. Along with pruning and replacing concrete, other mediation strategies include ramping and meandering or narrowing the sidewalk. Total expenditures for repair were $21,490 or $1.21/tree, accounting for about 7% of all tree expenditures.

Wood-Waste Program

Upon pruning and removal of trees, the BFD hauls the materials to the Bismarck City Landfill where 90% are salvaged and sold to private and commercial purchasers. Wood chips suitable for landscape mulch are sold for $0.02/lb. Tree logs suitable for firewood and saw logs for milling are also sold. In 2001, net operating costs were $21,490, accounting for the $25,000 in equipment purchased to operate the program and the $3,062 earned from sales of salvaged wood. Not included in this analysis was the value to the community of recycling the wood versus designating more landfill space to accommodate disposal rather than the salvage operation.

City of Bismarck, North Dakota Street Tree Resource Analysis

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Introduction

Estimates of benefits are initial approximations—as some benefits are intangible or difficult to quantify (e.g., impacts on psychological health, crime, and violence). Also, limited knowledge about the physical processes at work and their interactions make estimates imprecise (e.g., fate of air pollutants trapped by trees and then washed to the ground by rainfall). Tree growth and mortality rates are highly variable and benefits depend on the specific conditions at the site (e.g., tree species, growing conditions, maintenance practices). Therefore, this method of quantification was not intended to account for every benefit or penny. Rather, this approach was meant to be a general accounting of the benefits produced by municipal trees in Bismarck; an accounting with an accepted degree of uncertainty that can nonetheless, provide a platform on which decisions can be made (Maco 2003). Methods used to quantify and price these benefits are described in Appendix A.

Energy Savings

Trees modify climate and conserve building-energy use in three principal ways:

1. Shading—reduces the amount of radiant energy absorbed and stored by built surfaces.
2. Transpiration—converts moisture to water vapor and thus cools by using solar energy that would otherwise result in heating of the air.
3. Wind speed reduction—reduces the infiltration of outside air into interior spaces and conductive heat loss where thermal conductivity is relatively high (e.g., glass windows) (Simpson 1998).

Trees and other greenspace within individual building sites may lower air temperatures 5°F (3°C) compared to outside the greenspace (Chandler 1965). At the larger scale of urban climate (6 miles or 10 km square), temperature differences of more than 9°F (5°C) have been observed between city centers and more vegetated suburban areas (Akbari et al. 1992). The relative importance of these effects depends on the size and configuration of trees and other landscape elements (McPherson 1993). Tree spacing, crown spread, and vertical distribution of leaf area influence the transport of cool air and pollutants along streets and out of urban canyons. Appendix A provides additional information on specific areas of contribution trees make toward energy savings.

Electricity and Natural Gas Results

Electricity and natural gas saved annually in Bismarck from both shading and climate effects totaled 651 MWh and 6,242 Mbtu, respectively, for a total retail savings of $84,332 (Table 8) or a citywide average of $4.73/tree. Green ash and American elm contributed over three-quarters of the benefits. In general, larger trees produced larger benefits. Differences in benefits between life forms (evergreen, deciduous) were dramatic, with large deciduous street trees producing over three times the benefit of large coniferous street trees (Table 9). Medium deciduous trees produced lower benefits than small deciduous only because they were few in number (263 trees) and over 80% were relatively new plantings, measuring under 6 in. (15 cm) DBH. Energy benefits associated with conifers adjacent to homes were lower than deciduous tree benefits because the detrimental effect of their winter shade on heating costs outweighed their wind reduction benefit.

Table 8. Net annual energy savings produced by Bismarck municipal trees.

Species	Electricity (MWh)	Natural Gas (Mbtu)	Total ($)	% of total trees	% of Total $	Avg. $/tree
Green ash	185	1,904	24,848	31.7	29.5	4.40
American elm	330	2,920	41,149	19.7	48.8	11.74
American linden	14	147	1,882	7.5	2.2	1.40
Common chokecherry	12	141	1,696	4.2	2.0	2.28
Black ash	4	50	621	3.6	0.7	0.98
Littleleaf linden	6	74	887	3.0	1.0	1.65
Amur maple	6	79	940	2.8	1.1	1.86
Hackberry	10	109	1,370	2.7	1.6	2.88
Crabapple	5	61	727	2.2	0.9	1.89
Manchurian ash	2	19	242	1.8	0.3	0.75
Siberian elm	15	135	1,880	1.2	2.2	8.59
Burr oak	1	8	100	1.2	0.1	0.47
White/silver poplar	12	118	1,577	1.2	1.9	7.58
Norway maple	1	14	174	1.1	0.2	0.85
Boxelder maple	16	129	1,930	1.1	2.3	9.75
Other Street Trees	32	334	4,308	15.0	5.1	1.61
Citywide Total	651	6,242	84,332	100	100	4.73

Table 9. Average per tree energy benefit ($) by tree type.

Species	Street
Lg. Deciduous	5.44
Med. Deciduous	0.99
Sm. Deciduous	1.72
Lg. Conifer	0.92
Med. Conifer	0.65
Sm. Conifer	0.18
Citywide total	4.73

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.
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 unless recycled.

As Table 10 shows, the amount of CO_2 benefit produced is dependent on species present and their

Table 10. Net CO2 reductions of Bismarck street trees.

Species	Sequestered (lb)	Decomposition Release (lb)	Maintenance Release (lb)	Avoided (lb)	Net Total (lb)	Total ($)	% of Total Trees	% of Total ($)	Avg. $/ Tree
Green ash	778,412	66,122	46,953	492,680	1,158,018	8,685	31.7	31.9	1.54
American elm	994,964	186,629	69,352	878,895	1,617,877	12,134	19.7	44.5	3.46
American linden	66,170	4,594	7,181	36,678	91,074	683	7.5	2.5	0.51
Common chokecherry	23,931	3,809	4,674	30,615	46,063	345	4.2	1.3	0.46
Black ash	20,751	1,299	1,855	11,658	29,256	219	3.6	0.8	0.34
Littleleaf linden	34,759	1,900	3,004	16,028	45,883	344	3.0	1.3	0.64
Amur maple	20,974	1,161	2,211	16,722	34,324	257	2.8	0.9	0.51
Hackberry	19,965	1,415	2,916	26,180	41,813	314	2.7	1.1	0.66
Crabapple	16,320	1,084	1,693	13,071	26,613	200	2.2	0.7	0.52
Manchurian ash	8,259	441	797	4,542	11,563	87	1.8	0.3	0.27
Siberian elm	90,924	13,393	4,357	39,646	112,820	846	1.2	3.1	3.86
Burr oak	3,987	231	458	1,899	5,197	39	1.2	0.1	0.18
White/silver poplar	74,480	10,623	5,489	32,051	90,420	678	1.2	2.5	3.26
Norway maple	6,993	302	548	3,229	9,371	70	1.1	0.3	0.34
Boxelder maple	81,547	10,405	3,572	43,453	111,023	833	1.1	3.0	4.21
Other Street Trees	148,108	14,993	12,833	84,227	204,510	1,534	15.0	5.6	0.57
Citywide total	2,390,544	318,401	167,894	1,731,575	3,635,824	27,269	100	100	1.53

age. Citywide, street tree reduction of energy plant CO_2 emissions and net sequestration rates were 866 and 952 total tons, respectively, at a combined value of $27,269. Net sequestration was about 10% greater than reduced emissions. Green ash (31.9%) and

American elm (44.5%) accounted for over 76% of the CO_2 benefits produced by street trees. Tree species with the highest per tree savings were Boxelder maple ($4.21), Siberian elm ($3.86), American elm ($3.46), White/silver poplar (Populus alba, $3.26), and Green ash ($1.54).

Avoided emissions are extremely important in Bismarck because fossil fuels (92% coal) are the primary energy source (US EPA 2003). These fuels have a relatively high CO_2 emission factor. Shading by trees during hot summers reduces the need for air conditioning, resulting in reduced use of coal for cooling energy production.

Air Quality Improvement

Urban trees provide air quality benefits in five main ways:

1. Absorbing gaseous pollutants (ozone, nitrogen oxides) through leaf surfaces.
2. Intercepting particulate matter (e.g., dust, ash, dirt, pollen, smoke).
3. Reducing emissions from power generation by limiting building energy consumption.
4. Releasing oxygen through photosynthesis.
5. Transpiring water and shading surfaces, which lower 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). A computer simulation study for the Los Angeles basin found that increased tree planting of low BVOC emitting tree species would reduce ozone concentrations and exposure to ozone, while planting of medium- and high-emitters would increase overall ozone concentrations (Taha 1996).

Deposition and Interception Result

Annual pollutant uptake by trees foliage in Bismarck was 2.2 tons of combined uptake at a total value of $3,022 or $0.17/tree. American elm alone accounted for 62% of this amount with Green ash contributing another 14%. Ozone and sulfur dioxide (SO_2) uptake accounted for 86% and 14% of the savings, respectively.

Avoided Pollutants and BVOC Emissions Result

Annual avoided pollutant emissions at power plants plus BVOC emissions totaled 2,104 lb. Although street trees provided substantial reductions of power plant emissions due to energy savings, their release of more highly priced BVOCs can result in a net cost. However, high emitters (> 10 ug/g/hr) in Bismarck were limited to one species --Boxelder maple – and there were few of those (198 trees). This resulted in a net avoided emission benefit to the city of $1,491 or $0.08/tree.

Net Air Quality Improvement

Bismarck's municipal forest produced annual air quality benefits valued at $4,513 ($0.25/tree) by removing 6,412 lbs (3.2 tons) of pollutants from the atmosphere (Table 11). About 67% of the net air

Table 11. Net air quality benefits for all street trees.

	Deposition (lb)				Avoided (lb)				BVOC Emissions	Net		% of Total	% of Total	Avg. $
Species	O_3	NO_2	PM_{10}	SO_2	NO_2	PM_{10}	VOC	SO_2	(lbs)	Total (lb)	Total ($)	Trees	$	/tree
Green ash	418.5	14.3	145.7	37.8	243.2	46.7	44.5	331.1	0.0	1,281.7	888	31.7	19.7	0.16
American elm	1,878.6	63.9	543.3	169.1	437.9	86.2	82.4	621.3	0.0	3,882.7	2,730	19.7	60.5	0.78
American linden	26.6	0.9	9.6	2.4	18.2	3.5	3.3	24.6	-61.0	28.1	23	7.5	0.5	0.02
Common chokecherry	59.3	2.0	16.3	5.2	15.0	2.8	2.6	19.3	0.0	122.6	87	4.2	1.9	0.12
Black ash	6.3	0.2	2.5	0.6	5.7	1.1	1.0	7.6	0.0	25.0	17	3.6	0.4	0.03
Littleleaf linden	13.1	0.4	4.6	1.2	7.9	1.5	1.4	10.2	-19.9	20.2	15	3.0	0.3	0.03
Amur maple	9.7	0.3	3.7	1.1	8.2	1.5	1.4	10.4	-0.2	36.1	25	2.8	0.6	0.05
Hackberry	12.9	0.4	5.3	1.2	12.9	2.4	2.3	17.2	0.0	54.7	38	2.7	0.8	0.08
Crabapple	10.1	0.3	3.5	1.1	6.4	1.2	1.1	8.2	-0.2	31.8	22	2.2	0.5	0.06
Manchurian ash	1.9	0.1	0.8	0.2	2.2	0.4	0.4	2.9	0.0	8.9	6	1.8	0.1	0.02
Siberian elm	136.8	4.6	37.9	12.3	19.6	3.8	3.7	27.5	0.0	246.2	174	1.2	3.9	0.80
Bur oak	0.7	0.0	0.3	0.1	0.9	0.2	0.2	1.2	-13.5	-10.0	-6	1.2	-0.1	-0.03
White/silver poplar	168.6	5.6	44.3	17.8	15.8	3.1	2.9	21.9	0.0	280.0	199	1.2	4.4	0.96
Norway maple	1.1	0.0	0.5	0.1	1.6	0.3	0.3	2.1	-5.5	0.5	1	1.2	0.0	0.00
Boxelder maple	95.9	3.3	27.6	8.4	21.6	4.3	4.1	31.3	-54.9	141.6	103	1.1	2.3	0.52
Other Street Trees	187.3	6.2	54.8	19.6	41.7	8.0	7.6	56.3	-119.2	262.3	192	15.0	4.2	0.07
Citywide total	3,027.4	102.6	900.7	277.9	858.7	166.9	159.3	1,193.1	-274.3	6,412.4	4,513	100	100	0.25

quality savings were due to street tree pollutant uptake, with the remaining one-third attributable to the selection and planting of low-emitting species. Low deposition rates coupled with higher

BVOC emissions resulted in a net cost for Bur oak \$0.03/tree. Trees producing the greatest per tree benefit included White/silver poplar (\$0.96), Siberian elm (\$0.80), and American elm (\$0.78). However, the White poplar and Siberian elm are no longer being planted due to increasing health and liability issues attributed to weak-wood and canker (in the elm). Citywide, over 80% of the total net air quality benefit were attributable to two species -- American elm and Green ash. American elms constituted 19.7% of the street tree population but accounted for 60.5% of the air quality benefit.

Stormwater Runoff Reductions

Urban stormwater runoff is an increasing concern as a significant pathway for contaminants entering local streams, lakes and reservoirs. In effort to protect threatened fish and wildlife, stormwater management requirements are becoming increasingly broad, stringent, and costly; cost-effective means of mitigation are needed. Healthy urban trees can reduce the amount of runoff and pollutant loading in receiving waters in three primary ways:

1. Leaves and branch surfaces intercept and store rainfall, thereby reducing runoff volumes and delaying the onset of peak flows.
2. Root growth and decomposition increase the capacity and rate of soil infiltration by rainfall and reduce overland flow.
3. Tree canopies reduce soil erosion and surface transport by diminishing the impact of raindrops on barren surfaces.

The ability of Bismarck's street trees to intercept rain and reduce annual runoff was estimated at 7,132,889 gallons or 953,528 ft^3 (Table 12) with an implied value of \$496,227. On average each tree reduces stormwater runoff by 400 gallons (1,514 liters) and the value of this benefit is \$27.85. Green ash and American elm trees accounted for over 78% of this benefit. Street tree species that produced the greatest annual benefits per tree were White/silver poplar (\$92.52), American elm (\$80.21), Siberian elm (\$64.54) and Boxelder maple (\$59.15).

Property Values 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 not accounted for 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 quickly as unshaded streets. The social and psychological benefits provided by

Table 12. Annual stormwater reduction benefits of Bismarck street trees by species.

Species	Rainfall Intercept. (gal)	Total \$	% of total trees	% of Total \$	Avg. \$/tree
Green ash	1,526,165	106,174	31.7	21.4	18.81
American elm	4,042,501	281,232	19.7	56.7	80.21
American linden	166,876	11,609	7.5	2.3	8.65
Common chokecherry	77,952	5,423	4.2	1.1	7.29
Black ash	37,690	2,622	3.6	0.5	4.12
Littleleaf linden	57,160	3,977	3.0	0.8	7.38
Amur maple	33,692	2,344	2.8	0.5	4.63
Hackberry	98,962	6,885	2.7	1.4	14.46
Crabapple	27,530	1,915	2.2	0.4	4.99
Manchurian ash	14,233	990	1.8	0.2	3.06
Siberian elm	203,159	14,134	1.2	2.8	64.54
Bur oak	5,374	374	1.2	0.1	1.76
White/silver poplar	276,623	19,244	1.2	3.9	92.52
Norway maple	14,993	1,043	1.1	0.2	5.09
Boxelder maple	168,356	11,712	1.1	2.4	59.15
Other Street Trees	381,624	26,549	15.0	5.3	9.92
Citywide total	7,132,889	496,227	100	100	27.85

Bismarck's street trees improve human well-being. Trees also provide important settings for recreation in and near Bismarck. Research on the aesthetic quality of residential streets has shown that street trees are the single strongest positive influence on scenic quality. Also, urban and community forestry provides educational opportunities for residents who want to learn about nature through first-hand experience.

The estimated total annual benefit associated with property value increase in Bismarck was approximately $367,536, or $21/tree on average (Table 13). This value was about half that for trees in Fort Collins, CO, not surprising because median home prices greatly influence the average annual dollar savings and Fort Collins ($212,000; Mills 2002) had over twice the median home price of Bismarck ($101,640; CNN Money.com 2003).

Tree species contributing the largest portion of this benefit included Green ash (35.5%), American elm (25.5%), American linden (6.6%) and Hackberry (3.2%). Typically, those species adding the largest amount of leaf area over the course of a year tend to produce the highest average annual benefit. Siberian elm, American elm, and Norway maple, produced the highest average annual benefits per tree.

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

Total annual benefits produced by Bismarck's street trees were estimated to have a value of $979,877 or about $55/tree and $17/resident. Bismarck's street trees returned $3.09 to the community for every $1 spent on their management (Table 14).

Table 14. Benefit-Cost summary for Bismarck's street trees.

Benefit	Total ($)	Street $/tree	$/capita
Energy	84,332	4.73	1.50
CO2	27,269	1.53	0.48
Air Quality	4,513	0.25	0.08
Stormwater	496,227	27.85	8.82
Environmental Subtotal	612,341	34.36	10.89
Property Increase	367,536	20.62	6.54
Total benefits	979,877	54.98	17.42
Total costs	316,640	17.77	5.63
Net benefits	663,237	37.22	11.79
Benefit-cost ratio	3.09		

Bismarck street trees have beneficial effects on the environment. Approximately 62% of the annual benefits were attributed to environmental values. Reduction in stormwater runoff was 81% of this value, a substantial sum averaging $28/tree. Benefits associated with energy savings were second in importance (14% of total benefits, $4.73/tree) followed by carbon dioxide reductions (5% of total benefits, $1.78/tree).

While species varied in their ability to produce benefits, common characteristics of trees within tree-type classes aid in identifying the most beneficial street trees in Bismarck (Figure 3). As is typical in most cities, Bismarck's larger trees – deciduous and conifer -- generally produced the most benefits. The anomaly was small-stature deciduous trees; for total

Table 13. Total annual increases in property value from Bismarck street trees by species.

Species	Total ($)	% of total trees	% of Total $	Avg. $/tree
Green ash	130,570	31.7	35.5	23.13
American elm	93,619	19.7	25.5	26.70
American linden	24,389	7.5	6.6	18.17
Common chokecherry	4,865	4.2	1.3	6.54
Black ash	9,798	3.6	2.7	15.38
Littleleaf linden	8,802	3.0	2.4	16.33
Amur maple	4,967	2.8	1.4	9.82
Hackberry	11,869	2.7	3.2	24.93
Crabapple	4,053	2.2	1.1	10.56
Manchurian ash	4,760	1.8	1.3	14.69
Siberian elm	8,159	1.2	2.2	37.26
Bur oak	1,755	1.2	0.5	8.28
White/silver poplar	5,506	1.2	1.5	26.47
Norway maple	6,398	1.1	1.7	31.21
Boxelder maple	3,634	1.1	1.0	18.35
Other Street Trees	44,392	15.0	12.1	16.58
Citywide total	367,536	100	100	20.62

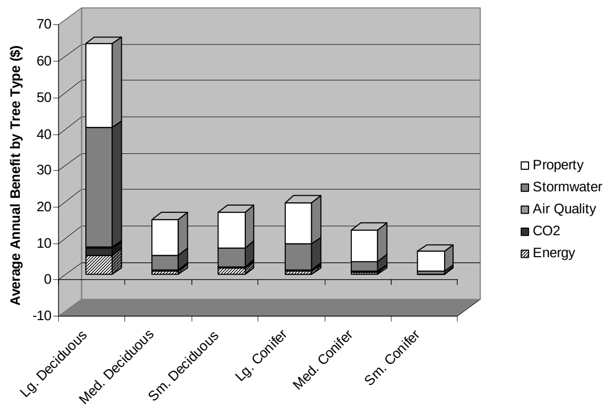

Figure 3. Average annual street benefits per tree by tree types.

benefits these trees provided a higher average return for the investment dollar than medium deciduous trees. This was primarily due to increased property value benefits associated with leaf area and total tree numbers. Medium-size trees were few and predominantly young with 211 of the 263 total trees less than 6” DBH. Conversely, there were 2,450 small trees, 1,633 at less than 6” DBH and 817 greater than 6” DBH.

Where environmental benefits are the primary concern, large deciduous trees provided the highest level of average benefits in Bismarck. Large conifers on streets provided more environmental benefits than small and medium deciduous trees due to higher savings associated with rainfall interception ($7/tree compared to $5 and $4/tree for the small and medium deciduous, respectively). However, large conifer contribution to energy savings and carbon dioxide reduction were lower than those generated by medium and small deciduous trees ($0.31/tree versus $0.48 and $0.36/tree, respectively). Small conifers produced the least benefit of all tree types, averaging $6.32/tree annually.

Average annual benefits by DBH size classes increased from $15/tree for small diameter trees to $231/tree for large diameter trees (Fig. 4). Property values and aesthetic benefits were most important for young trees because the result is influenced by growth rate, particularly the annual increase in leaf area. Conversely, stormwater runoff reduction benefits were greatest for older trees because leaf area and crown diameter influence rainfall interception. Energy benefits also increased, with larger crowns and leaf area providing more heating and cooling savings to residences.

Table 15 shows the distribution of total annual benefits in dollars for the predominant street species

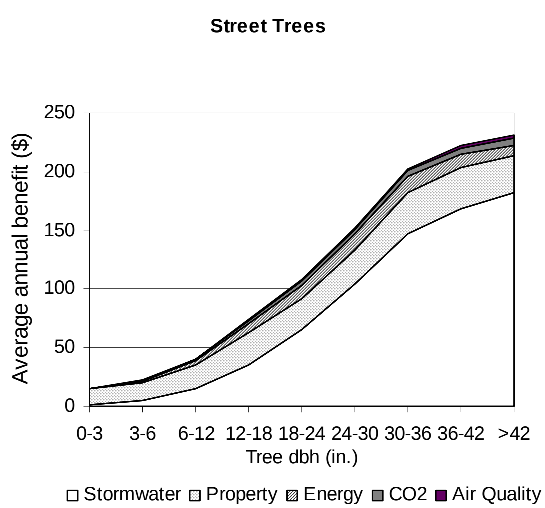

Figure 4. Average annual benefits per tree by DBH size classes.

Table 15. Total annual benefits ($) for predominant street trees in Bismarck.

Tree Species	# of Trees	Energy	CO2	Air Quality	Stormwater	Property	Benefit Total	% Total
American elm	3,506	41,149	12,134	2,730	281,232	93,619	430,865	44.0
Green ash	5,644	24,848	8,685	888	106,174	130,570	271,164	27.7
American linden	1,342	1,882	683	23	11,609	24,389	38,586	3.9
White/silver poplar	208	1,577	678	199	19,244	5,506	27,205	2.8
Siberian elm	219	1,880	846	174	14,134	8,159	25,193	2.6
Hackberry	476	1,370	314	38	6,885	11,869	20,475	2.1
Boxelder maple	198	1,930	833	103	11,712	3,634	18,212	1.9
Littleleaf linden	539	887	344	15	3,977	8,802	14,025	1.4
Black ash	637	621	219	17	2,622	9,798	13,278	1.4
Common chokecherry	744	1,696	345	87	5,423	4,865	12,417	1.3
Amur maple	506	940	257	25	2,344	4,967	8,534	0.9
Norway maple	205	174	70	1	1,043	6,398	7,686	0.8
Crabapple	384	727	200	22	1,915	4,053	6,917	0.7
Manchurian ash	324	242	87	6	990	4,760	6,085	0.6
Bur oak	212	100	39	(6)	374	1,755	2,262	0.2
Other Street Trees	2,677	4,308	1,534	192	26,549	44,392	76,975	7.9
Street Tree Total	17,821	84,332	27,269	4,513	496,227	367,536	979,876	100

in Bismarck. American elm, accounting for 20% of the tree population, produced 44% of all benefits. Green ash accounted for more of the population than the elm (32%), but produced fewer benefits (28% of the total) because the population is predominantly younger and smaller than the elms (Fig 5).

The 7,300 small, young trees (<6" DBH) in Bismarck accounted for 41% of the municipal tree population and 13% of the annual benefits ($18/tree). Nearly 70% of these young, small trees are large-growing and will assist eventually in continuing the flow of benefits into the future.

Maturing trees (6-18" DBH) were 38% of the population and contributed 37 % of the annual benefits ($52/tree). American elm and Green ash were the predominant species in these size classes (63%). Over 86% of the trees in the mature tree size classes (18-30" DBH) were American elm and Green ash. Mature trees composed 18% of the entire population and added 34% of the annual benefits to the community ($123/tree). About 2% of the population consisted of large, old trees, those greater than 30" DBH, producing over 9% of the total benefits ($209/tree). Over half were American elm with White/silver poplar accounting for another 23%.

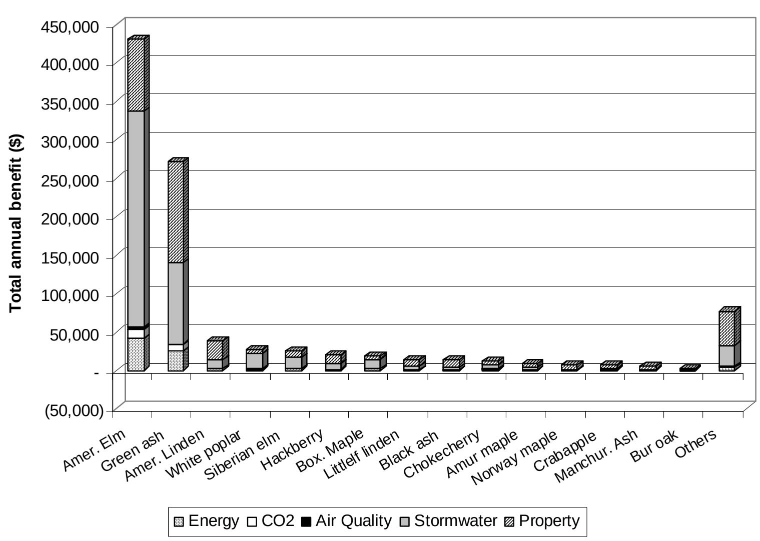

Figure 5. American elm and green ash account for 51% of the street tree population and 72% of all benefits. Because of rapid growth and large size they contribute substantially to property value and stormwater benefits.

The values presented in Figure 6 reflect the presence of specific tree types and population age. For example, Zone 6 – representing an area where development is ongoing – produced the second lowest total annual benefits of any residential area – approximately $19,215 or $29/tree. Compared to its neighbor to the west, Zone 5, trees are few and young. Zone 5 represents one of the most established core downtown areas. It is home to many of the oldest and largest trees in Bismarck, producing the highest total annual benefits ($324,000 or $78/tree).

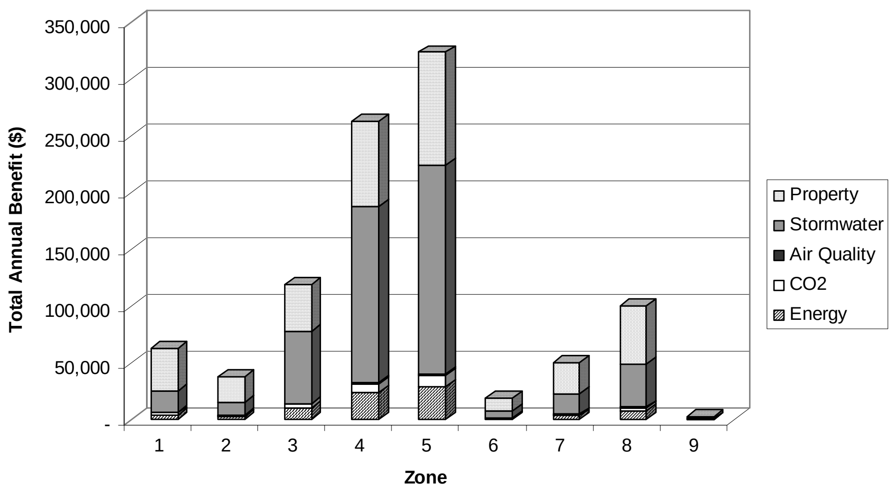

Figure 6. Total benefits by tree zone in Bismarck.

City of Bismarck, North Dakota
Street Tree Resource Analysis

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Street trees are only one component of a functional urban forest. In some cities, they are the most important component, defining the values of the community, thereby providing a portal to different neighborhoods and shopping districts. In other cities, street trees are treated with less concern than are parks, greenbelts, and private plantings. In any case, cities must seek to maintain a functional municipal forest that is both healthy and safe. In Bismarck, there is no doubt that trees are valued as an integral component of the city (Fig. 7).

Bismarck's 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 50 years ago and, at the same time, constantly changing as many new trees are planted. Although this study provides a "snapshot" in time of the resource, it also serves as an opportunity to speculate about the future. Given the status of Bismarck's street tree population, what future trends are likely and what management challenges will need to be met to achieve urban forest sustainability?

Achieving resource sustainability will produce long-term net benefits to the community while reducing the associated costs incurred with managing the resource. The structural features of a sustainable urban forest include adequate complexity (species and age diversity), well-adapted healthy trees, appropriate tree numbers and professional management. Focusing on these components – resource complexity, resource extent, pruning and maintenance – refines broader municipal tree management goals.

Resource Complexity

Although 93 different species have been planted along streets, Green ash and American elm are the dominant trees, accounting for 52% of all municipal trees and about 72% of the benefits. Figure 8 displays new and replacement planting trends. These ten species composed 70% of the new plantings in the street tree inventory. Only Green ash has been planted long enough for some trees to grow into mature size classes. The other species are relatively new introductions to the city. American and Littleleaf

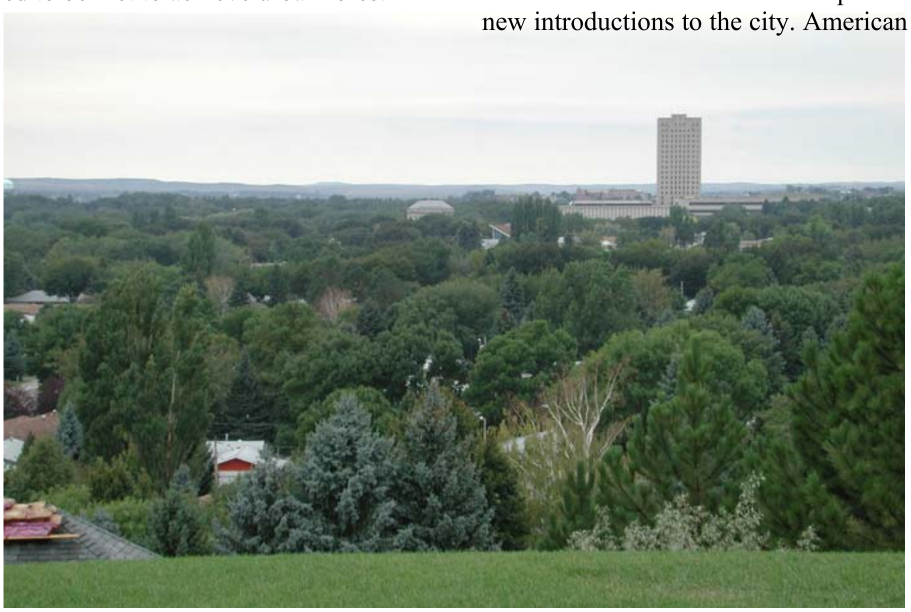

Figure 7. Bismarck today, showing an extensive urban forest in the downtown area planted originally to buffer the city from the effects of wind and weather on the open plains.

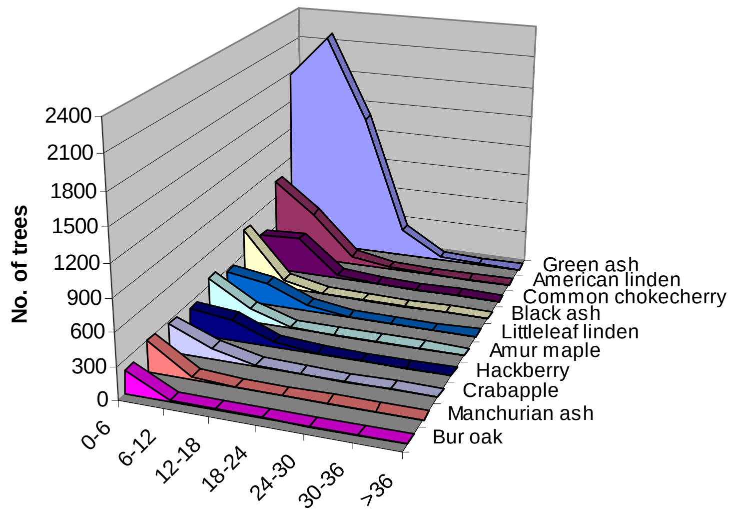

Figure 8. Top street trees planted by numbers and DBH in 2002.

linden, Hackberry and Chokecherry appear to be successful new selections with a number currently growing into the 12-18 inch DBH size class. Crabapple and Bur oak have done well in similar and more challenging climates (e.g., Fort Collins, CO and Cheyenne, WY) and should do well in Bismarck. Seven of ten of these newer species are large-growing, a vital consideration in efforts to diversify the forest while maintaining the flow of benefits the American elms currently produce.

The Chokecherry, Crabapple and Amur maple are small-stature and will produce fewer benefits than these larger-stature trees. However, as long as they are being planted in restricted sites only, not in sites appropriate for larger trees, they are good-performing selections.

As evident in Figure 9, large, long-lived deciduous trees were those that reached functionally large DBH classes. Typically, substantial tree numbers in large DBH classes indicate proven adaptability, but several of the large-stature species that reached maturity are no longer planted – Siberian elm, White/silver poplar, and Boxelder maple – because they are weak-wooded and associated with hazard and liability issues when planted along streets.

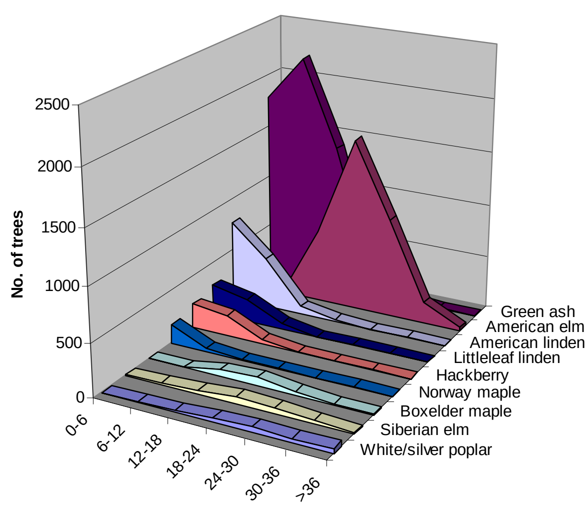

Figure 9. Age distribution of street trees in Bismarck that are currently producing the largest average annual benefits on a per tree basis.

The city has made a concerted effort to diversify the urban forest in recent years as indicated by the large number of trees in small size classes. The establishment of a systematic planting program focused on improving the age distribution for new, successful species is now necessary. A continuing examination of species performance will aid in determining which species, in addition to those in Figure 8, to include in the planting program.

Planting large and medium trees where space allows is vital to maintain the flow of benefits the community currently enjoys as the senescent portions of the American elm population is removed. A shift towards planting small-stature species or trees that have not proven to be long-lived could have the potential to reduce the future level of benefits afforded the community, but the placement for the smaller trees in Bismarck tends to be appropriate – under utility lines and in other restricted locations. Further evaluation of species performance and placement over the long-term is recommended with additional emphasis on planting long-lived large stature trees.

Condition class is likely to be an overriding indicator of selecting well-adapted and appropriate trees. Appendix D displays condition class and relative performance index (RPI) values for all species currently planted. As previously indicated, RPI values for Bismarck are probably of less value than reviewing individual condition classes since the majority of species are newer introductions that have not had adequate time to "prove" themselves. Bur oak, Black ash, Manchurian ash, Honeylocust, Freeman maple and Norway maple are among the newer species requiring continued observation to determine long-term suitability. Other large-growing species like Hackberry, Silver maple (Acer saccharinum), American and Littleleaf linden appear to be performing adequately as they grow into larger size classes. The predominant species – Green ash and American elm – continue to maintain higher percentages of trees in good and better condition categories. Many American elms have reached maturity, but they have served the city well and to not replant this species (particularly DED resistant varieties) would be short-sighted. However, because the predominance of both American elm and Green ash leaves Bismarck open to potentially catastrophic losses from disease and insect infestation, it is important to limit the numbers of both species to ideal planting levels. Simultaneously, the city should continue to increase age diversity by increasing the numbers of other large-growing species planted.

Resource Extent

Canopy cover, or more precisely, the amount and distribution of leaf surface area, is the driving force behind the urban forest's ability to produce benefits for the community. As canopy cover increases, so do the benefits afforded by leaf area. It is important to remember that street trees throughout the US—and those of Bismarck—likely represent less than 10% of the entire urban forest (Moll and Kollin 1993). In other words, the benefits Bismarck residents realize from all urban vegetation is far greater than the values found through this analysis. But due to their location and conflicts, street trees are typically the most expensive component to manage. The BFD invests 54% of its annual budget on the street tree population. It is unknown what amount residents expend on tree maintenance, but maximizing the return on the total investment is contingent upon maximizing and maintaining the canopy cover of these trees.

Increasing the street tree canopy cover requires a multifaceted approach in Bismarck. Plantable spaces must be filled and use of large stature trees must be encouraged wherever feasible. In 2002 there were 24,150 available street tree planting spaces in the city. To encourage increasing the flow of tree-provided benefits over time, sites for large street trees should be planted first wherever possible, followed by those for medium and then small trees. As large, brittle trees like Siberian elm and Poplar are phased out, they should be replaced with large-stature trees the BFD has experimented with and found suitable. These include varieties of Lindens, Oak, Hackberry, Maple, Pine, and Ash listed on the city's current approved tree list. Available large tree planting sites accounted for 37% of all available sites according to the 2002 inventory. This would accommodate nearly 9,000 trees. There were an additional 7,300 available sites for medium-stature trees like Black ash, Honeylocust, and medium-stature Ash and Linden. Lastly, space for 7,900 small trees was available. Focusing planting efforts in zones where stocking levels are lowest will improve the distribution of benefits provided to all neighborhoods.

Pruning & Maintenance

Unfortunately, budget constraints of municipal tree programs often dictate the length of pruning cycles and maintenance regimes rather than the needs of the urban forest and its constituent components. Programmed pruning, under a reasonable timeline, can improve public safety by eliminating conflicts and increase benefits by improving tree health and condition. Any dollar savings realized by the city deferring street tree planting and maintenance to residents is done at a loss in tree value and the cumulative value of the street tree population (Miller and Sylvester 1981).

In their study of Milwaukee, WI, Miller and Sylvester (1981) found that extending pruning cycles beyond 4 or 5 years resulted in a loss of tree value that exceeded any savings accrued by deferring maintenance. In order to maintain consistency and maximize urban forest benefits while reducing city liabilities and public safety conflicts, the city of Modesto, CA had also found 4 years to be the ideal pruning cycle for their municipal forest (Gilstrap 1983). Furthermore, Anderson and Eaton (1986) suggested that an adequate and systematic pruning and inspection program was the first step to avoiding liability stemming from trees.

About 57% (10,202) of all Bismarck street trees needed general pruning. Analysis of the 2002 inventory suggests that certain tree species may contribute a disproportionately large percentage of trees that require pruning. American elm, Green ash, American elm, Common chokecherry and Littleleaf linden represent 8,396 (92%) of all trees requiring a routine pruning. American elms are older and require regular maintenance to prolong their lives and maintain the flow of benefits they currently provide to the community. The other three species represent relatively new introductions that require training to improve form and structure. Increasing the frequency of inspection and training for young trees thereby reducing future pruning needs when they are mature and more expensive to maintain.

Chapter Six—Conclusion

City of Bismarck, North Dakota
Street Tree Resource Analysis

Paula J. Peper, E. Gregory McPherson, James R. Simpson, Scott E. Maco, Qingfu Xiao

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Bismarck's trees are a valuable asset, providing approximately $979,900 ($54.98/tree; $17.42/capita) in annual benefits. These benefits to the community were most pronounced in stormwater runoff reduction ($496,227; $27.85/tree) and increased local property values ($367,536; $20.62/tree). Street trees were also found to provide a particularly important function in maintaining air quality, reducing the amount of particulate matter by filtering the air, and reducing heating consumption by acting as windbreaks. Annual expenditures to manage and maintain this valuable resource totaled $316,640 ($17.77/tree; $5.63/capita). Pruning ($94,850; $5.32/tree), tree and stump removal ($50,061; $2.81/tree) and pest management ($17,429; $0.98/tree) were the largest costs other than administration ($71,678; $4.02/tree). The resultant benefit-cost ratio (BCR) was $3.09. Thus, the street trees returned $3.09 in benefits to the community for every dollar ($1.00) spent.

Bismarck's street trees are a dynamic resource. Managers of this resource and the community alike can delight in knowing that street trees do improve the quality of life in Bismarck, but they are also faced with a fragile resource that needs constant care to maximize and sustain these benefits through the foreseeable future. The challenge will be to maximize net benefits from available growth space over the long-term, providing an urban forest resource that is both functional and sustainable. American elms and Green ash are currently the most important species within the community, responsible for producing 71.7% of all benefits produced by street trees ($702,029 annually). The Bismarck Forestry Department's systematic effort to provide adequate care, pest management and maintenance for these species while expanding upon species diversity is right on target, as is its use of the street tree inventory as a resource assessment and management tool. The continuation of this work will be vital to maintaining the flow of benefits into the future. Similarly, the BFD's effort to increase pruning frequency for young trees demonstrates the understanding that early training will reduce future costs associated with pruning mature trees.

This analysis has provided the information necessary for resource managers to weigh the citywide needs with the more specific needs of individual tree management zones. Utilizing the structural indices outlined above— species composition, relative performance values, importance values, condition values, age distribution tables, maintenance requirements, etc.—along with benefit data, provide the requisite understanding for short- and long-term resource management.

Recommendations to management include the following:

- Use the street tree inventory as a tool for assessing long-term adaptability of new species, particularly large-stature species, through regular re-evaluations of tree condition and relative performance. This will assist in determining which species to include in a long-term planting program.
- Develop a long-term plan to achieve resource sustainability. This requires increasing diversity of the street tree population by balancing new plantings of proven, long-lived species with successful, newer introductions. This plan should address:
    - tree removal and replacement for senescent populations.
    - Planting available large sites first, followed by those allowing medium and small trees.
    - maximizing available growth space (24,000 sites) to provide for the largest amount of leaf area and canopy coverage as the trees mature.

- focusing planting efforts along streets and in zones where stocking levels are lowest to improve the distribution of benefits provided to all neighborhoods.

- Pruning needs for street trees were substantial. Within current budget constraints, the BFD re-allocated resources to reduce the 7-year rotational pruning cycle to a 5-year cycle for training smaller trees and a 6-year cycle for the contract pruning of larger trees. Tree health (the key to tree functionality and longevity) would improve by further reducing the inspection and pruning cycle to 2-3 years for smaller trees (<10” DBH) and 5 years for the larger trees.

City of Bismarck, North Dakota
Street Tree Resource Analysis

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Appendix A:

Methodology And Procedures

This analysis combines results of a citywide inventory with benefit-cost modeling data to produce four types of information:

1. Resource structure (species composition, diversity, age distribution, condition, etc.)
2. Resource function (magnitude of environmental and aesthetic benefits)
3. Resource value (dollar value of benefits realized)
4. Resource management needs (sustainability, pruning, planting, and conflict mitigation)

This section describes the inputs and calculations used to derive the aforementioned outputs: growth modeling, identifying and calculating benefits, estimating magnitude of benefits provided, assessing resource unit values, calculating net benefits and benefit-cost ratio, and assessing structure.

Growth Modeling

Bismarck's tree database contained information on 17,821 street trees, including species and size by DBH. There were a total of 93 broadleaf and conifer species.

A combination of regional tree growth models for the Northern Mountain and Prairie climate zone (based on tree data collected in Fort Collins, CO; McPherson et al. 2004) and local models developed from Bismarck data were used as the basis for modeling Bismarck tree growth. Applying Fort Collins's models to cities within the same climate region assumes that Fort Collins's trees grow at the same rate and to the same dimensions throughout the region. Using the Bismarck Forestry Department's current street tree inventory, a stratified random sample of six street tree species were measured to establish relations between tree age, size, leaf area and biomass for comparison with the regional growth curves. This comparison formed the basis for adjusting the regional curves to model Bismarck tree growth and estimate the magnitude of annual benefits derived from the Bismarck street and park tree resources. The six Bismarck species measured were Silver maple (Acer saccharinum), Green ash (Fraxinus pennsylvanica), Honeylocust (Gleditsia triacanthos), Littleleaf linden (Tilia cordata), Blue spruce (Picea pungens), and Siberian elm (Ulmus pumila). These represented long-established tree species. Because the Blue spruce models could be used to model growth of other conifers in the city, only the five broadleaf deciduous tree species were used to compare and adjust the Fort Collins' broadleaf deciduous tree models for use in Bismarck.

For both the regional and local growth models information spanning the life cycle of predominant tree species was collected. City inventories were stratified into 9 diameter-at-breast height (DBH) classes: 0-7.62 in (0-7.62 cm), 3-6 in (7.62-15.24 cm), 6-12 in (15.24-30.48 cm), 12-18 in (30.48-45.72 cm), 18-24 in (45.72-60.96 cm), 24-30 in (60.96-76.2 cm), 30-36 in (76.2-91.44), 36-42 in (91.44-106.68 cm), and >42 in (106.68 cm). Thirty-five to 70 randomly selected trees of each species were selected to survey, along with an equal number of alternative trees. Tree measurements 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 nearest 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. Tree age was determined from interviews with residents, the Director and Assistant Director of the Forestry Department, and historical planting records. Fieldwork was conducted in August and September 2002.

Crown volume and leaf area 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).

Linear regression was used to fit predictive models—DBH as a function of age—for each of the 22 sampled species in Fort Collins. 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). The same methods were applied to develop the models for the six species that Bismarck and Fort Collins shared in common. Midpoint DBH size class predictions for each growth parameter were calculated for each city's trees. The proportional difference in tree size by DBH class was calculated and averaged across the species to develop factors to adjust the Fort Collins' tree models to represent Bismarck tree size. Table A-1 shows that across species and age classes, Bismarck's deciduous broadleaf trees are about 20% shorter than Fort Collins' trees, not surprising, considering the region's shorter growing season and the effect of freezing, high winds in winter. Crown height is about 71% of Fort Collins' trees' crown heights. However, all other dimensions and leaf area

Table A-1. Bismarck tree dimensions as a proportion of Fort Collins' tree dimensions for each DBH class midpoint. For example, 15" DBH trees in Bismarck averaged 77.8% of the height of a Fort Collins' tree but had nearly the same crown diameter (97.8%).

DBH Class	Midpoint DBH (in)	% of Height	% of Crown Height	% of Crown Diameter	% of Crown Projection	% of Leaf Area
1	1.5	93.9	100.2	93.5	97.7	167.5
2	4.5	83.4	78.0	91.2	86.2	90.8
3	9.0	79.7	70.8	94.3	90.0	77.2
4	15.0	77.8	67.3	97.8	96.2	73.8
5	21.0	76.8	65.5	100.5	101.4	76.8
6	27.0	77.0	65.2	103.7	107.9	86.9
7	33.0	77.5	65.4	106.1	113.2	99.9
8	39.0	77.2	65.0	106.5	114.7	107.4
9	45.0	76.7	64.5	106.1	114.4	114.1
mean	21.7	80.0	71.3	99.9	102.4	99.4
std error	5.1	1.9	3.9	2.0	3.6	9.7

are nearly equal or, like crown projection, slightly larger than Fort Collins' tree dimensions and leaf area.

Identifying & Calculating Benefits

Annual benefits for Bismarck's street trees were estimated for the year 2002. 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 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) through direct estimation and implied valuation as environmental externalities. Implied valuation is used to price society's willingness to pay for the environmental benefits trees provide. Estimates of benefits are initial approximations—as some benefits are difficult to quantify (e.g., impacts on psychological health, crime, and violence). In addition, limited knowledge about the physical processes at work and their interactions makes estimates imprecise (e.g., fate of air pollutants trapped by trees and then washed to the ground by rainfall). Therefore, this method of quantification was not intended to account for each penny. Rather, this approach was meant to be a general accounting of the benefits produced by urban trees; an accounting with an accepted degree of uncertainty that can, nonetheless, provide a platform on which decisions can be made (Maco 2003).

Energy Savings

Buildings and paving, along with low canopy and soil cover, increase the ambient temperatures within a city. Research shows that even in temperate climate zones—such as those of the Pacific Northwest—temperatures in urban centers are steadily increasing by approximately 0.5°F (0.3°C) per decade. Winter benefits of this warming do not compensate for the detrimental effects of magnifying summertime temperatures. Because electric demand of cities increases about 1-2% per 1°F (3-4% per °C) increase in temperature, approximately 3-8% of current electric demand for cooling is used to compensate for this urban heat island effect of the last four decades (Akbari et al. 1992).

Warmer temperatures in cities, compared to surrounding rural areas, have other implications. Increases in CO_2 emissions from fossil fuel power plants, municipal water demand, unhealthy ozone levels, and human discomfort and disease are all symptoms associated with urban heat islands. In Bismarck, there are many opportunities to ameliorate the problems associated with hardscape through strategic tree planting and stewardship of existing trees allowing for streetscapes that reduce storm-water runoff, conserve energy and water, sequester CO_2, attract wildlife, and provide other aesthetic, social, and economic benefits through urban renewal developments and new development.

For individual buildings, street trees can increase energy efficiency in the summer and increase or decrease energy efficiency in winter, depending on placement. Solar angles are important when the summer sun is low in the east and west for several hours each day. Tree shade to protect east—and especially west—walls help keep buildings cool. In the winter, solar access on the southern side of buildings can warm interior spaces.

Trees reduce air infiltration and conductive heat loss from buildings. Rates at which outside air infiltrate into a building can increase substantially with wind speed. In cold, windy weather, the entire volume of air in a poorly sealed home may change two to three times per hour. Even in newer or tightly sealed homes, the entire volume of air may change every two to three hours. Trees can reduce wind speed and resulting air infiltration by up to 50%, translating into potential annual heating savings of 25% (Heisler 1986). Reductions in wind speed reduce heat transfer through conductive materials as well. Cool winter winds, blowing against single-pane windows, can contribute significantly to the heating load of homes and buildings by increasing the temperature gradient between inside and outside temperatures.

Electricity and Natural Gas Methodology

Calculating annual building energy use per residential unit (Unit Energy Consumption [UEC]) is 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 per 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.) are differentiated by a building's vintage, or age of construction: pre-1950, 1950-1980 and post-1980. Typical meteorological year (TMY2) weather data for Bismarck Airport were used (Marion and Urban 1995). Shading effects for each tree species measured were simulated at three tree-building distances, eight orientations and nine tree sizes.

Shading coefficients for tree crowns in leaf were based on a photographic method that 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) and adjusted for Bismarck's climate based on consultation with the assistant city forester (Heintz 2003).

Tree distribution by location (e.g. frequency of occurrence at each location determined from distance between trees and buildings (setbacks), and tree orientation with respect to buildings) specific to Bismarck was used to calculate average energy savings per tree as a function of distance and direction. 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 per tree 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. Tree location measurements were based on samples of 215 right-of-way trees taken in the summer of 2002.

Land use (single family residential, multifamily residential, commercial/industrial, other) for right-of-way trees was based on the same tree sample. 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 Bismarck (West North Central census region) (Ritschard et al. 1992). Building footprints were modeled as 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. Unit energy consumptions were adjusted to account for saturation of central air conditioners, room air conditioners, and evaporative coolers (Table A-2).

Single-Family Residential Adjustments

Unit energy consumptions 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

Table A-2. Saturation adjustments for cooling.

	Single family detached			Mobile Homes			Single family attached			MF 2-4 units			MF 5+ units			Commercial/ Industrial		Institutional/ Transportation
	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	Small	Large	
Cooling equipment factors																		
Central air/heat pump	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Evaporative cooler	33%	33%	33%	33%	33%	33%	33%	33%	33%	33%	33%	33%	33%	33%	33%	33%	33%	33%
Wall/window unit	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%	25%
None	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Cooling saturations																		
Central air/heat pump	47%	55%	78%	47%	55%	78%	47%	55%	78%	47%	55%	78%	47%	55%	78%	63%	63%	63%
Evaporative cooler	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	2%	2%
Wall/window unit	23%	25%	11%	23%	25%	11%	23%	25%	11%	23%	25%	11%	23%	25%	11%	13%	13%	13%
None	60%	39%	22%	60%	39%	22%	60%	39%	22%	60%	39%	22%	60%	39%	22%	22%	22%	22%
Adjusted cooling saturation	53%	62%	81%	53%	62%	81%	53%	62%	81%	53%	62%	81%	53%	62%	81%	67%	67%	67%

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 $F_{sh} = F_{equipment} \times APSF \times F_{adjacent\ shade} \times F_{multiple\ tree}$ Equation 1

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

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

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

Total change = $N \times \Delta UEC_x$. Equation 2

Subscript x refers to residential structures with 1, 2-4 or 5 or more units, *SFD* to single family detached structures which were simulated, *sh* to shade, and *cl* to climate effects.

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 was 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 per tree, 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 three existing trees per residence.

In addition to localized shade effects, which were assumed to accrue only to street trees within 18-60 ft (5-18 m) 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 and winter heating. Reduced wind speeds by themselves may increase or decrease cooling demand, depending on the circumstances. 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 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. A lot size of 10,000 ft^2 (929 m^2) was assumed.

Dollar value of electrical and natural gas (Montana Dakota Utility 2003) energy savings were based on electricity and natural gas prices of $0.0656 per kWh and $0.667 per therm, respectively. Cooling and heating effects were reduced based on the type and saturation of air conditioning (Table A-2) or heating (Table A-3) equipment by vintage. Equipment factors of 33% and 25% were assigned to homes with evaporative coolers and room air conditioners, respectively. These factors were combined with equipment saturations to account for reduced energy use and savings compared to those simulated for homes with central air conditioning ($F_{equipment}$). Building vintage distribution was combined with adjusted saturations to compute combined vintage/saturation factors for air conditioning (Table A-2). Heating loads were converted to fuel use based on efficiencies in Table A-3. The "other" and "fuel oil" heating equipment types were assumed 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 A-4).

Table A-3. Saturation adjustments for heating.

Electric heating																		
	Single family detached			Mobile Homes			Single family attached			MF 2-4 units			MF 5+ units			Commercial/ Industrial		Institutional/ Transportation
Equipment efficiencies	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	Small	Large	
AFUE	0.75	0.78	0.78	0.75	0.78	0.78	0.75	0.78	0.78	0.75	0.78	0.78	0.75	0.78	0.78	0.78	0.78	0.78
HSPF	6.8	6.8	8	6.8	6.8	8	6.8	6.8	8	6.8	6.8	8	6.8	6.8	8	8	8	8
HSPF	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412	3.412
Electric heat saturations																		
Electric resistance	3.0%	6.0%	19.0%	3.0%	6.0%	19.0%	3.0%	6.0%	19.0%	3.0%	6.0%	19.0%	3.0%	6.0%	19.0%	19.0%	19.0%	19.0%
Heat pump	0.5%	1.0%	3.2%	0.5%	1.0%	3.2%	0.5%	1.0%	3.2%	0.5%	1.0%	3.2%	0.5%	1.0%	3.2%	3.2%	3.2%	3.2%
Adjusted saturations	0.7%	1.5%	4.7%	0.7%	1.5%	4.7%	0.7%	1.5%	4.7%	0.7%	1.5%	4.7%	0.7%	1.5%	4.7%	4.7%	4.7%	4.7%
Natural Gas and other heating																		
Natural gas	47%	50%	44%	47%	50%	44%	47%	50%	44%	47%	50%	44%	47%	50%	44%	44%	44%	44%
Oil	20%	25%	11%	20%	25%	11%	20%	25%	11%	20%	25%	11%	20%	25%	11%	11%	11%	11%
Other	30%	18%	22%	30%	18%	22%	30%	18%	22%	30%	18%	22%	30%	18%	22%	22%	22%	22%
NG saturations	97%	93%	78%	97%	93%	78%	97%	93%	78%	97%	93%	78%	97%	93%	78%	78%	78%	78%

Table A-4. Building vintage distribution and combined vintage/saturation factors for heating and air conditioning.

	Siingle family detached			Mobile Homes			Single family attached			MF 2-4 units			MF 5+ units			Commercial/Industrial		Institutional/
	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	pre-1950	1950-1980	post-1980	Small	Large	Transportation
Vintage distribution by building type	36.0%	33%	31%	36%	33%	31%	36%	33%	31%	36%	33%	31%	36%	33%	31%	100%	100%	100%
Tree distribution by vintage and building type	22.8%	21.3%	19.7%	1.5%	01.4%	1.3%	2.2%	2.1%	1.9%	0.4%	0.4%	0.4%	1.4%	1.3%	1.2%	8.3%	8.0%	4.4%
Combined vintage, equipment saturation factors for cooling																		
Cooling factor: shade	11.72%	12.83%	15.54%	2.09%	0.83%	1.00%	1.00%	1.09%	1.32%	0.16%	0.17%	0.21%	0.29%	0.32%	0.39%	1.94%	0.93%	0.51%
Cooling factor: climate	11.99%	13.13%	15.9%	2.14%	0.85%	1.03%	1.16%	1.27%	1.54%	0.18%	0.19%	0.23%	0.59%	0.64%	0.78%	2.22%	1.6%	0.58%
Combined vintage, equipment saturation factors for heating																		
Heating factor, nat. gas: shade	21.57%	19.34%	15.00%	1.39%	12.25%	0.97%	1.84%	1.65%	1.28%	0.29%	0.26%	0.20%	0.54%	0.49%	0.38%	2.26%	1.09%	0.59%
Heating factor, electric: shade	0.15%	0.32%	0.90%	0.02%	0.06%	0.01%	0.01%	0.03%	0.08%	0.00%	0.00%	0.01%	0.00%	0.01%	0.02%	0.14%	0.07%	0.04%
Heating factor, nat. gas: climate	22.07%	19.79%	15.35%	3.95%	1.28%	0.99%	2.14%	1.91%	1.49%	0.32%	0.29%	0.23%	1.08%	0.97%	0.75%	2.60%	1.87%	0.68%
Heating factor, electric: climate	0.16%	0.32%	0.92%	0.03%	0.02%	0.06%	0.02%	0.03%	0.09%	0.00%	0.00%	0.01%	0.01%	0.02%	0.05%	0.16%	0.11%	0.04%

Multi-Family Residential Analysis

Unit energy consumptions (UECs) from shade for multi-family residences (MFRs) were calculated from single-family residential UECs adjusted by adjusted potential shade factors (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). A PSF=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).

Commercial and Other Buildings

Unit energy consumptions for commercial/industrial (C/I) and industrial/transportation (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 window area. Average potential shade factors for I/T structures were estimated to lie between these extremes; a value of 0.15 was used here. However, data relating I/T land use to building space conditioning were not readily available, so no energy impacts were ascribed to I/T structures. 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 (1992) who observed that commercial buildings are less sensitive to outdoor temperatures than houses.

Change in UECs due to shade tend to increase with conditioned floor area (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 [65-325 m^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 tend to diminish 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 for each species using tree growth equations for DBH and height described earlier in this appendix (see Tree Growth Modeling) to calculate either tree volume or biomass. Equations from Pillsbury et. al (1998) are used when calculating volume. Fresh weight (kg/m^3) and specific gravity ratios from Alden (1995, 1997) are then applied to convert volume to biomass. When volumetric equations for urban trees are unavailable, biomass equations derived from data collected in rural forests are applied (Tritton and Hornbeck 1982; Ter-Mikaelian and Korzukhin 1997).

Carbon dioxide released through decomposition of dead woody biomass varies with characteristics of the wood itself, fate of the wood (e.g., amount left standing, chipped, or 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. Calculations were 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 for Bismarck was 3.0% for the first five years after out-planting and 0.8% every year thereafter, based on mortality rates, provided by the

City Forester, unique to streets and parks (Blumhardt 2002). Finally, CO_2 released from tree maintenance was estimated to be 0.16 kg CO_2/cm DBH based on tree maintenance activities which release 6.3 kg CO_2/tree based on carbon dioxide equivalent annual release of 37,320 liters (9,859 gal) of gasoline and diesel fuel use (Blumhardt 2002).

Avoided CO_2 Emissions Methodology

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 fuel oil in Bismarck. The overall fuel mix for electrical generation provided from Montana Dakota Utilities (50%) and Basin Electric Power Coop (50%) was primarily coal (92%) and natural gas (8%) (U.S. EPA 2003). CO_2 emissions factors for electricity lb/MWh) and natural gas (lb/MBtu) weighted by the appropriate fuel mixes are given in Table A-5. Implied value of avoided CO_2 was \$0.008/lb based on average high and low estimates for emerging carbon trading markets (CO_2e.com 2002) (Table A-5).

Table A-5. Emissions factors and implied values for CO_2 and criteria air pollutants. See text for sources of data.

	Emission Factor		Implied
	Electricity	Natural gas	value
	(lb/MWh)	(lb/MBtu)	(\$/lb)
CO2	2,660	118	0.008
NO2	4.24	0.0922	0.66
SO2	7.34	0.0006	0.67
PM10	0.943	0.0075	0.16
VOC's	0.919	0.0054	0.64
Ozone			0.66

Improving Air Quality

Avoided Emissions Methodology

Reductions in building energy use also result in reduced emissions of criteria air pollutants from power plants and space heating equipment. This analysis considered volatile organic hydrocarbons (VOCs) and nitrogen dioxide (NO_2)—both precursors of ozone (O_3) formation—as well as sulfur dioxide (SO_2) and particulate matter of <10 micron diameter (PM_{10}). Changes in average annual emissions and their offset values (Table A-5) were calculated in the same way as for CO_2, again using utility specific emission factors for electricity and heating fuels. Values for criteria air pollutants were based on control-cost-based emissions for VOCs and damage-based emissions estimates for remaining pollutants using the methods of Wang and Santini (1995). Emissions concentrations are from U.S. EPA (2003) and population estimates from the U.S. Census Bureau (2003)

Deposition and Interception Methodology

Trees also remove pollutants from the atmosphere. The hourly pollutant dry deposition per tree is expressed as the product of a deposition velocity $V_d = 1/(R_a+R_b+R_c)$, a pollutant concentration (C), a canopy projection (CP) area, and a time step. Hourly deposition velocities for each pollutant were calculated using estimates for the resistances Ra, Rb, and Rc estimated for each hour for a year using formulations described by Scott et al. (1998). Hourly data from 1998 were selected as representative for modeling deposition based on a review of mean PM_{10} and ozone concentrations for years 1991-2002. Data for stations closest in proximity and climate to Bismarck were used – PM_{10} from Bismarck, ozone and NO_2 from Hannover, and SO_2 from Mandan (Harman 2003).

Deposition was determined for deciduous species only when trees were in-leaf. A 50% re-suspension rate was applied to PM_{10} deposition. A combination of damage-based (SO_2, PM_{10}) and control-cost based (NO_2, VOCs,) estimates for Bismarck (population 56,234) were used to value emissions reductions (Wang and Santini 1995); NO_2 prices were used for ozone since ozone control measures typically aim at reducing NO_x. Hourly meteorological data for Bismarck (air temperature, wind speed, solar radiation and precipitation) were used (NDAWN 2003).

BVOC Emissions Methodology

Emission of biogenic volatile organic carbon (sometimes called biogenic hydrocarbons or BVOCs) associated with increased ozone formation, were estimated for the tree canopy using methods described by McPherson et al. (1998). In this approach, the hourly emissions of carbon as isoprene and monoterpene are expressed as products of base emission factors and leaf biomass factors adjusted for sunlight and temperature (isoprene) or temperature (monoterpene). Hourly emissions were summed to get annual totals. 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. The cost of these emissions is based on control cost estimates and was valued at $0.64/lb for Bismarck (Wang and Santini 1995).

Reducing Stormwater Runoff and Hydrology

Stormwater Methodology

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, it drips from the leaf surface and flows down the stem surface to the ground or evaporates. Tree canopy parameters include species, leaf and stem surface area, shade coefficient (visual density of the crown), tree height, and foliation data. Tree height data were used to estimate wind speed at different heights above the ground and resulting rates of evaporation.

The volume of water stored in the tree crown was calculated from crown projection area (area under tree dripline), leaf area indices (LAI, the ratio of leaf surface area to crown projection area), and water depth on the canopy surface, while species-specific shade coefficients and tree surface saturation values influence the amount of projected throughfall. Hourly meteorological data for 1999 from Bismarck Municipal Airport (BIS) (latitude: 41°10' N; longitude: 104°49' W) were selected to best represent a typical meteorological year and, consequently, used for this simulation. Annual precipitation during 1999 was 16.1 inches (409.2 mm). A more complete description of the interception model can be found in Xiao et al. (1998).

To estimate the value of rainfall intercepted by urban trees, stormwater management control costs were used. The cost is estimated based on Bismarck's annual budget of $1.5 million required to adequately maintain the city's stormwater infrastructure. Precipitation causes 4,446,904 cubic meters of runoff annually (USDA Soil Conservation Service, 1986). Total runoff is based on the distribution of land use and the soils water holding capacity. Total costs are divided by total runoff resulting in an average annual savings of $\$0.34/m^3$ ($0.001).

Aesthetics & Other Benefits

Trees provide a host of aesthetic, social, economic, and health benefits that should be included in any benefit-cost analysis. One of the most frequently cited reasons that people plant trees is for beautification. Trees add color, texture, line, and form to the landscape. In this way, trees soften the hard geometry that dominates built environments. Research on the aesthetic quality of residential streets has shown that street trees are the single strongest positive influence on scenic quality (Schroeder and Cannon 1983). Consumer surveys have found that preference ratings increase with the presence of trees in the commercial streetscape. In contrast to areas without trees, shoppers indicated that they shop more often and longer in well-landscaped business districts, and were willing to pay more for goods and services (Wolf 1999).

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

Well-maintained trees increase the "curb appeal" of properties. Research comparing sales prices of residential properties with different tree resources suggests that people are willing to pay 3-7% 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 property values was based on actual sales prices and found that each large front-yard tree was associated with about a 1% increase in sales price (Anderson and Cordell 1988). 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). Depending on average home sales prices, the value of this benefit can contribute significantly to cities' property tax revenues.

Scientific studies confirm our intuition that trees in cities provide social and psychological benefits. Humans derive substantial pleasure from trees, whether it is inspiration from their beauty, a spiritual connection, or a sense of meaning (Dwyer et al. 1992; Lewis 1996). Following natural disasters, people often report a sense of loss if the urban forest in their community has been damaged (Hull 1992). Views of trees and nature from homes and offices provide restorative experiences that ease mental fatigue and help people to concentrate (Kaplan & Kaplan 1989). Desk-workers with a view of nature report lower rates of sickness and greater satisfaction with their jobs compared to those having no visual connection to nature (Kaplan 1992). Trees provide important settings for recreation and relaxation in and near cities. The act of planting trees can have social value, for community bonds between people and local groups often result.

The presence of trees in cities provides public health benefits and improves the well being of those who live, work and recreate in cities. Physical and emotional stress has both short term and long-term effects. Prolonged stress can compromise the human immune system. A series of studies on human stress caused by general urban conditions and city driving show that views of nature reduce the stress response of both body and mind (Parsons et al. 1998). City nature also appears to have an "immunization effect," in that people show less stress response if they've had a recent view of trees and vegetation. Hospitalized patients with views of nature and time spent outdoors need less medication, sleep better, and have a better outlook than patients without connections to nature (Ulrich 1985). Trees reduce exposure to ultraviolet light, thereby lowering the risk of harmful effects from skin cancer and cataracts (Tretheway and Manthe 1999).

Certain environmental benefits from trees are more difficult to quantify than those previously described, but can be just as important. Noise can reach unhealthy levels in cities. Trucks, trains, and planes can produce noise that exceeds 100 decibels, twice the level at which noise becomes a health risk. Thick strips of vegetation in conjunction with landforms or solid barriers can reduce highway noise by 6-15 decibels. Plants absorb more high frequency noise than low frequency, which is advantageous to humans since higher frequencies are most distressing to people (Miller 1997).

Although urban forests contain less biological diversity than rural woodlands, numerous types of wildlife inhabit cities and are generally highly valued by residents. For example, older parks, cemeteries, and botanical gardens often contain a rich assemblage of wildlife. Street tree corridors can connect a city to surrounding wetlands, parks, and other greenspace resources that provide habitats that conserve biodiversity (Platt et al. 1994).

Urban and community forestry can provide jobs for both skilled and unskilled labor. Public service programs and grassroots-led urban and community forestry programs provide horticultural training to volunteers across the U.S. Also, urban and community forestry provides educational opportunities for residents who want to learn about nature through first-hand experience (McPherson and Mathis 1999). Local nonprofit tree groups, along with municipal volunteer programs, often provide educational material, work with area schools, and hands-on training in the care of trees.

Property Value and Other Benefits Methodology

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 Bismarck include the difficulty associated with 1) determining the value of individual street trees adjacent to private properties and 2) the need to extrapolate results from front yard trees on residential properties to street and park 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 leaf surface area (LSA) of a typical mature large tree (30-year old Silver maple [Acer saccharum]) in Bismarck (6,062 ft^2) and using the average annual change in LSA per unit area for trees within each DBH class as a resource unit, this increase was the basis for valuing the capacity of trees to increase property value.

Assuming the 0.88% increase in property value held true for the City of Bismarck, each large tree would be worth $894 based on the median 2003 standard two-story home sales price in Bismarck ($101,640) (CNN Money 2003). However, not all trees are as effective as front yard residential trees in increasing property values. For example, 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, citywide street tree reduction factor of 0.71 was applied to prorate trees' 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%, 66%, and 50%, respectively, of the full $894 (McPherson et al. 2001). For this analysis, the reduction factor reflects Bismarck land-use distributions and assumes an even tree distribution.

Given these assumptions, a typical large tree was estimated to increase property values by \$0.30/ft^2 of LSA. For example, it was estimated that a single Silver maple tree adds about 137.8 ft^2 (12.8 m^2) of LSA per year when growing in the DBH range of 12-18 in (30.5-46.7 cm). Therefore, during this 12–18 inch period of growth silver maple trees effectively added \$29.35, annually, to the value of an adjacent home, condominium, or business property (137.8 ft^{2}x \$0.30/ft^2 x 0.71% = \$29.35).

Estimating Magnitude Of Benefits

Defined as resource units, the absolute value of the benefits of Bismarck's street and park trees—electricity (kWh/tree) and natural gas savings (kBtu/tree), atmospheric CO_2 reductions (lbs/tree), air quality improvement (NO_2, PM_{10} and VOCs [lbs/tree]), stormwater runoff reductions (precipitation interception [ft^3/tree]) and property value increases (D LSA [ft^2/tree])—were assigned prices through methods described above for model trees.

Estimating the magnitude of benefits (resource units) produced by all street trees in Bismarck required four procedures: 1) categorizing street trees by species and DBH based on the city's street tree inventory, 2) matching significant species with the growth models (those from the 6 modeled species in Bismarck and the additional 16 modeled species in Fort Collins, CO that were adjusted to account for size differences between the two cities), 3) grouping remaining "other" trees by type, and 4) applying resource units to each tree.

Categorizing Trees by DBH Class

The first step in accomplishing this task involved categorizing the total number of street trees by relative age (DBH class). The inventory was used to group trees using the following classes:

1. 0-3 in (0-7.5 cm)
2. 3-6 in (7.6-15.1 cm)
3. 6-12 in (15.2-30.4 cm)
4. 12-18 in (30.5-45.6 cm)
5. 18-24 in (45.7-60.9 cm)
6. 24-30 in (61-76.2 cm)
7. 30-36 in (76.3-91.4cm)
8. 36-42 in (91.4-106.7 cm)
9. >42 in (106.7 cm)

Because DBH classes represented a range, the median value for each DBH class was determined and subsequently 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 22 modeled species for the 9 midpoints (X-value) corresponding to each of the DBH classes assigned to the city's street trees.

Applying Benefit Resource Units to Each Tree

Once categorized, the interpolated resource unit values were matched on a one-for-one basis. For example, out of the 3,506 inventoried American elms (Ulmus americana) citywide, 39 were within the 6-12 in (15.2-30.4 cm) DBH class size. The interpolated electricity and natural gas resource unit values for the class size midpoint (9 in [23 cm]) were 31.5 kWh/tree and 359.5 kBtu/tree, respectively. Therefore, multiplying the size class resource units by 18 equals the magnitude of annual heating and cooling benefits produced by this segment of the population: 1,228.5 kWh in electricity saved and 14,020.5 kBtu natural gas saved.

Matching Species with Modeled Species

To infer from the 22 municipal species modeled and adjusted for growth in Bismarck to the inventoried street tree population, each species representing over 0.5% of the population was matched directly with corresponding model species. Where there was no corresponding tree, the best match was determined by identifying which of the 22 species was most similar in leaf shape/type, structure and habit.

Calculating Net Benefits And Benefit-Cost Ratio

It is impossible to quantify all the benefits and costs produced by trees. 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 (e.g., 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 city's street tree resource. To some extent connecting people with their city trees reduces costs for health care, welfare, crime prevention, and other social service programs.

Bismarck residents can obtain additional economic benefits from street trees depending on tree location and condition. For example, street trees can provide energy savings by lowering wind velocities and subsequent building infiltration, thereby reducing heating costs. This benefit can extend to the neighborhood, as the aggregate effect of many street trees reduces wind speed and reduces citywide winter energy use. Neighborhood property values can be influenced by the extent of tree canopy cover on streets. The community benefits from cleaner air and water. Reductions in atmospheric CO_2 concentrations due to trees can have global benefits.

Net Benefits and Costs Methodology

To assess the total value of annual benefits (B) for each park and street tree (i) in each management area (j) benefits were summed:

$$B = \sum_{1}^{n} j\left(\sum_{1}^{n} i\left(e_{ij} + a_{ij} + c_{ij} + h_{ij} + p_{ij}\right)\right)$$

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

(Equation 3)

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

$$C = p + t + r + d + e + s + c + l + a + q$$

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

(Equation 4)

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

$$\text{Citywide Net Benefits} = B\text{-}C \qquad \text{(Equation 1)}$$

$$\text{BCR} = B/C \qquad \text{(Equation 6)}$$

Assessing Structure

Street tree inventory information, including species composition, DBH, health, total number of trees, were collected and analyzed using the City of Cheyenne’s 1992 Municipal Tree Inventory.

Appendix B:

Population Summary

Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
Large Deciduous										
Green ash	813	962	2,192	1,386	260	24	7	0	0	5,644
American elm	0	4	39	689	1,621	929	197	23	4	3,506
American linden	439	330	475	78	19	1	0	0	0	1,342
Black ash	421	127	83	5	0	0	0	0	1	637
Littleleaf linden	183	96	209	51	0	0	0	0	0	539
Hackberry	98	136	195	41	6	0	0	0	0	476
Manchurian ash	251	40	27	6	0	0	0	0	0	324
Siberian elm	3	7	15	36	69	53	26	6	4	219
Bur oak	171	32	4	5	0	0	0	0	0	212
White/silver poplar	0	0	5	17	38	52	44	28	24	208
Norway maple	143	37	24	1	0	0	0	0	0	205
Boxelder maple	2	0	7	64	81	36	5	2	1	198
Silver maple	30	30	32	38	18	14	1	3	1	167
Honeylocust	30	28	72	12	0	0	0	0	0	142
Linden	56	52	5	0	0	0	0	0	0	113
Freeman maple	95	13	1	0	0	0	0	0	0	109
Sugar maple	59	28	14	0	0	0	0	0	0	101
Black ash x Manchurian ash	87	2	0	0	0	0	0	0	0	89
Eastern cottonwood	6	3	4	1	14	15	7	5	7	62
Red maple	58	2	1	0	0	0	0	0	0	61
Lombardy poplar	0	1	1	12	7	9	9	8	10	57
White ash	33	6	9	0	1	0	0	0	0	49
Black walnut	19	19	6	2	0	0	0	0	0	46
Ash	10	10	1	0	0	0	0	0	0	21
Maple	12	5	2	0	0	0	0	0	0	19
Willow	12	6	0	0	0	0	0	0	0	18
Swamp white oak	12	0	0	0	0	0	0	0	0	12
Kentucky coffee tree	4	4	1	1	0	0	0	0	0	10
Cottonwood/poplar	3	0	3	0	0	0	0	0	0	6
White oak	5	0	0	0	0	0	0	0	0	5
American sycamore	0	0	1	0	0	1	0	0	0	2
Japanese poplar	0	0	0	1	0	1	0	0	0	2
Northern catalpa	0	0	0	0	0	1	0	0	0	1
Ginkgo	0	1	0	0	0	0	0	0	0	1
European aspen	0	1	0	0	0	0	0	0	0	1
Oak	1	0	0	0	0	0	0	0	0	1
Siberian x slippery elm	0	0	0	0	1	0	0	0	0	1
Total	3,056	1,982	3,428	2,447	2,135	1,137	296	75	52	14,608
Medium Deciduous										
Showy mountain ash	54	47	9	0	0	0	0	0	0	110
European mountain ash	37	15	15	5	0	0	0	0	0	72
Laurel willow	11	1	8	4	0	0	0	0	0	24
Ohio buckeye	6	9	2	0	0	0	0	0	0	17
Quaking aspen	7	3	1	1	0	0	0	0	0	12
European white birch	2	0	3	1	1	0	0	0	0	7
Chinese pear	6	1	0	0	0	0	0	0	0	7
American mountain ash	0	3	1	0	0	0	0	0	0	4
Sibrica larch	3	0	0	0	0	0	0	0	0	3
Paper birch	0	2	0	0	0	0	0	0	0	2
Pea tree	2	0	0	0	0	0	0	0	0	2
European larch	1	0	0	0	0	0	0	0	0	1
Tamarak	0	0	1	0	0	0	0	0	0	1
Total	130	81	40	11	1	0	0	0	0	263
Small Deciduous										
Common chokecherry	60	282	364	36	2	0	0	0	0	744
Amur maple	152	217	132	5	0	0	0	0	0	506
Crabapple	152	116	101	14	1	0	0	0	0	384
Amur chokecherry	27	42	84	19	0	0	0	0	0	172
Japanese tree lilac	112	23	15	0	0	0	0	0	0	150
Spring snow crapapple	107	17	17	0	0	0	0	0	0	141
Dogwood	104	0	0	0	0	0	0	0	0	104
Smooth sumac	27	0	0	0	0	0	0	0	0	27
Late lilac	21	0	0	0	0	0	0	0	0	21
Crispleaf red spirea	20	0	0	0	0	0	0	0	0	20
Russian olive	3	6	6	1	1	0	0	0	0	17
Canadian plum	15	2	0	0	0	0	0	0	0	17
Hawthorn	9	6	0	0	0	0	0	0	0	15
Mayday tree	0	4	11	0	0	0	0	0	0	15
Wild plum	14	0	0	0	0	0	0	0	0	14
Cherry/ plum	9	4	0	0	0	0	0	0	0	13
Van Houtte Spirea	12	0	0	0	0	0	0	0	0	12
Flowering almond	9	0	0	0	0	0	0	0	0	9

Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
Small Deciduous cont.										
Chinese lilac	8	0	0	0	0	0	0	0	0	8
Apricot	4	2	1	0	0	0	0	0	0	7
Purple leaf sand cherry	5	0	0	0	0	0	0	0	0	5
Tatarian maple	4	0	0	0	0	0	0	0	0	4
Apple	1	0	2	1	0	0	0	0	0	4
Winged euonymus	3	0	0	0	0	0	0	0	0	3
European buckthorn	1	0	2	0	0	0	0	0	0	3
Glossy buckthorn	3	0	0	0	0	0	0	0	0	3
Staghorn sumac	0	2	1	0	0	0	0	0	0	3
Currant	3	0	0	0	0	0	0	0	0	3
Manchurian lilac	3	0	0	0	0	0	0	0	0	3
Serviceberry	1	0	0	0	0	0	0	0	0	1
Dwarf pea tree	1	0	0	0	0	0	0	0	0	1
Morden hawthorn	1	0	0	0	0	0	0	0	0	1
Forsythia	1	0	0	0	0	0	0	0	0	1
Siberian crabapple	0	0	1	0	0	0	0	0	0	1
Nanking cherry	1	0	0	0	0	0	0	0	0	1
Total	909	724	737	76	4	0	0	0	0	2,450
Large Conifer										
Blue spruce	42	29	34	18	2	0	0	0	0	125
Ponderosa pine	35	35	25	6	1	0	0	0	0	102
White spruce	6	6	9	4	3	0	0	0	0	28
Eastern red cedar	14	11	1	1	0	0	0	0	0	27
Total	106	81	69	29	6	0	0	0	0	291
Medium Conifer										
Colorado red cedar	65	6	4	2	0	0	0	0	0	77
Total	72	16	6	3	2	0	0	0	0	99
Small Conifer										
Chinese juniper	64	0	0	0	0	0	0	0	0	64
Mugo pine	28	13	3	0	0	0	0	0	0	44
Common juniper	0	1	0	0	0	0	0	0	0	1
Total	93	14	3	0	0	0	0	0	0	110
Citywide Total	4,366	2,898	4,283	2,566	2,148	1,137	296	75	52	17,821

Appendix C:

Population Summary By Zone

Zone 1

Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
Large Deciduous										
Green ash	146	169	481	102	6	0	0	0	0	904
American linden	90	50	42	4	0	0	0	0	0	186
Black ash	104	16	30	4	0	0	0	0	0	154
Littleleaf linden	55	24	16	7	0	0	0	0	0	102
Hackberry	30	22	22	0	0	0	0	0	0	74
Manchurian ash	36	9	0	0	0	0	0	0	0	45
Bur oak	43	2	0	0	0	0	0	0	0	45
Freeman maple	24	4	0	0	0	0	0	0	0	28
Linden	8	16	2	0	0	0	0	0	0	26
Red maple	20	0	0	0	0	0	0	0	0	20
Silver maple	7	4	4	2	3	0	0	0	0	20
Sugar maple	15	3	0	0	0	0	0	0	0	18
Black ash x Manchurian ash	16	0	0	0	0	0	0	0	0	16
Norway maple	10	3	0	0	0	0	0	0	0	13
Maple	7	1	0	0	0	0	0	0	0	8
Ash	4	4	0	0	0	0	0	0	0	8
Black walnut	2	6	0	0	0	0	0	0	0	8
White ash	5	2	0	0	0	0	0	0	0	7
Honeylocust	4	0	0	0	0	0	0	0	0	4
Swamp white oak	4	0	0	0	0	0	0	0	0	4
Eastern cottonwood	1	0	0	0	1	0	1	0	0	3
Boxelder maple	0	0	1	0	0	0	0	0	0	1
Kentucky coffee tree	1	0	0	0	0	0	0	0	0	1
Cottonwood/poplar	1	0	0	0	0	0	0	0	0	1
Oak	1	0	0	0	0	0	0	0	0	1
Total	634	336	599	120	10	0	1	0	0	1,700
Medium Deciduous										
European mountain ash	3	0	0	0	0	0	0	0	0	3
Ohio buckeye	0	2	0	0	0	0	0	0	0	2
Quaking aspen	0	0	1	1	0	0	0	0	0	2
Chinese pear	1	0	0	0	0	0	0	0	0	1
Total	13	7	2	1	0	0	0	0	0	23
Small Deciduous										
Common chokecherry	12	60	62	15	0	0	0	0	0	149
Amur maple	32	61	23	0	0	0	0	0	0	116
Amur chokecherry	13	16	21	10	0	0	0	0	0	60
Spring snow crapapple	44	4	0	0	0	0	0	0	0	48
Crabapple	12	13	1	0	0	0	0	0	0	26
Japanese tree lilac	16	0	0	0	0	0	0	0	0	16
Russian olive	3	1	5	0	0	0	0	0	0	9
Dogwood	5	0	0	0	0	0	0	0	0	5
Currant	2	0	0	0	0	0	0	0	0	2
Crispleaf red spirea	2	0	0	0	0	0	0	0	0	2
Manchurian lilac	2	0	0	0	0	0	0	0	0	2
Hawthorn	1	0	0	0	0	0	0	0	0	1
Purple leaf sand cherry	1	0	0	0	0	0	0	0	0	1
Cherry/ plum	1	0	0	0	0	0	0	0	0	1
Total	150	155	112	25	0	0	0	0	0	442
Large Conifer										
White spruce	2	1	0	0	0	0	0	0	0	3
Ponderosa pine	0	1	2	0	0	0	0	0	0	3
Eastern red cedar	2	0	0	0	0	0	0	0	0	2
Total	7	10	3	0	0	0	0	0	0	20
Medium Conifer										
Colorado red cedar	1	0	0	0	0	0	0	0	0	1
Total	1	8	0	0	0	0	0	0	0	9
Small Conifer										
Total	1	0	0	0	0	0	0	0	0	1
Zone 1 Total	**806**	**516**	**716**	**146**	**10**	**0**	**1**	**0**	**0**	**2,195**

Zone 2

Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
Large Deciduous										
Green ash	187	161	185	104	8	0	0	0	0	645
American linden	79	31	16	7	0	0	0	0	0	133
Black ash	102	18	5	0	0	0	0	0	0	125
Littleleaf linden	39	11	7	1	0	0	0	0	0	58
Hackberry	2	20	22	2	0	0	0	0	0	46
Bur oak	43	2	0	0	0	0	0	0	0	45
Manchurian ash	29	6	2	0	0	0	0	0	0	37
Norway maple	15	2	0	1	0	0	0	0	0	18
Silver maple	4	4	0	1	0	0	0	0	0	9
Freeman maple	7	0	0	0	0	0	0	0	0	7
Black ash x Manchurian ash	7	0	0	0	0	0	0	0	0	7
Sugar maple	0	2	4	0	0	0	0	0	0	6
Linden	5	1	0	0	0	0	0	0	0	6
Red maple	5	0	0	0	0	0	0	0	0	5
Maple	1	1	0	0	0	0	0	0	0	2
Ash	0	1	0	0	0	0	0	0	0	1
Eastern cottonwood	0	0	0	0	1	0	0	0	0	1
Total	525	261	241	116	9	0	0	0	0	1,152
Medium Deciduous										
European mountain ash	7	1	0	0	0	0	0	0	0	8
Quaking aspen	2	2	0	0	0	0	0	0	0	4
Ohio buckeye	0	3	0	0	0	0	0	0	0	3
Total	16	6	1	0	0	0	0	0	0	23
Small Deciduous										
Common chokecherry	3	11	56	5	0	0	0	0	0	75
Amur maple	15	21	15	1	0	0	0	0	0	52
Crabapple	21	18	10	0	0	0	0	0	0	49
Japanese tree lilac	15	4	0	0	0	0	0	0	0	19
Spring snow crapapple	3	5	0	0	0	0	0	0	0	8
Canadian plum	7	0	0	0	0	0	0	0	0	7
Hawthorn	2	0	0	0	0	0	0	0	0	2
Crispleaf red spirea	1	0	0	0	0	0	0	0	0	1
Total	69	59	81	6	0	0	0	0	0	215
Large Conifer										
White spruce	2	1	0	0	0	0	0	0	0	3
Ponderosa pine	0	1	0	0	0	0	0	0	0	1
Total	3	10	0	1	0	0	0	0	0	14
Medium Conifer	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0	0
Small Conifer										
Chinese juniper	1	0	0	0	0	0	0	0	0	1
Total	2	0	0	0	0	0	0	0	0	2
Zone 2 Total	**615**	**336**	**323**	**123**	**9**	**0**	**0**	**0**	**0**	**1,406**

Zone 3

Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
Large Deciduous										
American elm	0	0	7	120	292	142	21	0	0	582
Green ash	87	107	164	101	35	3	0	0	0	497
American linden	44	49	61	14	2	1	0	0	0	171
Hackberry	11	9	43	4	2	0	0	0	0	69
Littleleaf linden	25	10	18	2	0	0	0	0	0	55
Bur oak	21	1	3	0	0	0	0	0	0	25
White/silver poplar	0	0	0	1	13	2	3	1	3	23
Willow	11	6	0	0	0	0	0	0	0	17
Boxelder maple	0	0	0	4	6	4	1	0	0	15
Silver maple	1	6	4	3	0	1	0	0	0	15
Manchurian ash	12	3	0	0	0	0	0	0	0	15
Eastern cottonwood	3	0	0	0	3	5	1	0	0	12
Norway maple	9	2	0	0	0	0	0	0	0	11
Linden	8	3	0	0	0	0	0	0	0	11
Honeylocust	3	5	0	0	0	0	0	0	0	8
Sugar maple	3	2	2	0	0	0	0	0	0	7
Black ash	4	3	0	0	0	0	0	0	0	7
Black walnut	5	1	0	0	0	0	0	0	0	6
Swamp white oak	4	0	0	0	0	0	0	0	0	4
Freeman maple	3	0	0	0	0	0	0	0	0	3
Lombardy poplar	0	0	0	0	2	0	1	0	0	3
Red maple	1	0	0	0	0	0	0	0	0	1
Total	256	209	306	252	362	160	29	1	3	1,578
Medium Deciduous	0	0	0	0	0	0	0	0	0	0
Laurel willow	0	1	6	4	0	0	0	0	0	11
Showy mountain ash	6	1	1	0	0	0	0	0	0	8
European mountain ash	2	3	2	0	0	0	0	0	0	7
European white birch	1	0	1	1	0	0	0	0	0	3
Sibrica larch	3	0	0	0	0	0	0	0	0	3
Chinese pear	2	1	0	0	0	0	0	0	0	3
Paper birch	0	2	0	0	0	0	0	0	0	2
Pea tree	2	0	0	0	0	0	0	0	0	2
Total	17	8	10	5	0	0	0	0	0	40
Small Deciduous	0	0	0	0	0	0	0	0	0	0
Amur maple	33	19	6	0	0	0	0	0	0	58
Crabapple	9	5	9	1	0	0	0	0	0	24
Common chokecherry	0	10	12	0	0	0	0	0	0	22
Spring snow crapapple	14	0	4	0	0	0	0	0	0	18
Japanese tree lilac	12	0	1	0	0	0	0	0	0	13
Wild plum	11	0	0	0	0	0	0	0	0	11
Crispleaf red spirea	10	0	0	0	0	0	0	0	0	10
Van Houtte Spirea	7	0	0	0	0	0	0	0	0	7
Chinese lilac	7	0	0	0	0	0	0	0	0	7
Dogwood	6	0	0	0	0	0	0	0	0	6
Russian olive	0	5	0	0	0	0	0	0	0	5
Flowering almond	5	0	0	0	0	0	0	0	0	5
Hawthorn	4	0	0	0	0	0	0	0	0	4
Amur chokecherry	0	3	1	0	0	0	0	0	0	4
Cherry/ plum	2	1	0	0	0	0	0	0	0	3
Purple leaf sand cherry	2	0	0	0	0	0	0	0	0	2
European buckthorn	1	0	1	0	0	0	0	0	0	2
Dwarf pea tree	1	0	0	0	0	0	0	0	0	1
Apple	1	0	0	0	0	0	0	0	0	1
Apricot	1	0	0	0	0	0	0	0	0	1
Total	129	43	34	1	0	0	0	0	0	207
Large Conifer	0	0	0	0	0	0	0	0	0	0
Ponderosa pine	11	16	14	3	0	0	0	0	0	44
Blue spruce	16	6	10	8	0	0	0	0	0	40
Eastern red cedar	6	6	0	0	0	0	0	0	0	12
White spruce	1	0	1	2	1	0	0	0	0	5
Total	37	28	25	13	1	0	0	0	0	104
Medium Conifer	0	0	0	0	0	0	0	0	0	0
Colorado red cedar	28	2	2	0	0	0	0	0	0	32
Total	28	3	3	1	0	0	0	0	0	35
Small Conifer	0	0	0	0	0	0	0	0	0	0
Chinese juniper	13	0	0	0	0	0	0	0	0	13
Total	17	0	0	0	0	0	0	0	0	17
Zone 3 Total	**484**	**291**	**378**	**272**	**363**	**160**	**29**	**1**	**3**	**1,981**

Zone 4

Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
Large Deciduous										
American elm	0	2	14	217	595	436	111	14	2	1,391
Green ash	36	85	271	265	77	9	1	0	0	744
American linden	28	47	90	8	4	0	0	0	0	177
Littleleaf linden	17	15	64	14	0	0	0	0	0	110
Black ash	22	12	14	1	0	0	0	0	0	49
Norway maple	18	8	17	0	0	0	0	0	0	43
Manchurian ash	30	1	3	1	0	0	0	0	0	35
Siberian elm	0	0	2	3	11	10	6	3	0	35
Hackberry	3	13	11	5	1	0	0	0	0	33
Boxelder maple	0	0	0	7	12	9	2	1	1	32
Honeylocust	1	5	10	5	0	0	0	0	0	21
White/silver poplar	0	0	0	0	2	11	5	1	1	20
Bur oak	5	15	0	0	0	0	0	0	0	20
Freeman maple	10	1	1	0	0	0	0	0	0	12
Silver maple	0	3	1	4	1	2	0	1	0	12
Linden	3	8	0	0	0	0	0	0	0	11
White ash	2	1	7	0	0	0	0	0	0	10
Sugar maple	3	4	2	0	0	0	0	0	0	9
Black walnut	3	2	3	1	0	0	0	0	0	9
Eastern cottonwood	1	0	1	0	1	0	2	2	2	9
Red maple	8	0	0	0	0	0	0	0	0	8
Lombardy poplar	0	0	1	2	0	0	0	0	4	7
Black ash x Manchurian ash	5	0	0	0	0	0	0	0	0	5
Ash	3	0	0	0	0	0	0	0	0	3
Swamp white oak	3	0	0	0	0	0	0	0	0	3
White oak	2	0	0	0	0	0	0	0	0	2
Maple	0	1	0	0	0	0	0	0	0	1
European aspen	0	1	0	0	0	0	0	0	0	1
Willow	1	0	0	0	0	0	0	0	0	1
Siberian x slippery elm	0	0	0	0	1	0	0	0	0	1
Total	204	224	512	534	705	478	127	22	10	2,816
Medium Deciduous										
European mountain ash	3	1	2	3	0	0	0	0	0	9
Ohio buckeye	0	1	0	0	0	0	0	0	0	1
European white birch	0	0	1	0	0	0	0	0	0	1
Total	5	9	6	3	0	0	0	0	0	23
Small Deciduous										
Crabapple	1	7	39	5	0	0	0	0	0	52
Common chokecherry	4	16	28	1	0	0	0	0	0	49
Amur maple	12	17	16	0	0	0	0	0	0	45
Japanese tree lilac	25	0	2	0	0	0	0	0	0	27
Amur chokecherry	4	3	10	1	0	0	0	0	0	18
Spring snow crapapple	9	3	1	0	0	0	0	0	0	13
Tatarian maple	4	0	0	0	0	0	0	0	0	4
Canadian plum	0	2	0	0	0	0	0	0	0	2
Dogwood	1	0	0	0	0	0	0	0	0	1
Russian olive	0	0	0	1	0	0	0	0	0	1
Apple	0	0	1	0	0	0	0	0	0	1
Wild plum	1	0	0	0	0	0	0	0	0	1
Total	61	49	97	8	0	0	0	0	0	215
Large Conifer										
Ponderosa pine	0	0	6	2	0	0	0	0	0	8
White spruce	1	4	0	1	0	0	0	0	0	6
Eastern red cedar	0	0	0	1	0	0	0	0	0	1
Total	2	4	10	4	0	0	0	0	0	20
Medium Conifer										
Colorado red cedar	1	1	0	0	0	0	0	0	0	2
Total	1	1	0	0	1	0	0	0	0	3
Small Conifer										
Total	0	0	0	0	0	0	0	0	0	0
Zone 4 Total	273	287	625	549	706	478	127	22	10	3,077

Zone 5

Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
Large Deciduous										
American elm	0	0	12	293	659	330	59	7	2	1,362
Green ash	59	82	401	495	91	8	5	0	0	1,141
American linden	44	42	95	32	13	0	0	0	0	226
White/silver poplar	0	0	2	7	19	36	35	26	20	145
Black ash	64	21	19	0	0	0	0	0	1	105
Boxelder maple	1	0	3	41	45	10	1	1	0	102
Hackberry	4	15	47	26	2	0	0	0	0	94
Littleleaf linden	2	21	37	22	0	0	0	0	0	82
Silver maple	5	3	9	15	13	10	1	2	1	59
Manchurian ash	25	8	17	5	0	0	0	0	0	55
Lombardy poplar	0	1	0	4	3	7	7	7	5	34
Bur oak	16	8	1	5	0	0	0	0	0	30
Honeylocust	5	8	9	4	0	0	0	0	0	26
Linden	12	13	0	0	0	0	0	0	0	25
Freeman maple	12	2	0	0	0	0	0	0	0	14
Black ash x Manchurian ash	12	2	0	0	0	0	0	0	0	14
Eastern cottonwood	0	0	1	1	1	6	1	2	1	13
Sugar maple	9	1	2	0	0	0	0	0	0	12
Norway maple	5	2	4	0	0	0	0	0	0	11
Black walnut	3	5	2	1	0	0	0	0	0	11
Red maple	4	0	1	0	0	0	0	0	0	5
Ash	3	1	1	0	0	0	0	0	0	5
Cottonwood/poplar	2	0	3	0	0	0	0	0	0	5
Maple	2	0	2	0	0	0	0	0	0	4
White ash	0	0	2	0	1	0	0	0	0	3
Kentucky coffee tree	1	2	0	0	0	0	0	0	0	3
American sycamore	0	0	1	0	0	1	0	0	0	2
Japanese poplar	0	0	0	1	0	1	0	0	0	2
Northern catalpa	0	0	0	0	0	1	0	0	0	1
Ginkgo	0	1	0	0	0	0	0	0	0	1
White oak	1	0	0	0	0	0	0	0	0	1
Total	291	240	676	973	880	445	124	47	34	3,710
Medium Deciduous										
European mountain ash	2	1	6	2	0	0	0	0	0	11
Ohio buckeye	2	2	2	0	0	0	0	0	0	6
American mountain ash	0	3	1	0	0	0	0	0	0	4
European white birch	0	0	0	0	1	0	0	0	0	1
Tamarak	0	0	1	0	0	0	0	0	0	1
Laurel willow	0	0	1	0	0	0	0	0	0	1
Total	11	18	11	2	1	0	0	0	0	43
Small Deciduous										
Common chokecherry	4	46	77	6	1	0	0	0	0	134
Amur maple	10	31	31	3	0	0	0	0	0	75
Crabapple	12	12	6	6	1	0	0	0	0	37
Amur chokecherry	2	0	15	8	0	0	0	0	0	25
Spring snow crapapple	7	3	12	0	0	0	0	0	0	22
Japanese tree lilac	15	2	2	0	0	0	0	0	0	19
Cherry/ plum	4	3	0	0	0	0	0	0	0	7
Winged euonymus	3	0	0	0	0	0	0	0	0	3
Apricot	1	2	0	0	0	0	0	0	0	3
Staghorn sumac	0	2	1	0	0	0	0	0	0	3
Crispleaf red spirea	3	0	0	0	0	0	0	0	0	3
Apple	0	0	1	1	0	0	0	0	0	2
Russian olive	0	0	0	0	1	0	0	0	0	1
Forsythia	1	0	0	0	0	0	0	0	0	1
Siberian crabapple	0	0	1	0	0	0	0	0	0	1
Nanking cherry	1	0	0	0	0	0	0	0	0	1
Van Houtte Spirea	1	0	0	0	0	0	0	0	0	1
Chinese lilac	1	0	0	0	0	0	0	0	0	1
Total	67	101	146	24	3	0	0	0	0	341
Large Conifer										
White spruce	0	0	5	1	1	0	0	0	0	7
Ponderosa pine	1	1	0	1	0	0	0	0	0	3
Eastern red cedar	0	0	1	0	0	0	0	0	0	1
Total	1	1	9	6	2	0	0	0	0	19
Medium Conifer										
Colorado red cedar	0	0	2	0	0	0	0	0	0	2
Total	1	0	2	0	0	0	0	0	0	3
Small Conifer										
Common juniper	0	1	0	0	0	0	0	0	0	1
Total	0	14	3	0	0	0	0	0	0	17
Zone 5 Total	**371**	**374**	**847**	**1,005**	**886**	**445**	**124**	**47**	**34**	**4,133**

Zone 6

Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
Large Deciduous										
Green ash	66	59	121	20	1	1	0	0	0	268
American linden	27	22	48	0	0	0	0	0	0	97
Black ash	24	1	2	0	0	0	0	0	0	27
Littleleaf linden	12	3	10	0	0	0	0	0	0	25
Manchurian ash	24	0	0	0	0	0	0	0	0	24
Black ash x Manchurian ash	9	0	0	0	0	0	0	0	0	9
Silver maple	0	0	2	5	0	1	0	0	0	8
Sugar maple	2	3	3	0	0	0	0	0	0	8
Norway maple	5	1	1	0	0	0	0	0	0	7
American elm	0	0	1	2	4	0	0	0	0	7
Bur oak	6	0	0	0	0	0	0	0	0	6
Linden	2	1	3	0	0	0	0	0	0	6
Honeylocust	4	0	0	1	0	0	0	0	0	5
Hackberry	0	1	2	1	0	0	0	0	0	4
Eastern cottonwood	0	0	2	0	1	0	0	0	1	4
Lombardy poplar	0	0	0	3	0	1	0	0	0	4
Freeman maple	3	0	0	0	0	0	0	0	0	3
White ash	1	1	0	0	0	0	0	0	0	2
Red maple	1	0	0	0	0	0	0	0	0	1
Total	186	92	195	33	6	3	0	0	1	516
Medium Deciduous										
European mountain ash	4	0	0	0	0	0	0	0	0	4
Chinese pear	3	0	0	0	0	0	0	0	0	3
Ohio buckeye	2	0	0	0	0	0	0	0	0	2
European larch	1	0	0	0	0	0	0	0	0	1
Quaking aspen	0	1	0	0	0	0	0	0	0	1
Total	14	5	0	0	0	0	0	0	0	19
Small Deciduous										
Common chokecherry	5	13	8	1	0	0	0	0	0	27
Amur maple	7	10	2	0	0	0	0	0	0	19
Crabapple	16	1	0	0	0	0	0	0	0	17
Spring snow crapapple	14	0	0	0	0	0	0	0	0	14
Amur chokecherry	1	1	4	0	0	0	0	0	0	6
Total	44	25	14	1	0	0	0	0	0	84
Large Conifer										
Ponderosa pine	5	16	3	0	0	0	0	0	0	24
Blue spruce	0	1	2	0	0	0	0	0	0	3
Total	7	17	5	0	0	0	0	0	0	29
Medium Conifer										
Total	0	2	0	0	0	0	0	0	0	2
Small Conifer										
Chinese juniper	15	0	0	0	0	0	0	0	0	15
Total	16	0	0	0	0	0	0	0	0	16
Zone 6 Total	**267**	**141**	**214**	**34**	**6**	**3**	**0**	**0**	**1**	**666**

Zone 7

Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
Large Deciduous										
Green ash	86	112	171	91	26	3	1	0	0	490
American linden	53	25	21	1	0	0	0	0	0	100
Hackberry	34	13	11	1	1	0	0	0	0	60
Black ash	40	13	3	0	0	0	0	0	0	56
Manchurian ash	36	1	0	0	0	0	0	0	0	37
Norway maple	27	4	1	0	0	0	0	0	0	32
Littleleaf linden	22	0	7	0	0	0	0	0	0	29
Boxelder maple	0	0	2	7	11	6	1	0	0	27
White ash	22	2	0	0	0	0	0	0	0	24
Sugar maple	19	3	0	0	0	0	0	0	0	22
Bur oak	21	1	0	0	0	0	0	0	0	22
American elm	0	0	1	0	9	7	3	0	0	20
Freeman maple	18	1	0	0	0	0	0	0	0	19
White/silver poplar	0	0	2	9	3	2	0	0	0	16
Eastern cottonwood	1	1	0	0	4	4	1	1	2	14
Honeylocust	12	0	1	0	0	0	0	0	0	13
Silver maple	4	6	1	1	0	0	0	0	0	12
Black ash x Manchurian ash	12	0	0	0	0	0	0	0	0	12
Red maple	5	0	0	0	0	0	0	0	0	5
Linden	5	0	0	0	0	0	0	0	0	5
Ash	0	3	0	0	0	0	0	0	0	3
Maple	1	1	0	0	0	0	0	0	0	2
White oak	2	0	0	0	0	0	0	0	0	2
Black walnut	1	0	0	0	0	0	0	0	0	1
Swamp white oak	1	0	0	0	0	0	0	0	0	1
Total	422	186	222	115	61	23	7	1	2	1,039
Medium Deciduous										
European mountain ash	5	3	3	0	0	0	0	0	0	11
European white birch	0	0	1	0	0	0	0	0	0	1
Total	11	3	4	0	0	0	0	0	0	18
Small Deciduous										
Common chokecherry	15	48	59	2	0	0	0	0	0	124
Dogwood	92	0	0	0	0	0	0	0	0	92
Crabapple	42	16	10	0	0	0	0	0	0	68
Smooth sumac	27	0	0	0	0	0	0	0	0	27
Amur maple	10	9	3	0	0	0	0	0	0	22
Spring snow crapapple	12	0	0	0	0	0	0	0	0	12
Amur chokecherry	3	1	2	0	0	0	0	0	0	6
Hawthorn	2	3	0	0	0	0	0	0	0	5
Crispleaf red spirea	4	0	0	0	0	0	0	0	0	4
Wild plum	2	0	0	0	0	0	0	0	0	2
Purple leaf sand cherry	2	0	0	0	0	0	0	0	0	2
Canadian plum	2	0	0	0	0	0	0	0	0	2
Cherry/ plum	2	0	0	0	0	0	0	0	0	2
Flowering almond	2	0	0	0	0	0	0	0	0	2
Van Houtte Spirea	2	0	0	0	0	0	0	0	0	2
Serviceberry	1	0	0	0	0	0	0	0	0	1
Morden hawthorn	1	0	0	0	0	0	0	0	0	1
Manchurian lilac	1	0	0	0	0	0	0	0	0	1
Total	232	79	74	2	0	0	0	0	0	387
Large Conifer										
Blue spruce	18	3	0	1	0	0	0	0	0	22
Ponderosa pine	9	0	0	0	0	0	0	0	0	9
White spruce	0	0	2	0	0	0	0	0	0	2
Total	31	3	2	1	0	0	0	0	0	37
Medium Conifer										
Colorado red cedar	17	0	0	2	0	0	0	0	0	19
Total	18	1	0	2	1	0	0	0	0	22
Small Conifer										
Chinese juniper	31	0	0	0	0	0	0	0	0	31
Total	50	0	0	0	0	0	0	0	0	50
Zone 7 Total	**764**	**272**	**302**	**120**	**62**	**23**	**7**	**1**	**2**	**1,553**

Zone 8

Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
Large Deciduous										
Green ash	135	173	375	208	16	0	0	0	0	907
American linden	69	64	102	12	0	0	0	0	0	247
American elm	0	1	4	57	62	14	3	2	0	143
Black ash	58	43	7	0	0	0	0	0	0	108
Hackberry	11	38	32	2	0	0	0	0	0	83
Littleleaf linden	11	12	50	5	0	0	0	0	0	78
Manchurian ash	59	10	4	0	0	0	0	0	0	73
Norway maple	54	15	1	0	0	0	0	0	0	70
Honeylocust	1	9	52	2	0	0	0	0	0	64
Silver maple	9	4	11	7	1	0	0	0	0	32
Black ash x Manchurian ash	22	0	0	0	0	0	0	0	0	22
Boxelder maple	1	0	1	5	7	7	0	0	0	21
Linden	9	10	0	0	0	0	0	0	0	19
Red maple	14	2	0	0	0	0	0	0	0	16
Sugar maple	5	10	1	0	0	0	0	0	0	16
Bur oak	13	2	0	0	0	0	0	0	0	15
Freeman maple	12	2	0	0	0	0	0	0	0	14
Lombardy poplar	0	0	0	3	2	1	1	1	1	9
Kentucky coffee tree	2	2	1	1	0	0	0	0	0	6
Black walnut	5	1	0	0	0	0	0	0	0	6
Eastern cottonwood	0	2	0	0	2	0	1	0	1	6
White/silver poplar	0	0	1	0	1	1	1	0	0	4
White ash	3	0	0	0	0	0	0	0	0	3
Maple	1	1	0	0	0	0	0	0	0	2
Ash	0	1	0	0	0	0	0	0	0	1
Total	496	403	644	304	102	28	8	4	2	1,991
Medium Deciduous										
European mountain ash	11	6	2	0	0	0	0	0	0	19
Laurel willow	11	0	1	0	0	0	0	0	0	12
Quaking aspen	5	0	0	0	0	0	0	0	0	5
Ohio buckeye	2	1	0	0	0	0	0	0	0	3
European white birch	1	0	0	0	0	0	0	0	0	1
Total	43	25	6	0	0	0	0	0	0	74
Small Deciduous										
Common chokecherry	17	78	62	6	1	0	0	0	0	164
Amur maple	28	49	36	1	0	0	0	0	0	114
Crabapple	28	44	26	2	0	0	0	0	0	100
Amur chokecherry	4	18	31	0	0	0	0	0	0	53
Japanese tree lilac	19	15	10	0	0	0	0	0	0	44
Late lilac	21	0	0	0	0	0	0	0	0	21
Mayday tree	0	4	11	0	0	0	0	0	0	15
Spring snow crapapple	4	2	0	0	0	0	0	0	0	6
Canadian plum	6	0	0	0	0	0	0	0	0	6
Hawthorn	0	3	0	0	0	0	0	0	0	3
Apricot	2	0	1	0	0	0	0	0	0	3
Glossy buckthorn	3	0	0	0	0	0	0	0	0	3
Flowering almond	2	0	0	0	0	0	0	0	0	2
Van Houtte Spirea	2	0	0	0	0	0	0	0	0	2
Russian olive	0	0	1	0	0	0	0	0	0	1
European buckthorn	0	0	1	0	0	0	0	0	0	1
Total	141	213	179	9	1	0	0	0	0	543
Large Conifer										
Eastern red cedar	6	5	0	0	0	0	0	0	0	11
White spruce	0	0	1	0	1	0	0	0	0	2
Ponderosa pine	0	0	0	0	1	0	0	0	0	1
Total	9	8	15	4	3	0	0	0	0	39
Medium Conifer										
Colorado red cedar	18	1	0	0	0	0	0	0	0	19
Total	23	1	1	0	0	0	0	0	0	25
Small Conifer										
Chinese juniper	4	0	0	0	0	0	0	0	0	4
Total	7	0	0	0	0	0	0	0	0	7
Zone 8 Total	**719**	**650**	**845**	**317**	**106**	**28**	**8**	**4**	**2**	**2,679**

Zone 9

Species	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total
Large Deciduous										
Green ash	11	14	23	0	0	0	0	0	0	48
Hackberry	3	5	5	0	0	0	0	0	0	13
Freeman maple	6	3	0	0	0	0	0	0	0	9
Black ash	3	0	3	0	0	0	0	0	0	6
Black walnut	0	4	1	0	0	0	0	0	0	5
American linden	5	0	0	0	0	0	0	0	0	5
Black ash x Manchurian ash	4	0	0	0	0	0	0	0	0	4
Bur oak	3	1	0	0	0	0	0	0	0	4
Linden	4	0	0	0	0	0	0	0	0	4
Sugar maple	3	0	0	0	0	0	0	0	0	3
Manchurian ash	0	2	1	0	0	0	0	0	0	3
Honeylocust	0	1	0	0	0	0	0	0	0	1
Total	42	31	33	0	0	0	0	0	0	106
Small Deciduous										
Amur maple	5	0	0	0	0	0	0	0	0	5
Total	16	0	0	0	0	0	0	0	0	16
Large Conifer										
Total	9	0	0	0	0	0	0	0	0	9
Zone 9 Total	**67**	**31**	**33**	**0**	**0**	**0**	**0**	**0**	**0**	**131**

Appendix D:

Condition And Relative Performance Index For All Species

	% of Trees in Each Condition Class						No. of	% of Total
Common Name	Dead	Poor	Fair	Good	Excellent	RPI	Trees	Population
Green ash	0.3	4.5	42.0	52.4	0.7	1.13	5,644	31.7
American elm	0.1	2.0	30.9	64.2	2.9	1.42	3,506	19.7
American linden	1.1	4.2	60.3	32.5	1.9	0.73	1,342	7.5
Common chokecherry	-	1.6	34.3	61.6	2.4	1.36	744	4.2
Black ash	0.3	1.3	80.7	17.4	0.3	0.38	637	3.6
Littleleaf linden	1.3	3.9	53.2	39.3	2.2	0.88	539	3.0
Amur maple	0.8	2.6	59.1	36.6	1.0	0.80	506	2.8
Hackberry	0.6	3.8	48.5	44.3	2.5	1.00	476	2.7
Crabapple	-	1.8	64.3	33.6	-	0.71	384	2.2
Manchurian ash	0.9	4.0	80.9	13.3	0.9	0.30	324	1.8
Siberian elm	-	12.8	40.2	45.7	1.4	1.00	219	1.2
Bur oak	1.4	1.9	78.3	14.2	4.2	0.39	212	1.2
White/silver poplar	0.5	5.8	50.5	41.3	1.9	0.92	208	1.2
Norway maple	-	6.3	83.9	8.8	-	0.19	205	1.2
Boxelder maple	0.5	11.1	49.0	37.9	1.5	0.84	198	1.1
Amur chokecherry	0.6	4.1	65.1	30.2	-	0.64	172	1.0
Silver maple	1.8	5.4	50.9	40.1	1.8	0.89	167	0.9
Japanese tree lilac	-	3.3	82.0	14.7	-	0.31	150	0.8
Honeylocust	0.7	4.2	35.9	57.0	2.1	1.26	142	0.8
Spring snow crapapple	-	0.7	85.8	12.8	-	0.27	141	0.8
Blue spruce	-	4.8	49.6	43.2	2.4	0.97	125	0.7
Linden	-	1.8	96.5	1.8	-	0.04	113	0.6
Showy mountain ash	2.7	4.5	71.8	20.0	0.9	0.44	110	0.6
Freeman maple	0.9	-	97.2	0.9	-	0.02	109	0.6
Dogwood	1.0	5.8	74.0	19.2	-	0.41	104	0.6
Ponderosa pine	2.0	-	54.9	42.2	1.0	0.92	102	0.6
Sugar maple	2.0	9.9	65.3	21.8	1.0	0.48	101	0.6
Black ash x Manchurian ash	-	1.1	98.9	-	-	-	89	0.5
Colorado red cedar	-	2.6	15.6	70.1	11.7	1.74	77	0.4
European mountain ash	1.4	5.6	62.5	27.8	2.8	0.65	72	0.4
Chinese juniper	-	-	18.8	81.3	-	1.73	64	0.4
Eastern cottonwood	-	6.5	40.3	45.2	8.1	1.13	62	0.3
Red maple	1.6	4.9	90.2	1.6	-	0.03	61	0.3
Lombardy poplar	-	1.8	28.1	68.4	1.8	1.49	57	0.3
White ash	-	2.0	77.6	20.4	-	0.43	49	0.3
Black walnut	2.2	2.2	65.2	30.4	-	0.65	46	0.3
Mugo pine	-	2.3	40.9	54.5	2.3	1.21	44	0.2
White spruce	3.6	-	50.0	39.3	7.1	0.99	28	0.2
Smooth sumac	-	-	33.3	66.7	-	1.42	27	0.2
Eastern red cedar	-	-	51.9	48.1	-	1.02	27	0.2
Laurel willow	-	-	54.2	45.8	-	0.97	24	0.1
Scotch pine	-	-	72.7	18.2	9.1	0.58	22	0.1
Late lilac	9.5	9.5	42.9	38.1	-	0.81	21	0.1
Ash	-	-	95.2	-	-	-	21	0.1
Crispleaf red spirea	-	5.0	40.0	55.0	-	1.17	20	0.1

Common Name	% of Trees in Each Condition Class Dead	Poor	Fair	Good	Excellent	RPI	No. of Trees	% of Total Population
Maple	-	-	100.0	-	-	-	19	0.1
Willow	-	11.1	83.3	5.6	-	0.12	18	0.1
Common lilac	-	17.6	29.4	52.9	-	1.12	17	0.1
Ohio buckeye	-	-	52.9	47.1	-	1.00	17	0.1
Russian olive	-	-	70.6	29.4	-	0.62	17	0.1
Canadian plum	11.8	5.9	76.5	5.9	-	0.12	17	0.1
Mayday tree	-	-	46.7	53.3	-	1.13	15	0.1
Hawthorn	-	13.3	73.3	13.3	-	0.28	15	0.1
Wild plum	7.1	21.4	57.1	14.3	-	0.30	14	0.1
Cherry/ plum	-	-	61.5	38.5	-	0.82	13	0.1
Van Houtte Spirea	-	-	66.7	33.3	-	0.71	12	0.1
Quaking aspen	8.3	8.3	66.7	16.7	-	0.35	12	0.1
Swamp white oak	-	-	100.0	-	-	-	12	0.1
Kentucky coffee tree	-	-	70.0	30.0	-	0.64	10	0.1
White cedar	-	-	33.3	66.7	-	1.42	9	0.1
Flowering almond	-	11.1	44.4	44.4	-	0.94	9	0.1
Chinese lilac	-	-	87.5	12.5	-	0.27	8	0.0
Apricot	-	-	42.9	57.1	-	1.21	7	0.0
European white birch	-	-	57.1	42.9	-	0.91	7	0.0
Chinese pear	-	-	85.7	-	-	-	7	0.0
Cottonwood/poplar	-	-	100.0	-	-	-	6	0.0
Purple leaf sand cherry	-	20.0	20.0	60.0	-	1.27	5	0.0
White oak	-	-	60.0	40.0	-	0.85	5	0.0
Apple	-	-	50.0	50.0	-	1.06	4	0.0
American mountain ash	-	25.0	25.0	50.0	-	1.06	4	0.0
Tatarian maple	-	25.0	75.0	-	-	-	4	0.0
Staghorn sumac	-	-	33.3	66.7	-	1.42	3	0.0
European buckthorn	-	33.3	33.3	33.3	-	0.71	3	0.0
Currant	-	-	66.7	33.3	-	0.71	3	0.0
Manchurian lilac	-	-	66.7	33.3	-	0.71	3	0.0
Winged euonymus	-	66.7	33.3	-	-	-	3	0.0
Sibrica larch	-	-	100.0	-	-	-	3	0.0
Glossy buckthorn	-	33.3	66.7	-	-	-	3	0.0
Japanese poplar	-	-	-	100.0	-	2.12	2	0.0
American sycamore	-	-	50.0	50.0	-	1.06	2	0.0
Slippery elm	-	-	50.0	50.0	-	1.06	2	0.0
Paper birch	-	50.0	50.0	-	-	-	2	0.0
Pea tree	-	50.0	50.0	-	-	-	2	0.0
Dwarf pea tree	-	-	-	100.0	-	2.12	1	0.0
Forsythia	-	-	-	100.0	-	2.12	1	0.0
Common juniper	-	-	-	100.0	-	2.12	1	0.0
European larch	-	-	-	100.0	-	2.12	1	0.0
Tamarak	-	-	-	100.0	-	2.12	1	0.0
Siberian crabapple	-	-	-	100.0	-	2.12	1	0.0
Yew	-	-	-	100.0	-	2.12	1	0.0
Siberian x slippery elm	-	-	-	100.0	-	2.12	1	0.0
Serviceberry	-	-	100.0	-	-	-	1	0.0
Northern catalpa	-	-	100.0	-	-	-	1	0.0
Morden hawthorn	-	-	100.0	-	-	-	1	0.0
Ginkgo	-	-	100.0	-	-	-	1	0.0
European aspen	-	-	100.0	-	-	-	1	0.0
Nanking cherry	-	-	100.0	-	-	-	1	0.0
Oak	-	-	100.0	-	-	-	1	0.0
Hybrid mountain ash	-	-	100.0	-	-	-	1	0.0
Street Tree Total	0.5	3.6	48.7	45.5	1.5		17,821	100

Appendix E:

Maintenance Tasks Citywide By Type, Zone, And Species

Two tables are presented for each maintenance category. The first table shows number of trees in each DBH class and zone that require maintenance. The second table shows the top five species in each zone requiring the maintenance task described.

Plant

Zone	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total	% of Total
1	-	6	-	-	-	-	-	-	-	6	37.5
2	2	-	-	-	-	-	-	-	-	2	12.5
3	-	1	-	-	-	-	-	-	-	1	6.3
4	-	-	-	-	-	-	-	-	-	-	-
5	1	-	-	-	-	-	-	-	-	1	6.3
6	-	1	-	-	-	-	-	-	-	1	6.3
7	-	-	-	-	-	-	-	-	-	-	-
8	2	3	-	-	-	-	-	-	-	5	31.3
9	-	-	-	-	-	-	-	-	-	-	-
Citywide Total	5	11	-	-	-	-	-	-	-	16	100

Zone	1st (%)	2nd (%)	3rd (%)	4th (%)	5th (%)	# of Trees
1	Green ash (83.3)	Hackberry (16.7)	(0)	(0)	(0)	6
2	Black ash (50)	Littleleaf linden (50)	(0)	(0)	(0)	2
3	Chinese pear (100)	(0)	(0)	(0)	(0)	1
4	(0)	(0)	(0)	(0)	(0)	0
5	Showy mountain ash (	(0)	(0)	(0)	(0)	1
6	Green ash (100)	(0)	(0)	(0)	(0)	1
7	(0)	(0)	(0)	(0)	(0)	0
8	Norway maple (40)	Green ash (40)	Ash (20)	(0)	(0)	5
9	(0)	(0)	(0)	(0)	(0)	0
Citywide total	Green ash (50)	Norway maple (12.5)	Hackberry (6.3)	Black ash (6.3)	Ash (6.3)	16

Pruning Level 1

Zone	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total	% of Total
1	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	1	-	-	-	-	1	33.3
4	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	1	-	-	-	-	-	1	33.3
6	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	1	-	-	-	-	1	33.3
8	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-
Citywide Total	-	-	-	1	2	-	-	-	-	3	100

Zone	1st (%)	2nd (%)	3rd (%)	4th (%)	5th (%)	# of Trees
1	(0)	(0)	(0)	(0)	(0)	0
2	(0)	(0)	(0)	(0)	(0)	0
3	American elm (100)	(0)	(0)	(0)	(0)	1
4	(0)	(0)	(0)	(0)	(0)	0
5	American elm (100)	(0)	(0)	(0)	(0)	1
6	(0)	(0)	(0)	(0)	(0)	0
7	Green ash (100)	(0)	(0)	(0)	(0)	1
8	(0)	(0)	(0)	(0)	(0)	0
9	(0)	(0)	(0)	(0)	(0)	0
Citywide total	American elm (66.7)	Green ash (33.3)	(0)	(0)	(0)	3

Pruning Level 2

Zone	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total	% of Total
1	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	1	-	-	-	-	1	10.0
5	-	-	-	-	2	2	-	-	-	4	40.0
6	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	2	-	-	-	1	3	30.0
8	-	1	-	1	-	-	-	-	-	2	20.0
9	-	-	-	-	-	-	-	-	-	-	-
Citywide Total	-	1	-	1	5	2	-	-	1	10	100

Zone	1st (%)	2nd (%)	3rd (%)	4th (%)	5th (%)	# of Trees
1	(0)	(0)	(0)	(0)	(0)	0
2	(0)	(0)	(0)	(0)	(0)	0
3	(0)	(0)	(0)	(0)	(0)	0
4	American elm (100)	(0)	(0)	(0)	(0)	1
5	Siberian elm (50)	Boxelder maple (25)	American elm (25)	(0)	(0)	4
6	(0)	(0)	(0)	(0)	(0)	0
7	Eastern cottonwood (6	Boxelder maple (33.3)	(0)	(0)	(0)	3
8	Amur maple (50)	Green ash (50)	(0)	(0)	(0)	2
9	(0)	(0)	(0)	(0)	(0)	0
Citywide total	Boxelder maple (20)	Eastern cottonwood (20)	American elm (20)	Siberian elm (20)	Amur maple (10)	10

Pruning Level 3

Zone	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total	% of Total
1	-	-	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-
4	-	-	1	1	1	-	-	-	-	3	13.6
5	-	-	3	2	3	1	-	-	-	9	40.9
6	-	-	-	-	-	-	-	-	-	-	-
7	-	-	2	2	3	-	-	-	-	7	31.8
8	-	-	-	-	2	1	-	-	-	3	13.6
9	-	-	-	-	-	-	-	-	-	-	-
Citywide Total	-	-	6	5	9	2	-	-	-	22	100

Zone	1st (%)	2nd (%)	3rd (%)	4th (%)	5th (%)	# of Trees
1	(0)	(0)	(0)	(0)	(0)	0
2	(0)	(0)	(0)	(0)	(0)	0
3	(0)	(0)	(0)	(0)	(0)	0
4	American elm (66.7)	Green ash (33.3)	(0)	(0)	(0)	3
5	Green ash (44.4)	American elm (22.2)	Boxelder maple (11.1)	Apple (11.1)	White/silver poplar (11.1)	9
6	(0)	(0)	(0)	(0)	(0)	0
7	Boxelder maple (28.6)	Green ash (28.6)	Siberian elm (28.6)	Eastern cottonwood (14.3)	(0)	7
8	American elm (100)	(0)	(0)	(0)	(0)	3
9	(0)	(0)	(0)	(0)	(0)	0
Citywide total	Green ash (31.8)	American elm (31.8)	Boxelder maple (13.6)	Siberian elm (9.1)	Apple (4.5)	22

Removal Level 1

Zone	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total	% of Total
1	-	-	-	-	-	-	-	-	-	-	-
2	1	1	-	-	-	-	-	-	-	2	13.3
3	-	-	-	-	1	-	-	-	-	1	6.7
4	-	-	-	-	-	2	1	-	-	3	20.0
5	-	-	-	2	1	2	1	-	-	6	40.0
6	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	1	2	-	-	-	-	3	20.0
8	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-
Citywide Total	1	1	-	3	4	4	2	-	-	15	100

Zone	1st (%)	2nd (%)	3rd (%)	4th (%)	5th (%)	# of Trees
1	(0)	(0)	(0)	(0)	(0)	0
2	Green ash (50)	White spruce (50)	(0)	(0)	(0)	2
3	Boxelder maple (100)	(0)	(0)	(0)	(0)	1
4	American elm (100)	(0)	(0)	(0)	(0)	3
5	American elm (100)	(0)	(0)	(0)	(0)	6
6	(0)	(0)	(0)	(0)	(0)	0
7	Boxelder maple (33.3)	Green ash (33.3)	Siberian elm (33.3)	(0)	(0)	3
8	(0)	(0)	(0)	(0)	(0)	0
9	(0)	(0)	(0)	(0)	(0)	0
Citywide total	American elm (60)	Boxelder maple (13.3)	Green ash (13.3)	White spruce (6.7)	Siberian elm (6.7)	15

Removal Level 2

Zone	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total	% of Total
1	-	1	5	2	-	-	-	-	-	8	4.5
2	-	-	2	1	-	-	-	-	-	3	1.7
3	1	-	1	1	12	3	3	-	1	22	12.3
4	2	-	15	5	13	9	1	-	-	45	25.1
5	5	3	8	17	12	8	2	2	1	58	32.4
6	1	-	1	-	1	-	-	-	1	4	2.2
7	-	-	7	4	5	2	-	-	-	18	10.1
8	1	4	6	5	5	-	-	-	-	21	11.7
9	-	-	-	-	-	-	-	-	-	-	-
Citywide Total	10	8	45	35	48	22	6	2	3	179	100

Zone	1st (%)	2nd (%)	3rd (%)	4th (%)	5th (%)	# of Trees
1	Amur maple (37.5)	Green ash (25)	Amur chokecherry (25)	Common chokecherry (12.5)	(0)	8
2	Common chokecherry	Hackberry (33.3)	(0)	(0)	(0)	3
3	American elm (36.4)	White/silver poplar (27.3)	Green ash (18.2)	Eastern cottonwood (13.6)	Siberian elm (4.5)	22
4	American elm (37.8)	Green ash (24.4)	Boxelder maple (8.9)	Amur maple (6.7)	Norway maple (6.7)	45
5	American elm (25.9)	Green ash (15.5)	Boxelder maple (12.1)	Siberian elm (12.1)	White/silver poplar (8.6)	58
6	Green ash (50)	Eastern cottonwood (50)	(0)	(0)	(0)	4
7	Boxelder maple (38.9)	Green ash (16.7)	Common chokecherry (16.7)	American elm (11.1)	Siberian elm (11.1)	18
8	Green ash (33.3)	Boxelder maple (14.3)	Honeylocust (14.3)	Siberian elm (14.3)	Lombardy poplar (4.8)	21
9	(0)	(0)	(0)	(0)	(0)	0
Citywide total	American elm (24)	Green ash (21.2)	Boxelder maple (11.7)	White/silver poplar (7.8)	Siberian elm (7.8)	179

Removal Level 3

Zone	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total	% of Total
1	2	4	7	1	-	-	-	-	-	14	5.1
2	-	-	-	-	1	-	-	-	-	1	0.4
3	2	5	5	5	6	3	2	-	-	28	10.3
4	2	4	4	9	17	19	4	-	-	59	21.6
5	3	7	11	33	30	6	1	5	1	97	35.5
6	1	3	3	3	-	-	-	-	-	10	3.7
7	2	1	3	5	3	1	1	-	-	16	5.9
8	2	12	14	11	7	1	-	-	-	47	17.2
9	-	1	-	-	-	-	-	-	-	1	0.4
Citywide Total	14	37	47	67	64	30	8	5	1	273	100

Zone	1st (%)	2nd (%)	3rd (%)	4th (%)	5th (%)	# of Trees
1	Green ash (42.9)	Amur maple (21.4)	Amur chokecherry (21.4)	Quaking aspen (7.1)	Littleleaf linden (7.1)	14
2	Green ash (100)	(0)	(0)	(0)	(0)	1
3	American elm (32.1)	Green ash (25)	Siberian elm (10.7)	Amur maple (7.1)	Boxelder maple (3.6)	28
4	American elm (55.9)	Boxelder maple (11.9)	Green ash (10.2)	White/silver poplar (3.4)	American linden (3.4)	59
5	American elm (29.9)	Green ash (20.6)	Boxelder maple (17.5)	American linden (6.2)	Siberian elm (6.2)	97
6	Green ash (50)	Lombardy poplar (20)	Hackberry (10)	American linden (10)	American elm (10)	10
7	Green ash (31.3)	Boxelder maple (25)	Common chokecherry (12.5)	Siberian elm (12.5)	European mountain ash (	16
8	Green ash (27.7)	American elm (17)	Common chokecherry (8.5)	Boxelder maple (6.4)	Crabapple (6.4)	47
9	Siberian elm (100)	(0)	(0)	(0)	(0)	1
Citywide total	American elm (29.3)	Green ash (23.1)	Boxelder maple (11.7)	Siberian elm (5.1)	American linden (4.4)	273

Routine

Zone	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total	% of Total
1	22	229	585	142	10	-	1	-	-	989	9.7
2	4	65	245	120	8	-	-	-	-	442	4.3
3	4	125	328	263	341	153	24	1	2	1,241	12.2
4	5	71	511	517	655	429	113	21	5	2,327	22.8
5	10	113	693	934	825	417	117	39	27	3,175	31.1
6	1	57	195	28	4	3	-	-	-	288	2.8
7	8	93	243	107	46	19	6	1	1	524	5.1
8	26	206	551	284	88	24	8	3	2	1,192	11.7
9	4	-	20	-	-	-	-	-	-	24	0.2
Citywide Total	84	959	3,371	2,395	1,977	1,045	269	65	37	10,202	100

Zone	1st (%)	2nd (%)	3rd (%)	4th (%)	5th (%)	# of Trees
1	Green ash (56.8)	Common chokecherry (12.7)	Amur maple (6.1)	American linden (5.2)	Amur chokecherry (4.4)	989
2	Green ash (73.3)	Common chokecherry (9)	American linden (4.3)	Amur maple (3.6)	Hackberry (2.7)	442
3	American elm (45)	Green ash (27.3)	American linden (7.4)	Hackberry (4.4)	Littleleaf linden (1.9)	1,241
4	American elm (55.2)	Green ash (26.4)	American linden (3.8)	Littleleaf linden (3)	Siberian elm (1.2)	2,327
5	American elm (40.3)	Green ash (31.2)	White/silver poplar (4.1)	American linden (3.9)	Siberian elm (3.1)	3,175
6	Green ash (59.7)	American linden (18.4)	Common chokecherry (3.8)	Littleleaf linden (3.1)	Silver maple (2.4)	288
7	Green ash (62.6)	Common chokecherry (6.5)	American linden (5.9)	Hackberry (3.8)	American elm (3.4)	524
8	Green ash (47.7)	American elm (10.5)	American linden (9.2)	Common chokecherry (5.8)	Honeylocust (4.2)	1,192
9	Green ash (79.2)	Hackberry (16.7)	Black walnut (4.2)	(0)	(0)	24
Citywide total	Green ash (38.4)	American elm (32.1)	American linden (5.6)	Common chokecherry (3.8)	Littleleaf linden (2.4)	10,202

Train

Zone	0-3	3-6	6-12	12-18	18-24	24-30	30-36	36-42	>42	Total	% of Total
1	781	263	115	-	-	-	-	-	-	1,159	16.9
2	608	230	74	2	-	-	-	-	-	914	13.3
3	477	160	44	1	-	-	-	-	-	682	10.0
4	262	204	82	2	-	-	-	-	-	550	8.0
5	346	245	130	2	-	-	-	-	1	724	10.6
6	264	79	13	1	-	-	-	-	-	357	5.2
7	752	178	46	1	-	-	-	-	-	977	14.3
8	687	422	264	12	-	-	-	-	-	1,385	20.2
9	63	30	13	-	-	-	-	-	-	106	1.5
Citywide Total	4,240	1,811	781	21	-	-	-	-	1	6,854	100

Zone	1st (%)	2nd (%)	3rd (%)	4th (%)	5th (%)	# of Trees
1	Green ash (27.7)	American linden (11.3)	Black ash (9.8)	Littleleaf linden (6)	Amur maple (4.1)	1,159
2	Green ash (32.2)	Black ash (13.5)	American linden (12.1)	Littleleaf linden (5.3)	Burr oak (4.9)	914
3	Green ash (21.6)	American linden (11.4)	Amur maple (6.6)	Ponderosa pine (5.1)	Littleleaf linden (4.5)	682
4	Green ash (18)	American linden (14.9)	Littleleaf linden (6.2)	Manchurian ash (5.6)	Amur maple (5.3)	550
5	Green ash (15.2)	American linden (13)	Black ash (11.2)	Common chokecherry (7.5)	Amur maple (7.2)	724
6	Green ash (23.5)	American linden (12)	Black ash (7)	Manchurian ash (6.7)	Ponderosa pine (6.4)	357
7	Green ash (15.4)	Dogwood (9.4)	Common chokecherry (8.7)	American linden (7)	Crabapple (6.7)	977
8	Green ash (22.6)	American linden (9.7)	Black ash (6.7)	Common chokecherry (6.5)	Amur maple (6)	1,385
9	Green ash (27.4)	Crabapple (10.4)	Freeman maple (8.5)	Hackberry (8.5)	Ponderosa pine (8.5)	106
Citywide total	Green ash (22.6)	American linden (10.9)	Black ash (7.5)	Common chokecherry (4.9)	Amur maple (4.8)	6,854

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