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A forested urban park : what is the value of Allan Gardens to the City of Toronto?

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By

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Abstract

A Forested Urban Park: What is the value of Allan Gardens to the City of Toronto?

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The purpose of this study was to conduct an assessment of Allan Gardens' urban forest and to investigate the value of environmental and aesthetic benefits it provides to the City of Toronto. This project used the Street Tree Resource Analysis Tool for Urban Forest Managers (STRATUM) model to assess forest structure, function, and monetary value of benefits. Soil in Allan Gardens was also investigated to determine the growing conditions for park trees.

Results indicate that Allan Gardens maintained 309 trees that provide $60,407 annually in net annual environmental and property value benefits to the City of Toronto. Soil conditions in the park were found to be highly variable, where some locations were highly compacted and may be restricting tree root growth. To sustain and enhance these benefits in the future, Toronto's urban forest requires dedicated management and maintenance that includes new plantings, but prioritizes protection and maintenance of existing trees and soil.

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List of Acronyms

AG - Allan Gardens

ALB - Asian Long-Horned Beetle

BD - Bulk Density

BVOC - Biogenic Volatile Organic Compound

dB - Decibel

DBH - Diameter at Breast Height

DR - Decomposition Release

GTA - Greater Toronto Area

IVal - Importance Value

KWh - Kilowatt hour

LA - Leaf Area

LAD - Leaf Area Density

LAI - Leaf Area Index

Mg - Megagram (1000 kilograms)

MR - Maintenance Release

MW - Megawatt (one million watts)

GIS - Geographic Information System

GJ - Gigajoule (one thousand million joules)

GWh - Gigawatt Hour (one thousand megawatt hours)

PFRD - Parks, Forestry and Recreation Department (City of Toronto)

PLAD - Potential Leaf Area Density

STRATUM - Street Tree Resource Analysis Tool for Urban Forest Managers

Therm - Heat Energy Equal to 100,000 British thermal Units (BTU)

UFORE - Urban Forest Effects Model

UFRED - Urban Forest Research & Ecological Disturbance Group (Dr. Millward, Ryerson U.)

VOC - Volatile Organic Compound

1.0 INTRODUCTION

1.1 Vegetation in the Cityscape

Urbanization is a process that occurs as cities grow and become more densely settled. It is manifest in a landscape of intermixed built and natural features – the cityscape. Urbanization is in large part driven by the requirement to support dynamic and expanding local economies. This growth triggers significant changes in both land use and land cover, which consequently affect the structure, pattern and function of existing ecosystems (McPherson et al., 2008; Wu et al., 2008). Urbanization increases the density and distribution of impervious land cover (Morrison, 2008), which has been shown to have a direct ill-effect on the well-being of human and non-human components of these ecosystems (Carreiro, 2008). Recent research investigating inhabitants of cities suggests that they are becoming increasingly stressed by environmental and social factors brought about by urban living (e.g., elevated summertime temperatures, congestion, air pollution (Marzluff et al., 2008)).

On a global-scale, urbanization has led to the following critical ramifications: long-term pollution, loss of productive-agricultural land, fragmentation and degradation of habitat, depletion of groundwater resources, contamination of surface waters and aquifers, and aberrant changes in biogeochemical cycles of both terrestrial and aquatic systems (Carreiro, 2008). For example, a recent study conducted in Toronto investigated the influence of impervious surfaces on the chemical dynamics associated with semi-volatile compounds (Wu et al., 2008). It concluded that many impervious surfaces (i.e., glass, concrete and asphalt) had measurable amounts of accumulated polychlorinated biphenyls (PCBs), which wash off during precipitation events and contribute to contaminant loads in urban aquatic ecosystems. These authors state that impermeable materials act as both dynamic source and sink for pollutants. Soil, on the other hand, serves as a long-term sink (Wu et al., 2008). In another example, a study in a highly urbanized district of California found that between 627,800 and 1.48 million annual gastrointestinal illnesses were caused by citizens swimming at contaminated beaches (Given et al., 2006); health care costs related to this were estimated at between $21 to $51 million (McPherson et al., 2008).

An important direction for the improvement of the aforementioned urbanization issues resides in (re)designing cities to be more efficient in their consumption of energy and materials, and in their disposal of waste (Carreiro, 2008). This can be approached by shifting development toward building resilient eco-cities, where an eco-city is focused on well managed resources, minimization of point and non-point pollution, and the provision of a rich variety of spatial structures prioritizing the integration of vegetation and natural cover amongst built spaces (Carreiro, 2008; Morrison, 2008). Abundant, dense and well distributed vegetation can greatly improve environmental quality and human health in urban areas.

Current research quantifying the benefits provided by healthy urban forests shows that trees provide numerous social, environmental, and economic services. Several of these benefits include: enhancing public health programs, reduction in the cost of city services, microclimate modification, air pollutant abatement, energy conservation, and stormwater runoff mitigation (McPherson and Simpson, 2002; Conway and Urbani, 2007; Escobedo et al., 2008; McPherson et al., 2008). Urban trees provide increased community attractiveness, improved wildlife habitat, and recreational opportunities; these qualities generally make cities more enjoyable, which as well as fostering psychological well-being have also been demonstrated to increase neighbourhood desirability reflected in real estate values (McPherson and Simpson, 2002).

The term urban forestry can be traced back to Jorgenson in 1965 when it was first introduced at the 46th International Shade Tree Conference (Knuth, 2005). Urban forests are composed of both publicly and privately owned trees, stands of trees, remnant forests, and all other forms of major vegetation found in areas that are both influenced and utilized by the urban population (Jorgensen, 1970). The more generally used term, urban greenspace, includes urban forests, but may also refer to vegetated areas such as playgrounds or sports fields with few to no trees present (Thaiutsa et al., 2008). Urban forestry is a specialized branch of forestry and its objectives include the cultivation and management of trees for their present and potential contribution to the physiological, sociological and economic well-being of the urban society (Jorgenson, 1974). The collective management of these vegetated spaces, urban forest management, is described as the planned, integrated and systematic approach to managing urban forests for their contribution of environmental, socio-psychological, and economic benefits to the broader wellbeing of the urban community (Knuth, 2005).

The concept of greening urban spaces grew out of beautifying movements in the United States and Europe during the mid-1800s (Carreiro, 2008). This included landscaping of public parks for relaxation and recreation, designing tree-lined avenues and restoring nature in town squares for aesthetic gentility. By the 1970s, forestry professionals recognized that city trees, in particular, provide the urban community with more than just social amenities. Over the next decades, research initiatives investigated, and began to quantify, urban forest ecological benefits. By 1978, the US government decided that urban trees and forests had sufficient purpose and distinct requirements that the division of Urban Forestry was established within the United States Forest Service (Konijnendijk et al., 2006; Carreiro, 2008). This department's role was to investigate and implement planning and management strategies involving the acquisition, restoration, and maintenance of urban green spaces in the US (USDA, 2003).

1.2 Benefits of the Urban Forest

At present, urban forestry studies are investigating four main themes: 1) economic costs and benefits of trees; 2) ecological and environmental services provided by trees; 3) social benefits and public perception of the urban forest; and, 4) urban forest policy (McLean et al., 2007). Research focused on the economic costs and benefits of the urban forest seeks to describe how urban trees impact the economy. The investigation of ecological services attempts to quantify the positive and negative influences of urban forests on the city environment. A focus on social benefits and public perception of trees elucidates the role of the urban forest in a social context (McLean et al., 2007). Public policy research is essential to both maintaining and enhancing the urban forest. Private and public-based research conducted in numerous cities and countries has acted to form a confluence of diverse knowledge required for identifying and improving approaches to the stewardship of the urban forest (McLean et al., 2007).

A benefits analysis is not without complications when considering the magnitude of factors influencing urban forests. Some of these challenges include: variation in urban growing conditions, the range of ecological functions performed by trees, and selection of methods for data collection and analysis. As a result, there are many procedures and interpretations described in the recent literature. In this research, the functional benefits derived from the urban forest are discussed in terms of ecosystem services. These services are identified as direct and indirect benefits city inhabitants and proximate communities can gain from such ecosystem functions; they provide important contributions to addressing local environmental problems.

1.2.1 Energy Savings

Studies in the US have found that urban vegetation and trees located in close proximity to buildings can lower air temperatures by as much as 3°C relative to areas of the same building not shaded by vegetation (Akbari et al. 1992; McPherson et al., 2006). Strategically planting trees around individual buildings, relative to daylight duration and the sun's position in the sky, are useful for increasing energy efficiency in both the summer and winter seasons. Common building materials are ineffective heat insulators and have high thermal capacities; large levels of heat energy are absorbed and conducted during the daylight hours (McPherson et al., 2006; Chen and Jim, 2008). This absorbed energy causes temperatures to increase throughout the building material; thermal heat transfer then acts to elevate indoor air temperatures.

During the summer, solar angles are low in the east and west for several hours each day (early morning and late afternoon) and high in the south during mid-day. This implies that south- and west-facing walls receive high levels of summer irradiance; this in turn warms interior spaces. Planting large shading trees along the south, and specifically the southwest walls, of a building reduces the occurrence of building material heating and thus decreases the energy required by air conditioners for interior cooling. By leaving the south-facing walls of a building bare, solar irradiance can warm interior spaces during the winter (McPherson et al., 2006). To this end, broadleaf deciduous trees are recommended for southern exposures in the northern hemisphere, as they do not retain their leaves during the winter. However, the bare trunks and branches of trees that shade south- and west-facing walls during winter may slightly increase heating costs by blocking winter solar irradiance (McPherson, 1984; McPherson et al., 2006). Urban vegetation and trees can lower outdoor temperature via evapotranspiration processes. Water transpired from leaf surfaces cools the surrounding air because the latent heat of vaporization from the ambient air is absorbed to convert liquid water into vapour. Previous studies in the US have indicated that on a hot summer day, a mature tree can transpire approximately 378.5 kg of water into the atmosphere (Kozlowski and Pallardy, 1997; Chen and Jim, 2008). Several authors report that energy consumption for indoor cooling may decrease by as much as 4% for every 1°C increase in outdoor temperature (McPherson et al., 1995; Jensen et al., 2003).

Finally, by acting as windbreaks urban trees reduce wind speed and can decrease air infiltration into buildings by up to 50%. This has been reported to translate into potential annual heating savings of up to 25% (McPherson et al., 2006). Wind-speed diminution reduces heat loss where thermal conductivity is relatively high (e.g., glass windows). Coniferous evergreen species (e.g., cedar, pine, spruce) are recommended for this purpose and can be optimally positioned to provide a barrier between the building and the prevailing wind (west to northwest in southern Ontario).

One effect of urbanization is the urban heat island, which often expands and intensifies as a city grows. Ventilation provided by winds dissipates the heat island, but increasingly stronger winds are required to overcome the trapped air in denser cities (Marzluff et al., 2008). For a typical city with 25,000 occupants, wind speeds of 5 m/s can eliminate the heat island; cities with a larger population of 1,000,000 require speeds of 10 m/s, and those with 10,000,000 may require speeds up to 14 m/s (Marzluff et al., 2008). City greening is a crucial step towards mitigating the urban heat island effect. Cooler building and pavement surfaces, brought about by the presence of urban vegetation, can potentially reduce air-conditioning loads by improving thermal comfort; this saves peak-demand electricity and money (Akbari and Konopacki, 2004; Hardin and Jensen, 2007). Moreover, lower urban air temperatures can decelerate the formation rate of ground-level ozone (O_3), which can have a significant effect on improving ambient air quality. In a remote sensing study conducted in Terre Haute, Indiana, US, Hardin and Jensen (2007) quantified the relationship between canopy density measurements and surface temperatures. Their results indicate that the leaf area (LA) of urban tree canopies was inversely correlated with urban surface temperatures. Urban commercial areas devoid of vegetation were measured, on average, to have surface temperatures of 32.5 °C while sylvan areas had temperatures as low as 21 °C. With every additional leaf canopy layer, daytime surface temperatures were found to decrease by approximately 1.3 °C (Hardin and Jensen, 2007).

The Centre for Urban Forest Research conducted a study that found protecting and enhancing urban forests was more cost-effective than building new power plants (McPherson et al., 2006). This study proposed increasing California's urban tree count by 28% in strategic planting locations such that the enhanced urban forest potential would improve so significantly that in 15 years it could provide $462 million annually in electricity purchasing and generation cost savings (McPherson et al., 2006). The end result would be the deferral of the requirement to build an equivalent of seven 100 MW power plants.

Another study conducted by Akbari and Konopacki (2004) investigated tree planting for potential energy savings and peak-power avoidance in the building sector of the Greater Toronto Area (GTA). Their results showed that a potential annual electricity savings of approximately 150 GWh and a peak-power avoidance of 250 MW (translating to $11 million in annual energy savings) could be realized with the implementation of strategies that aggressively remodelled tree planting design with the aim to improve shading and windbreak benefits.

1.2.2 Air Quality Improvement and Reduction in Atmospheric Carbon Dioxide

Air pollution is a serious urban issue and poses evident risks to human health, particularly for individuals suffering respiratory diseases such as allergic asthma or chronic obstructive pulmonary disease (Chen and Jim, 2008). In addition, air pollution has been shown to damage vegetation and building materials through acidic deposition. Common urban air pollutants include sulphur dioxide (SO_2), carbon oxides (CO_X), nitrogen oxides (NO_X), ozone (O_3) and particulates (PM_{10}) (Chen and Jim, 2008). Air pollutants are believed to be intercepted from the atmosphere by urban trees, mainly via dry deposition (Chen and Jim, 2008). This process occurs when gaseous and particulate pollutants are transported to, and absorbed into plants mainly through their leafy surfaces. In some situations, gaseous pollutants are absorbed into the plant via the stomata cells (Chen and Jim, 2008; Lovett et al., 2000). Other pollutants, such as SO_2 and NO_2, react with water found on inner-leaf cells to form sulphuric and sulphurous acids, and nitric and nitrous acids, respectively (Chen and Jim, 2008). These acids can further react with other compounds and are eventually transported to other plant cells, after which, assimilation processes fix the pollutants into the plant tissues (Chen and Jim, 2008).

Leaves, stems, branches, and trunks trap particles that are later washed off by precipitation. Tree canopies are effective at capturing particles due to their surface roughness, which increases turbulent deposition and impaction processes by inducing localized increases in wind speed (Chen and Jim, 2008). However, the effectiveness of this ecosystem service varies according to factors such as aerodynamic roughness, atmospheric stability, pollution concentration, solar radiation, temperature, wind velocity and turbulence, particle size, gaseous chemical activity and solubility. Nowak (1991) indicates that all of these factors must be taken into consideration when estimating the amount of air pollutants removed by urban trees on an annual basis.

Urban forests have been recognized as important sinks for carbon dioxide (CO_2); they directly sequester CO_2 to form woody and foliar biomass. Indirectly, trees planted strategically near buildings reduce the demand for heating and air conditioning, thereby reducing CO_2 emissions associated with electric power production and consumption of natural gas (McPherson et al., 2006). With regard to other air pollutants, urban trees improve air quality by absorbing gaseous pollutants (O_3, NO_2) through their leaf surfaces, by intercepting particulate matter (PM_{10} such as dust, ash, pollen), by minimizing emissions from power generation through reduced energy consumption, by releasing O_2 through the process of photosynthesis, and by reducing energy consumption, resulting in lower local air temperatures, thereby reducing the formation of ground-level O_3 (McPherson et al., 2006).

For instance, a study evaluating the effect of urban forest on air quality in Chicago found that the dense urban forest intercepted approximately 5575 Mg of air pollution in 1991 (McPherson et al., 1997). This included 223 Mg of CO, 706 Mg of SO_2, 806 Mg of NO_2, 1840 Mg of PM_{10}, and 2000 Mg of O_3, which provided a total savings of approximately US $9.2 million (McPherson et al., 1997). With regard to carbon sequestration, one study evaluated field data from 10 USA cities and found that urban trees in the US (as of 2002) store 700 million tonnes of carbon (a service valued at US $14,300 million) with a gross carbon sequestration rate of 22.8 million tC/yr (valued annually at US $460 million) (Nowak and Crane, 2002).

1.2.3 Stormwater Runoff Reduction and Hydrological Improvement

Urban stormwater runoff has been recognized as one of the major causes of environmental degradation to proximate water bodies. It has been demonstrated to alter the hydrological regime, sediment regime, physical habit structure, thermal modifications, and chemical inputs that affect water quality (Grapentine, 2008). Urban forests can reduce the amount of runoff and pollutant loading in receiving waters by two primary ways: 1) leaf and branch surfaces intercept and store rainfall, reducing runoff volumes and delaying the onset of peak flows; and 2) root growth and decomposition increase the capacity and rate of water infiltration into soil layers, and thus reduce overland flow (McPherson et al., 2006).

When rain falls on a tree canopy it moves toward the ground as throughfall or stemflow. Throughfall refers to precipitation that reaches the understory soil surface by passing directly through or dripping from a tree canopy, whereas stemflow is precipitation that reaches the understory soil surface after it is intercepted by leaves and branches and subsequently diverted to the tree bole (base) (McPherson et al., 2006). Otherwise, rainfall intercepted by the canopy that does not move to the underlying ground cover will evaporate into the atmosphere. Trees with relatively large crown and leaf surface areas provide significant storage for rainwater. This interaction between rainfall and tree canopy mitigates the urban runoff flow rate and reduces the runoff concentration time by way of temporary water storage on the canopy surface (Sanders, 1986; McPherson et al., 2006; Chen and Jim, 2008). Decreasing runoff volume reduces flooding hazard, surface pollutant wash out, and pollutant loading into receiving water bodies, which ultimately reduces municipal expenses for erosion control, stormwater control, and pollutant treatment. This is attributable to the city requiring fewer storm drains, and hence lowering the costs of constructing and maintaining drainage infrastructure, as well as the costs of processing stormwater at sewage treatment plants. Several factors influence the rainfall interception capacity of the urban forest: 1) forest structure, which includes species, age and stocking levels; 2) tree architecture, which considers leaf and stem surface area, foliation period, and storage capacity; and, 3) meteorological factors such as rainfall amount, duration, intensity and frequency of events (Xiao et al., 2000).

The mechanisms by which urban forests influence urban hydrology have been conceptualized, but few studies have quantified the processes involved and resulting benefits. One study conducted by Xiao and McPherson (2002) quantified rainfall interception by Santa Monica's street and park tree population, found that this city's approximate 29,000 trees intercepted 1.6% of annual precipitation, resulting with 193,168 m^3 of mitigated stormwater runoff (or an average of 6.6 m^3/tree), providing runoff benefits valued at a total of $110,890 (or $3.80/tree).

1.2.4 Aesthetics and Other Benefits

1.2.4.1 House Value

It has been documented that well-maintained street and yard trees increase the curb appeal of house properties (Peper et al., 2007). This has been supported by research comparing the influence of trees on residential property values. Findings suggest that people were willing to pay 3 to 7% more for properties boasting ample trees relative to homes with few or no trees (Peper et al., 2007). Anderson and Cordell (1988) studying this influence for 844 single family residences in Georgia and found that each large front-yard tree was associated with a 0.9% increase in sale price.

1.2.4.2 Noise Reduction

High frequencies are absorbed, deflected and refracted by leaves, twigs, and branches, making urban forests effective noise attenuators (Chen and Jim, 2008). A 30 m wide belt containing trees with sufficient crown width and density can effectively reduce noise ranging between 6 and 10 dB by 50%. Narrower tree belts also produce a similar noise reduction function: 3 to 5 dB can be effectively reduced by 3m wide tree belts (Nowak and Dwyer, 2000; Chen and Jim, 2008). Unfortunately, in compact urban spaces this amount of room is seldom available. So, trees and shrubs found in an urban landscape are more effectively employed as moderately effective noise screens at the source, rather than actual sound barriers (Chen and Jim, 2008).

1.2.4.3 Health and Psychological Services

While it is important to note that urban forest management depends heavily on knowledge of tree and urban ecological dynamics, arborists and urban foresters should also be familiar with the social complexities of the urban communities they serve (Johnston and Shimada, 2004). By landscaping and designing green spaces with trees and shrubs, the urban forest can make an important contribution to civic spaces where people can gather and mingle. Where appropriate, many urban forests are complemented with playgrounds, sport fields and outdoor theatres; this creates an inclusive recreational green urban system. When well-tended, urban forests and related public green spaces are positive symbols of landscape beauty, and provide residents with contrasts and diversions from the built cityscape. Several recent studies add to the results of Ulrich (1984) regarding the restorative functions of the natural environment (Chiesura, 2004; Chen and Jim, 2008); he found that the feelings and the emotions evoked in urban parks and public green spaces are perceived by people to be very important contributions to their well-being. The direct benefits include regeneration of psychophysical equilibrium, relaxation, break from the daily routine, and the stimulation of a spiritual connection with the natural world. All these perceived emotional and psychological benefits contribute to the quality of human life, which in turn is a key component of sustainable development (Chiesura, 2004). Unfortunately, the socio-psychological benefits of urban forestry, although intuitively recognized, continue to be advocated with limited public enthusiasm (Johnston and Shimada, 2004). In practice, urban forestry is as much about people as it is about trees; knowledge of trees is only half the equation (Johnston and Shimada, 2004).

1.3 Evaluation of the Urban Forest Canopy

Urban populations receive many environmental and aesthetic benefits from mature trees growing in the downtown core of cities. However, a general analysis of these benefits is, in and of itself, incomplete information to manage forested urban landscapes in an informed manner. Acquisition of data describing the structure of an urban forest, including tree species and canopy distribution, provides urban forest managers with a more comprehensive picture necessary to implement strategies that can maximize the forest's desired ecological functions (Duffy, 1999). In addition to urban forest benefit analyses, organizing current tree and canopy information into an updated inventory will inform park managers of the number, species, size, health, and distribution of trees. This can assist managers to plan for tree maintenance as required by growth stages, as well as for future tree loss and replacement needs.

McPherson (1998) stresses that quantifying tree canopy cover, tree health, and the potential for additional canopy cover, provides a strong foundation on which to invigorate interest in the urban forest and its potential positive impacts within cities. i-Tree is a peer reviewed software suite developed by the USDA Forest Service to provide urban and community forest analysis and benefits assessment tools. These tools include the Urban Forest Effects Model (UFORE) and Street Tree Resource Analysis Tool for Urban Forest Managers (STRATUM) (i-Tree, 2006). Measuring canopy cover is one way to evaluate how much forest a city supports, relative to other land types (e.g., residential, industrial, commercial) (Morrison, 2008). A healthy urban forest sustains canopy coverage ranging from between 30 and 40% (City of Toronto, 2008).

There is plenty of evidence in the literature that employs canopy cover as a representative factor illustrating the wellbeing of an urban forest (Nowak and Crane, 2002; Kenney, 2008). The Town of Oakville's current urban forest has 29.1% canopy cover, and is considered a healthier urban forest than the City of Toronto's, which is at about 17.5% (McNeil et al., 2006; Morrison, 2008). However, it is important to note that this story fails to recognize differences in each urban forest's species composition and tree condition, both of which play a central role in the amount of realized ecological benefits (Kenney, 2008). Differences in function can be accounted for by the variance in both size and structure of tree species, and more specifically to their respective LA, and canopy densities. Accurate estimates of tree LA and leaf biomass are critical in measuring and modelling an urban forest's physiological and functional processes, which include evapotranspiration, atmospheric deposition, biogenic volatile organic emission, and light interception (Nowak, 1996). Therefore, estimating an urban forest's leaf area index (LAI) would be more informative than estimating its percent canopy cover (Kenney, 2000; Kenney, 2008).

Kenney (2000) maintains that LAI is a valuable measure that provides constructive insight into an urban forest's structure. LAI is a dimensionless variable, and is defined as the estimate of the sum of all leaves on a plant (or a group of plants) relative to the ground area occupied by that plant (or plants) (Kenney, 2000). Leaf area density (LAD) is a similar measure, and is defined as the estimate of the sum of all the leaves on all the plants relative to the total land area, (e.g., area of an urban park). Moreover, LAD can be considered as: 1) existing leaf area density (LAD), described as the leaf area presently supported by an area; and, 2) potential leaf area density (PLAD), described as the maximum supportable leaf area given the specific site characteristics (e.g., plantable space).

To further explain the aforementioned LAD, consider two plots of land, each 1 hectare in size with a canopy cover of 50%. In the first plot, the canopy cover is composed of 120 small stature trees, with a leaf area of 100 m^2 per tree, or a total leaf area density of 12,000 m^2/ha. The second plot has its canopy cover composed of 70% small stature (LA=100 m^2) and 30% medium stature trees (LA=250 m^2). The leaf area density is 14,500 m^2/ha, which is a 20% increase over the plot composed of only small stature trees. Consequently, the benefits resulting from the forest in the second scenario would be expected to be greater than the first. Considering leaf area density rather than the canopy cover also makes it possible to recognize species differences, because tree species vary in their shading ability (Duffy, 1999).

Studies maintain that successful urban forest management requires some indication of an area's potential to expand leaf area (McPherson, 1998; Kenney, 2008). The city of Toronto's current mayor, David Miller, has expressed interest in increasing Toronto's current 17.5% canopy cover to 34% within the next forty years (Irvine, 2007). Yet without knowing Toronto's carrying capacity to support additional trees, planners are unaware of the practical possibilities of reaching this goal; LAD may be very useful in this regard. The use of LAD and PLAD are also applicable on a more local scale, such as within urban parks.

1.4 Urban Soil Conditions

In heavily built urban locations, natural spaces are commonly 'containerized' into spaces designated by urban planners for "greenery". These spaces are often intertwined with infrastructure systems, and are physically constrained to a degree that renders their living systems vulnerable, and when left untended, they quickly degrade. Soil is an essential component in these 'green spaces'. Healthy soils have the potential to positively influence the vitality of an urban forest ecosystem (Craul, 1999). This is due to the fact that the physical ability of roots to grow and access nutrients, water, and oxygen is dependent on both the physical and chemical properties of soil (Coder, 2000). An ideal soil has approximately 50% pore space, which is shared equally with air and water; 45% is composed of mineral materials, and the final 5% of organic material (Daniels and Haering, 2006). However, urban soil is seldom found in the aforementioned condition. This is due, in large part, to these soils being commonly fill-derived, compacted, excavated, and poorly developed (Coder, 2000).

Soil compaction refers to a process whereby soil particles are forced into a closer state of packing with a corresponding reduction in volume and expulsion of air (Whitlow, 1995; Kozlowski, 1999). Vibrations due to traffic movement, heavy machinery, and repeated passes of light equipment all eventually compress soil and break down soil aggregates (Whitlow, 1995; Coder, 2000). Compression also increases the bulk density and reduces the ability of air and water to permeate through the soil medium (Coder, 2000). The degree to which soil becomes compacted is dependent on: 1) texture; 2) water content; 3) pH levels; 4) cation-exchange capacity; 5) clay particle thickness; 6) availability of organic matter; 7) iron oxides; and, 8) concentration of free aluminium hydroxide (Kozlowski, 1999). Generally, soils with a high clay content are readily compacted, especially when wet, whereas dry soils resist compaction due to their stiff matrices, high degree of bonding particles and frictional resistance to deformation (Kozlowski, 1991). Interestingly, as a soil approaches saturation, the proportional volume of air that can be expelled by exerted forces (that cause compaction) is decreased, so the said force cannot compact the soil as much as it could in marginally wet conditions (Hillel, 1982).

In urban parks, many human activities regularly impact soil aggregates causing a loss of pore space, which in turn leads to soil compaction, increased soil erosion and surface runoff (Kozlowski, 1999). A study conducted in Hong Kong found that urban parks exhibited seriously degraded soil conditions attributable to trampling caused by high foot traffic (Jim, 1998; Paudel, 2008). Additionally, due to the lack of open space availability as a result of intensification of urban land there has been a substantial increase in usage of urban parks within cities. This has lead to urban park soils experiencing nutrient and organic content deficiencies, and high levels of soil compaction, which in turn lead to root growth restriction, respiration diminution, and retarded rainfall infiltration (Jim, 1998; Paudel, 2008; Toleti, 2008).

Bulk density (BD) can be used to evaluate an urban park's soil's structure. It is not an intrinsic value of soil, rather it varies depending on many conditions (Whitlow, 1995), and is defined as a measure of the weight of soil per unit volume (g/cm^3) (Craul, 1999). Factors such as the porosity and specific gravity of soil particles (organic and inorganic) determine the variation in BD from one site to the next (Craul and Patterson, 1989; Trowbridge and Bassuk, 2004). Intensive pedestrian use of parks increases soil compaction. In Washington D.C., this caused compaction in several urban parks resulting in an increase in soil BD from a range of 1.2 to 1.6 g/cm^3 to a range of 1.7 to 2.2 g/cm^3 (Trowbridge and

Bassuk, 2004). This increased BD range is higher than the 1.39 to 1.69 g/cm^3 threshold identified by Hanks and Lewandowski (2003) (Table 1.1), and thus points to a significant impairment of successful plant growth.

Table 1.1: Relationship between soil bulk density and root growth
Source: Adapted from Hanks and Lewandowski (2003)

Soil Texture	Ideal BD (g/cm^3)	Potential Harm to Root Growth (g/cm^3)	Root Growth Restriction (g/cm^3)
Sands, loamy sands	<1.60	1.69	>1.80
Sandy loams, loams	<1.40	1.63	>1.80
Sandy clay loams, clay loams	<1.40	1.60	>1.75
Silts, silt loams	<1.30	1.60	>1.75
Silt loams, silty clay loams	<1.10	1.55	>1.65
Sandy clays, (35-45% clay)	<1.10	1.49	>1.58
Clays (>45% clay)	<1.10	1.39	>1.47

Increasing BD leads to decreased rainfall infiltration rates, which in turn causes soil water deficits, mineral nutrients leaching, surface runoff, sheet erosion and gully formation. In addition, sub-surface soil horizons with higher BD values than soil layers above them will inhibit both air and water infiltration into deeper soil horizons (Craul, 1999). When soil compaction encroaches into the first metre of depth (location where 90 percent of tree roots exist) (Jim, 1998; Toleti, 2008), the effects of compaction lead to conditions that make it difficult for tree roots to penetrate soil layers, thus constraining the size, reach and extent of root systems (Kozlowski, 1999; Coder, 2000). Also, it shifts soil conditions toward an anaerobic state. Aerobic conditions at the rooting zone are necessary for the synthesis and maintenance of cell membranes; lack of O_2 renders the roots incapable of producing enough energy required for the uptake of necessary nutrients and water (Kozlowski, 1999; Coder, 2000). Soil oxygen restriction has been demonstrated to reduce elongation and radial growth of roots, resulting in long-term tree survival problems (Coder, 2000).

1.5 Street Trees and Urban Parks

According to Sæbø et al. (2003), street trees are exposed to a relatively high stress level and because of this exposure their average life span is short. In contrast, trees growing in urban parks are exposed to moderate stresses and, relative to street trees, their average lifespan is comparatively longer.

Therefore, as urban parks serve as important green spaces, it would be prudent management practice to work toward lessening the stress these trees face so as to maximize their functional capabilities. Structurally larger, and older, trees provide greater benefits relative to younger trees with smaller canopies. Streets trees seldom live as long or grow as big as park trees, so unless there is a city-wide investment in tree box re-examination and reconstruction to vastly improve growing conditions, the degree of benefits derived from these trees will always be less than the benefits derived from open-grown trees with comparatively larger canopies. In addition, because the renovation of tree boxes on a city-wide basis would be extremely costly to the public, improving growing conditions in green spaces (e.g., backyards) and in urban parks is a much more feasible goal.

To date, there has been very little written about the potential of forested urban parks to play a role in the provision of environmental benefits for cities. One exception to this may be the comprehensive field monitoring data reported by Lam et al. (2005), which warned that inadequately designed and managed urban parks in an extremely dense city (Hong Kong) were limited in their ability to improve issues of both air and noise pollution.

1.6 Goal and Objectives

The overall goal of this study was to conduct an assessment of Allan Gardens' urban forest and to investigate the value of environmental and aesthetic benefits it provides to the City of Toronto. Specifically, this study examined the structure and spatial distribution of the trees within the forested urban park, in order to conduct a comprehensive accounting of forest benefits. It aimed to provide baseline information for the evaluation of a future urban forest management program. In addition, it investigated the environmental quality of the urban park with respect to soil condition and tree canopy density. This was done using a comprehensive measurement program undertaken to build upon a previous tree survey (Aboud and Associates Inc., 2006) and soil analysis (Toleti, 2008) conducted in the park.

To achieve the study goal, five objectives were identified:

1) Inventory tree and soil resources;
2) Design and populate a spatial database with collected data;
3) Run the STRATUM model to both document the current state of Allan Gardens' urban forest as well as to evaluate its environmental and aesthetic benefits;
4) Generate and interpret soil condition surfaces (maps) for the park; and,
5) Document and synthesize the current status of Allan Gardens' tree and soil resources as well as potential park vulnerabilities and future management recommendations.

2.0 STUDY SITE

Research was conducted in Allan Gardens, a forested urban park located in downtown Toronto (79.42W, 43.67N, 100 m elevation) (Figure 2.1). The City of Toronto has an area of 63,000 ha, and at the time the study was conducted it had a population of approximately 2.5 million. Within the city, Allan Gardens is bounded by Jarvis Street to the west, Gerrard Street East to the south, Sherbourne Street to the east, and Carlton Street to the north. From this point forward Allan Gardens will be referred to in the text as AG. The park was named after and donated by George William Allan, a one-time mayor of Toronto and long-time senator. AG was first established in the 1860s, and presently houses a Victorian-style conservatory known as the Palm House in which the City of Toronto operates a botanical garden. The park's total area is 6.1 ha, whereas its pervious surface (plantable ground) amounts to 4 ha. Its urban forest is maintained by the City of Toronto's Parks, Forestry and Recreation Department (PFRD) and the City of Toronto's Urban Forest Services, South District Office.

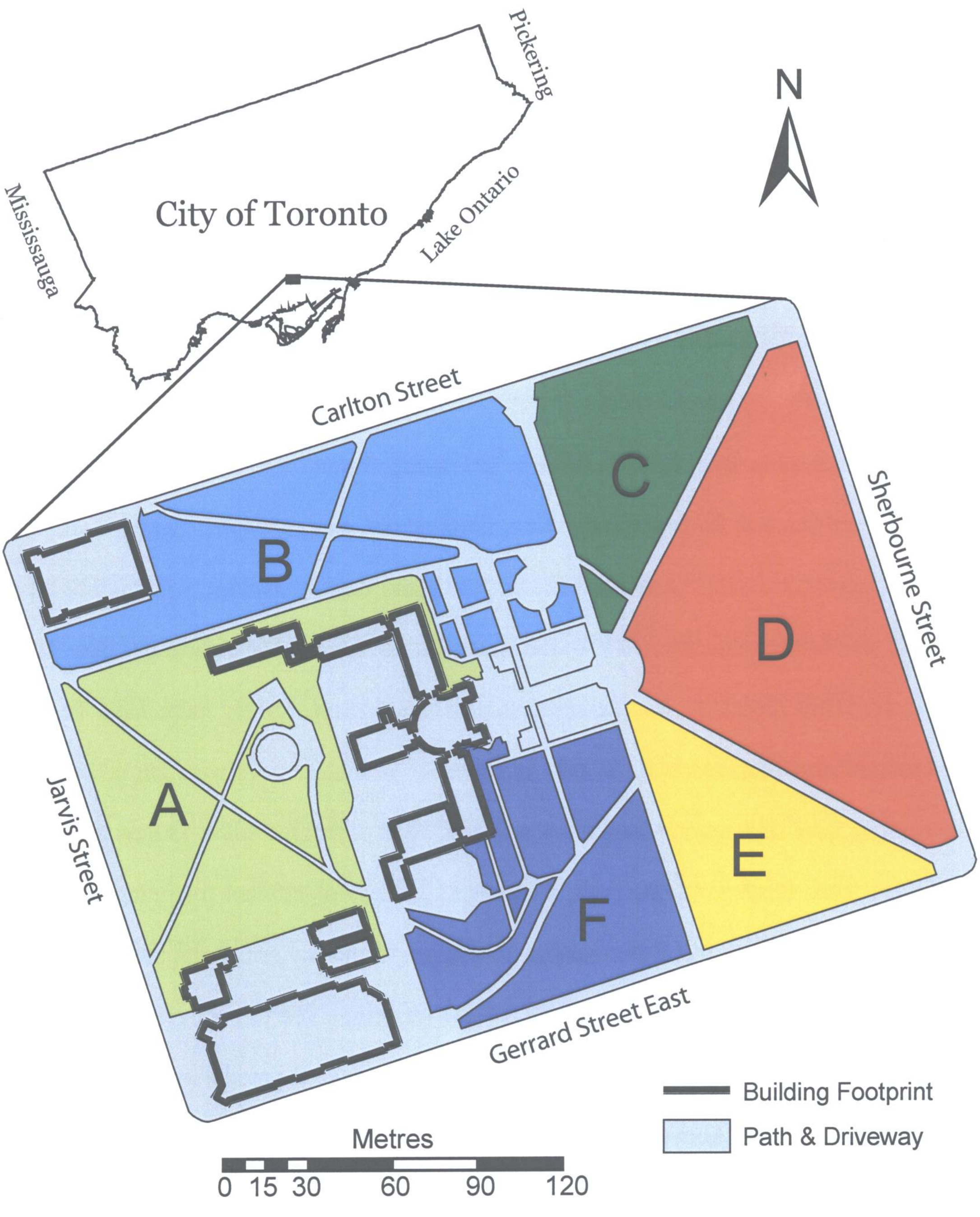


Figure 2.1: Study site: Allan Gardens Park, Toronto
Sectors labeled A through F are for interpretive purposes.
Source: Urban Forest Research & Ecological Disturbance (UFRED) Group, 2007

3.0 METHODS

3.1 Field Research

A combination of research methods was employed to determine: 1) AG urban forest structure; 2) the monetary value of environmental services provided by AG trees; and, 3) the interactions that may influence the wellbeing of the urban forest (i.e., the relationship between tree health and soil characteristics). These investigations required the analysis of tree and canopy resource structure, and specific soil conditions found in AG. A description of these methods follows.

3.1.1 Tree Analysis

Data was collected to describe tree characteristics in AG during the summer of 2007 and 2008. Tree and canopy characteristics included: species composition, biodiversity, canopy depth, canopy width, drip-line area, canopy area, canopy volume, Leaf Area Index (LAI), and canopy density. Although two previous inventories exist, the first conducted in 1976 and a second by Aboud and Associates Inc. (2006), an updated and reorganized inventory was essential to this study. Since 2006, there have been various plantings and several important removals in AG: 1) a total of 14 mature trees were cut down; 2) 5 trees, though still standing, have died and no longer leaf out; and, 3) as of August 2008, 13 new trees have been planted in various areas throughout the park. Documenting these significant alterations, by way of a detailed inventory, is essential to the demonstration of changes in the environmental services provided by the park's urban forest. Furthermore, because STRATUM was employed to conduct an analysis of AG, additional information not available in the 2006 inventory was required for model input.

In the 2006 inventory (Aboud and Associates Inc., 2006), the arborists lumped trees of similar species or cultivated variety found at the same location into one 'group' tree. This was found with six Japanese Yews, five Kentucky Yellowwoods, seven Amur Maples, and five Alaska Cedars. For input into STRATUM, this method of aggregation was limiting due to the fact that each tree provides benefits relative to its physical characteristics. Clumping a number of same-species trees together exaggerates the physical attributes of the 'group' tree (e.g., crown dimensions), affecting further calculations involving this 'group' tree's structure and allometrics. Also, if any of the contributing trees were removed for any reason, it would be difficult to display this change in the inventory directly, or in calculations indirectly dependant on these quantified tree features (e.g., canopy density).

In this research, leaf area data were determined by employing one of two regression equations suitable for all tree species in AG. These linear models were developed by Nowak (1994, 1996) for open grown deciduous trees using different tree morphological variables. The STRATUM model estimates leaf area using the allometric relationship between total leaf area, crown outer surface area, and trunk diameter at breast height (DBH) using a shading factor of 0.83, such that:

$$\ln Y = b_0 + b_1X + b_2S \quad (r^2 = 0.64) \tag{1}$$

where Y is leaf area (m^2), X is DBH, and b_0, $b_1$and b_2 are regression coefficients. S is based on the outer surface area of the tree crown. A description regarding how S is calculated is found in Equation 3.

In addition, this study ran a separate and parallel investigation of leaf area evaluation in AG to compare with the total value produced by STRATUM. In this study, total leaf area was estimated using tree crown parameters, such that:

$$\ln Y = -4.3309 + 0.2942H + 0.7312D + 5.7217Sh - 0.0148S \quad (r^2 = 0.91) \tag{2}$$

where Y is leaf area (m^2), H is crown depth (m), D is crown width (m), Sh is the shading coefficient (defined as the percent of light intensity intercepted by foliated tree crowns and is considered to be different for individual species, and thus investigated separately), and S is based on the outer surface area of the tree crown.

S is calculated according to:

$$S = D\,\pi\,((H + D)/2) \tag{3}$$

and, leaf area index (LAI) is calculated such that:

$$LAI = Y/G \tag{4}$$

where G is drip-line area and is calculated according to:

$$G = \pi\,(D/2)^2 \tag{5}$$

While shading coefficient (Sh) values are specific to each tree species, little in the way of literature discussing Sh for many of the 45 tree species located in AG could be found. Despite acquiring 25 Sh values from Nowak (1996) that were derived from a study conducted by McPherson (1984), these data were not fully representative of AG trees because they were based on measurements describing open grown, medium-sized, mature trees with full crowns. Equation 1 and 2, with published Sh values, estimate near-maximum leaf area for an individual urban tree in its present size, and the equations work on the assumption of perfect tree health. Peper and McPherson (2003) evaluated four methods for estimating leaf area of two tree species (London Plane and California Sycamore) in an urban setting. They determined that applying Equation 1 and 2 generally overestimated leaf area. They attributed this overestimation of true leaf area to the McPherson (1984) shading coefficient values that they employed. They maintain that due to the differences between their study site's tree structures and those investigated by McPherson (1984) and Nowak (1996) contributed to their inaccurate estimates. Knowing this, it was important that this study utilized Sh values based on measurements taken in AG for all 45 tree species.

Many of AG's trees are either younger or larger than those studied by McPherson (1984) and Nowak (1996). Therefore, this study benefits from determining shading coefficients that are more faithful to AG tree characteristics for three reasons: 1) the trees investigated by McPherson (1984) were structurally different when compared with trees in AG; 2) the methodology used to obtain shading coefficients in 1984 was different from that employed in this research's study, which could lead to a more accurate estimation of shading coefficients; and, 3) shading coefficient values are not reported in the literature for all AG's tree species. For reasons of consistency, it did not seem justifiable to only collect the missing Sh values and amalgamate these with those reported in the literature.

3.1.2 Methodology and Instrumentation

A field inventory to document the present canopy structure, species diversity and tree conditions was conducted during summer 2007 and June 2008. These data were used to supplement information available in the 2006 inventory conducted by Aboud and Associates Inc.. For each tree in AG, species, condition, height, crown height, crown width, and DBH were collected (Table 3.1; Figure 3.1). Each tree was assigned an updated identification number and individually tagged with a permanent, City of Toronto, numbered aluminium disk.

Collected as part of this research	Required for	Integrated from 2006 Inventory	Required for
Diameter at Breast Height (cm)	Updated AG Inventory	Tree Species	STRATUM & Updated AG Inventory
Tree Height (m)	Updated AG Inventory	Tree Structural Condition	STRATUM & Updated AG Inventory
Crown Width (m)	Updated AG Inventory & LAI calculations & Canopy evaluation		
Crown Depth (m)	Updated AG Inventory & LAI calculations & Canopy evaluation		
Tree Condition	STRATUM		
Bark condition			
Leaf condition			
Overall tree health			
Shading coefficient & Leaf Area (m^2)	Canopy evaluation & LAI		

Table 3.1: Summary of the data collected for each tree in Allan Gardens Park

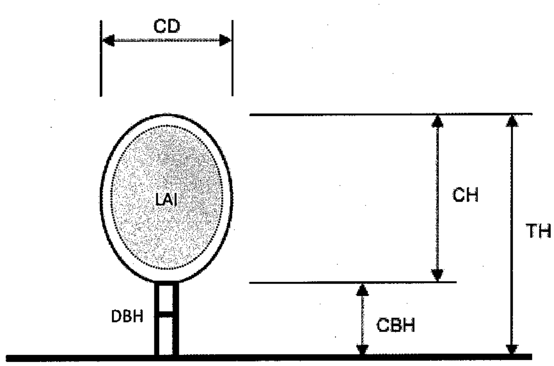


Figure 3.1: Tree measurements
Tree Height (TH), Crown Height (CH), Crown Base Height (CBH), Crown Diameter (CD), Leaf Area Index (LAI), Diameter at Breast Height (DBH). Source: Stoffberg et al. (2008)

Tree species identification was completed with the aid of the 2006 inventory by Aboud and Associates Inc. Each tree's species was identified in the inventory and further confirmed using a dichotomous key found in Farrar (1995). A dichotomous key is an essential tool that is employed to identify a tree by using the key's descriptions of crown structure, bark texture and colour, leaf shape, colour and texture, twigs shape, flowering parts, and other distinguishing characteristics. Each key's description is divided into two parts or classifications (e.g., is this tree's bark smooth or rough?) that allow the identifier to narrow down the unknown tree to a final classification (Nix, 2009). All newly planted trees were identified in this manner.

DBH was initially collected as tree circumference (cm) using an ordinary calibrated measuring tape at 1.4 m above ground level. The DBH value was then calculated by dividing the value of its circumference by the value of π (assuming a trunk of circular shape). In circumstances where a tree trunk forked into stems below the 1.4 m mark, all the stems were considered and each was measured individually.

Tree height (m) was determined using a percent scale clinometer and metric measuring wheel. Standing along the horizontal baseline of the tree at a measured distance (where both the top and the base of the tree were observable through the clinometer), the percent value observed on the scale when levelling the mark at sight of the top of the tree was recorded. Subsequently, by pointing the clinometer at the bottom of the tree (where trunk meets ground) the base percent reading was noted. The tree's height was then determined by subtracting these two percents to give the percent of the measured distance that is the tree's height. Such that,

$$\text{Total \% Height} = \text{Top\%} - \text{Base\%} \tag{6}$$

then,

$$\text{Tree Height (m)} = \text{Total \% Height} \times \text{Horizontal Baseline Distance (m)} \tag{7}$$

Crown width (D) was measured using a metric measuring wheel. Tree crown drip-line was projected onto the ground and the length along one axis from edge to edge was measured, with the trunk designated as the centre. Due to the irregularities of each tree's crown structure, it was reasonable to measure the diameter of the maximum axis (a-b) and then the axis at 90 degrees to that (c-d). The two axes were then averaged arithmetically to give the final crown width value. Such that,

$$\text{Crown Width (D)} = [(a\text{-}b) + (c\text{-}d)]/2 \tag{8}$$

Each tree's crown depth (H) was determined using a percent scale clinometer and a metric measuring wheel. Standing along the horizontal baseline of the tree at a measured distance, the top percent reading value on the scale when levelling the mark at sight of the top of the crown was recorded. This was repeated for the bottom of the tree's crown. After calculating the heights of these two points relative to ground level, they were subtracted to give an estimate of the crown depth. The bottom of the crown was considered to be at an imaginary horizontal line drawn across the trunk at the bottom of the lowest live foliage. This bottommost point of the crown is described as the level at which most live branches above which are continuous and typical for that particular tree species (and/or tree size). In cases where there were many water-shoots growing on a tree, the bottom of the crown was considered to start at the first branch (from the ground looking up) that had a basal diameter equal to or greater than 2.5cm.

Crown surface area (Ca) is the area available for a tree's leaves to intercept atmospheric gases, deposit pollutants, and filter out the sun's radiation (Brack, 1999). It is estimated assuming a solid geometric shape for the crown, and knowing crown depth and width values for the individual tree. During data collection, all tree crown shapes were considered and designated as either conoid or paraboloid. The conoid shape was assigned to trees whose crown displayed a more triangular shape, either due to past pruning activities or as a result of natural crown shape (i.e., coniferous trees). The paraboloid shape was assigned to trees whose crowns displayed a more circular shape; most deciduous tree species possessed this crown type. Ca, measured in m^2, for both conoid and paraboloid crown shape was calculated as follows (Brack, 1999):

Conoid: $Ca = (\pi D)/2\ [(H^2 + (D/2)^2]^{0.5}$ (9)

Paraboloid: $Ca = [(\pi D)/(12H^2)((D^2/4) + 4H^2)^{1.5}] - D^3/8$ (10)

Crown volume (Cv) is calculated from the crown width (D) and depth (H). Cv, measured in m^3, was also estimated after assuming one of the two geometric shapes (Brack, 1999):

Conoid: $Cv = \pi\ (D^2H/12)$ (11)

Paraboloid: $Cv = \pi\ (D^2H/8)$ (12)

For the most part, the evaluation of tree condition relied on the 2006 inventory by Aboud and Associates Inc. In situations where there was evidence that a tree's biological and/or structural issues noted by the arborist had been resolved by forest maintenance activities, the health rating was adjusted. All newly planted trees were identified as healthy provided they did not exhibit excessive pest damage or vandalism. In some cases, newly planted trees suffered from the drought conditions present during summer 2007.

Collection of direct LAI measurements for all trees in AG was not conducted as part of this study. Instead, direct measurements to determine the LAI values for select trees, based on species, were taken. With these measurements, indirect methods were applied to estimate the LAI of all AG trees. Specifically, hemispherical photos were taken of 45 trees representative of the tree species present in AG. Photographs were taken on July 22nd, 2008 under fairly uniform overcast conditions so as to minimize the anisotropy of the sky radiance. The images were taken using a Coolpix 8400 equipped with a fisheye adapter Nikon FC-E9 lens, (Nikon Inc., Japan), which was levelled and adjusted on a tripod at different locations underneath the tree canopy. Two pictures were taken of each representative tree at varying distances between the tree trunk and edge of the drip-line. Each photo location was checked to ensure that the photo captured the examined tree crown most fully.

The hemispheric photos were saved as JPEG images and downloaded for processing on a personal computer. After ensuring that each photo contained a full and unobstructed view of the investigated tree crown, the photo was loaded into a hemispherical photo evaluating program (HemiView Ver. 2.1), for LAI analysis. HemiView required the following inputs: 1) camera and fisheye lens specifics; 2) day and time of photo acquisition; and, 3) AG site properties (latitude, longitude, and altitude). All images were then aligned north to south in the software; this was essential for LAI calculation.

Images were classified to assist HemiView to distinguish between the visible and obscured sky (i.e., distinguish the canopy openings from the foliage). This was achieved by converting the continuous tone display (colour digital image) into a binary display where all visible sky was classified as white, and all items obstructing sunlight as black. To do this, a threshold intensity value was established, above which the image was classified as visible, and below which it was classified as obscured. This threshold intensity was achieved by toggling back and forth between the binary display and the continuous tone display for each photo, while increasing or decreasing the threshold value until edges of the classified image best matched the obscured sky edges of the continuous tone image.

Once it was determined that the threshold intensity level produced a binary image that corresponded well with sky visibility at the time of photography, a section of the image that encompassed at least 30% of tree canopy was selected. This selection was made to minimize the area of tree branches and trunks influencing the LAI estimation. This is due to the fact that tree limbs do not contribute to the LAI value by definition, and thus, their inclusion in LAI analysis would lead to an exaggeration of the final output value. Because limbs appear as black in the binary image, it was important to toggle back and forth between the continuous tone image and the binary tone to visually assess the area of the canopy that had both the lowest number of tree limbs displayed as well as foliage volume that was representative of the entire tree canopy. After selecting this area of the canopy HemiView produced estimates of LAI for the tree species captured in each image. As there were two images collected for each tree, the arithmetic mean of the output values was taken. This produced 45 LAI values, one for each tree species in AG.

To determine the shading coefficient (Sh) for each species, Equation 2 was rearranged as follows:

$$Sh = ((\ln [LAI \times G]) + 4.3309 - 0.29424H - 0.7312D + 0.0148S)/5.2717 \quad (13)$$

LAI values were then submitted to Equation 13 to determine the Sh values of the 45 species investigated. For example in the case of Tree# 127 (Black Walnut), the LAI value was be multiplied with the drip-line area of the canopy for that respective tree (G), producing Tree # 127's leaf area (Y). This value was then used in equation 13 along with Tree # 127's H, D, and S values; solving this equation provided the Sh value of Black Walnut species. This Sh value was then compared to the reference values (where available) obtained from McPherson (1984), and evaluated for similarity. After the acquisition of this Sh value, LAI values were estimated for all the remaining Black Walnut trees found in AG using Equations 2 through 5, and repeated for the remaining tree species.

LAI values for deciduous urban trees whose morphological characteristics exceeded the limitations of the equation (i.e., $H > 12$ m, $D > 14$ m, $0.5 > H/D > 2$, and / or $S > 500$) were calculated using an extrapolation of leaf area for similar trees (Nowak and Crane, 2004). For these trees, average LAI was calculated using Equation 2 for the maximum allowable tree size based on the appropriate crown height, crown width, and crown height to width ratio for the tree in question. Height and width values greater than 12 m and 14 m, respectively were 'capped' at these measurements and used in Equation 2; all other inputs were unaltered (D. Nowak, personal communication, October 28th, 2008). Where trees had an S value that exceeded 500 m, crown height and width were similarly 'capped' at the maximum allowable values. For trees with crown height to width ratios that were less than 0.5 or greater than 2, the ratio was scaled up to reach the minimum, or down to reach the maximum ratio allowable. Equation 2 was then solved with the final leaf area, produced by Equation 5, and scaled proportionally to the corrected leaf area value for that specific tree (D. Nowak, personal communication, October 28th, 2008).

3.2 STRATUM Analysis

This study used the STRATUM model version 3.4, part of the i-Tree software suite, to evaluate the tree resource in AG (i-Tree, 2006). STRATUM is a non GIS-based program, and is utilized as an urban forest analysis tool that employs either a sample or, as in the case of this study, a complete inventory of tree data. Its function is to describe tree management needs, and to quantify the value of annual environmental and aesthetic benefits provided by an urban forest (i-Tree, 2006). STRATUM has been used by communities to assess their street tree resource; this study employs it at the neighbourhood scale to assess the benefits of a forested urban park. By examining an urban forest with this tool, it is expected that managers can better understand trees as a resource, and develop informed management plans to ensure their health and longevity.

STRATUM uses growth curves for significant urban tree species found in each respective climate zone contained in the model's database, along with other regionally specific data, such as climate data, building construction and energy use patterns, fuel mix for energy production, and air pollutant concentrations. STRATUM uses this information to calculate: (1) urban forest structure (species composition, extent and diversity); (2) urban forest function (the environmental and aesthetic benefits trees provided to the urban community); (3) urban forest value (the annual monetary value of the benefits provided and costs accrued). The reports generated by STRATUM allow urban forest managers and planners to interpret the complexity of AG's tree resource and to evaluate its management needs (i.e., diversity, canopy cover, planting, pruning, and removal). With these report interpretations, urban forest managers and planners are supported with quantitative information that allows them to lobby for additional municipal funding, create public enthusiasm, involvement and investment, and to promote sound decision making relative to AG's urban forest.

Current research on urban forests commonly use another i-tree tool, the Urban Forests Effect Model (UFORE), to evaluate its resource complexity and functions. However, this study elected to use STRATUM over UFORE for the following reasons: (1) STRATUM allowed this study to perform a full inventory of the AG tree resource, whereas UFORE would have required performing sample inventories throughout the study site; (2) STRATUM is a non-GIS based analysis tool, which requires only basic inventory data, whereas UFORE requires three categories of data (field inventory, meteorological, and air pollution concentrations and boundary layer heights); (3) STRATUM is designed for analyzing street tree populations, and the design of the model allowed this study to tailor the model to fit the scale of an urban park, UFORE would have not easily permitted scaling of the model down from its intended city-wide analysis; and, (4) STRATUM is a computer application that allows for in-house report generation, yet UFORE requires all collected data be sent to Syracuse, New York, for processing with results returning to the principal investigators within 2-6 weeks.

In addition to the data collected in the aforementioned inventory, STRATUM requested formatted information be organized according to the following specific field names, and in the following order: (1) TreeId; (2) Zone; (3) StreetSeg; (4) CityManaged; (5) SpCode; (6) LandUse; (7) LocSite; (8) DBH; (9) MtncRec; (10) PriorityTask; (11) SwDamg; (12) WireConflict; (13) CondWood; (14) CondLvs.

The following are specific descriptions for each (i-Tree, 2008):

TreeId is the tree identification number. This is the unique number assigned to each tree in AG that permitted identification. *TreeId* numbers ranged from 1 – 309.

Zone is the particular name of a managed area within a city where the tree is located. STRATUM permits up to 20 zones within an analysis. Because this feature was not applicable to this study (all AG trees are in the same location), a value of one was assigned to all trees.

StreetSeg is interpreted as street segment. This is a numeric code used to identify the street segment within a city where the tree is located. Again, this feature was not applicable to this study due to all the trees being located in the same area. The value zero was assigned for each tree.

CityManaged is a numeric code used to distinguish city owned and managed trees from privately owned and managed trees. If the tree is owned by the city then the value one would be assigned, if it was privately owned the value two was given. In the case of AG, all trees are city owned and managed, so the value one was assigned to each.

SpCode identifies species code. This is a 4 letter alphanumeric code used to identify each tree species. It consists of the first two letters of the genus name, followed by the first two letters of the species name. For example, the species code for Tree of Heaven (*Ailanthus altissima*) would be AIAL. In the case of Sugar Maple (*Acer saccharum*) and Silver Maple (*Acer saccharinum*) trees, the codes ACSA1 and ACSA2 were assigned to each respectively.

LandUse is a numeric code used to describe the area where the tree is growing. The values selected in this study were one for Park and two for Sidewalk.

LocSite refers to the location of the tree on the study site. This is a numeric code used to describe the specific location where the tree is growing. The values assigned for this study were as follows: Grass - one; Bare Soil - two; 50:50 Grass:Soil - three; 25:75 Grass:Soil - four; 75:25 Grass:Soil - five; Flowerbed - six; Dog Park - seven; Concrete/Asphalt - eight; and, Gravel (semi-pervious) - nine. Trees found in a location where there was as much under-canopy bare soil as there was grass (i.e., a 1:1 ratio) were assigned the value three, whereas trees found in locations where there was distinctly less grass than there was bare soil (i.e., a 1:3 ratio) were assigned the value four. Finally, in the case where the presence of under-canopy bare soil was much greater than the amount of grass (i.e., a 3:1 ratio) the value five was assigned. Trees growing in tree boxes along the sidewalk were assigned the value eight, and all trees found within the newly constructed dog park were assigned the value seven.

DBH is diameter at breast height. This is a numeric entry for the measured diameter at breast height taken during field data collections. In cases where there was more than one stem for a certain tree (i.e., more than one DBH value for a tree because the trunk forked underneath the 1.4m height) the largest DBH measurement for that tree was recorded; STRATUM does not allow for multiple entries in such a situation.

MtncRec is interpreted as a maintenance recommendation. It is a numeric code used to identify the recommended maintenance for the tree depending on both age and condition. Values used for this study were as follows: One – None; tree requires no immediate or routine maintenance; Two – Routine for young tree; tree height < 5.48 m (or 18ft) and tree is in need of maintenance, but health of tree is not compromised by deferring maintenance up to 5 years; Three – Immediate for young tree; tree height < 5.48 m and in need of maintenance, postponing maintenance beyond 1 year will compromise health of tree; Four – Routine for mature tree; tree height > 5.48 m and in need of maintenance, but health of tree is not compromised by deferring maintenance up to 5 years; Five – Immediate for mature tree; tree height > 5.48 m and tree is in need of maintenance, postponing maintenance beyond 1 year will compromise health of tree; and, Six – Critical concern (public safety); tree requires immediate inspection. All newly planted trees, within the past 2 years, were assigned the value one; remaining trees were assigned values relative to their height and health condition ascertained from field data collection and the 2006 Aboud and Associates Inc. inventory.

PriorityTask is a numeric code describing the highest priority task required for a tree; it takes into consideration the abovementioned MtncRec codes. Values were selected for this study as follows: One – None; tree does not require maintenance; Two – Stake/Train; staking or training involves manipulating the trunk to grow straight, eliminating multiple leaders, crossing branches and girdling ties; Three – Clean; crown requires cleaning to remove dead, diseased, damaged, or poorly attached branches; Four – Raise; in the case of obstruction issues crown requires raising by removing lower branches from tree trunk; Five – Reduce; crown needs to be thinned by pruning to deal with overcrowding, wind resistance or light infiltration issues; Six – Treat pest/disease; treatment of insects, pathogens or parasites is required to maintain tree health; and, Seven – Remove; tree is dangerous, > 80% dead, or dead and no level of maintenance will increase longevity or safety. All trees assigned *MtncRec* values of one required no maintenance, so these trees were assigned a *PriorityTask* value of one. Remaining trees were assigned maintenance values based on field observations, and consultation with 2006 Aboud and Associates Inc. inventory.

SwDamg refers to the degree of sidewalk damage. This is a numeric code to describe the degree of sidewalk damage caused by tree roots growing underneath the pavement. This STRATUM field was not applicable to this study as most trees were found in the park; for those located on the sidewalk, none had caused visible damage.

WireConflict is a numeric code used to identify a tree that is high enough for utility lines present in the vicinity to have interfered with crown growth. The values selected were as follows: One – No lines; there are no utility lines in the vicinity of the tree crown; Two – Present but not conflicting; utility lines are present in the vicinity of the tree crown, but crown branches do not presently intersect wires; and, Three – Present and conflicting; utility wires are present in the vicinity of the tree crown, and the tree crown branches intersect the wires. Since there is no height recommendation for utility lines found in the presence of a growing tree, these data were collected through field observation.

The remaining two fields relied on field observations and the 2006 Aboud and Associates Inc. inventory.

CondWood indicated the condition of the wood. This is a numeric code used to identify the health of a tree's branches. Values used in this study were as follows: One – Dead; Two – Very poor: > 75% dead; Three – Poor: 50 – 75% dead; Four – Fair: 25 – 50% dead; and, Five – Good: < 25% dead.

CondLvs represents condition of leaves. This is a numeric code used to identify the health of the tree's leaves. The values entered were as follows: One – Dead; Two – Poor; Three – Fair; and, Four – Good.

STRATUM was used to calculate the following aspects of AG's tree resource: 1) Structure – population summary, importance values, species composition, canopy cover; 2) Function – environmental benefits; and, 3) Value – annual monetary value of benefits. More specifically, STRATUM quantified the following environmental services based on detained inputs describing AG's urban forest: 1) energy conservation; 2) air quality improvement; 3) CO_2 sequestration; 4) storm-water runoff mitigation; and, 5) property value increase.

These analyses involved creating a new SRATUM project by translating the full 2008 AG inventory database from Microsoft Excel to Microsoft Access format. Location data, specific to AG was inputted so that an appropriate climate zone could be used. It should be pointed out that the model's benefit analysis is extensively based on regionally specific tree growth measurements, hourly climate and air pollution concentration data, building construction information and cost data based on reference cities in 19 different climate zones throughout the United States. Due to the fact that variability of these factors exists from region-to-region, reliable benefit results can only be obtained when using data from the climate zone where the tree resource is actually located. Unfortunately, STRATUM does not provide climate zones outside of the US, thus there is no data for cities in Canada. As a result, any analysis that has been conducted outside of the US using STRATUM has lacked regional field data to support it. In addition, STRATUM does not allow for regionally specific data (e.g. hourly climate data) to be input instead of the default choices. Nowak advised using the northeast climate zone (Figure 3.2), because the City of Toronto's climate is most similar to that of the closest US reference city, New York (D. Nowak, personal communication, October 28th, 2008). This was deemed acceptable as this study used the STRATUM model as a management tool that is capable of providing a general accounting of the benefits provided by AG's tree resource. It should be noted that although a STRATUM study was conducted by the City of Vancouver, British Columbia, the authors do not specify which climate zone was used for their analysis.

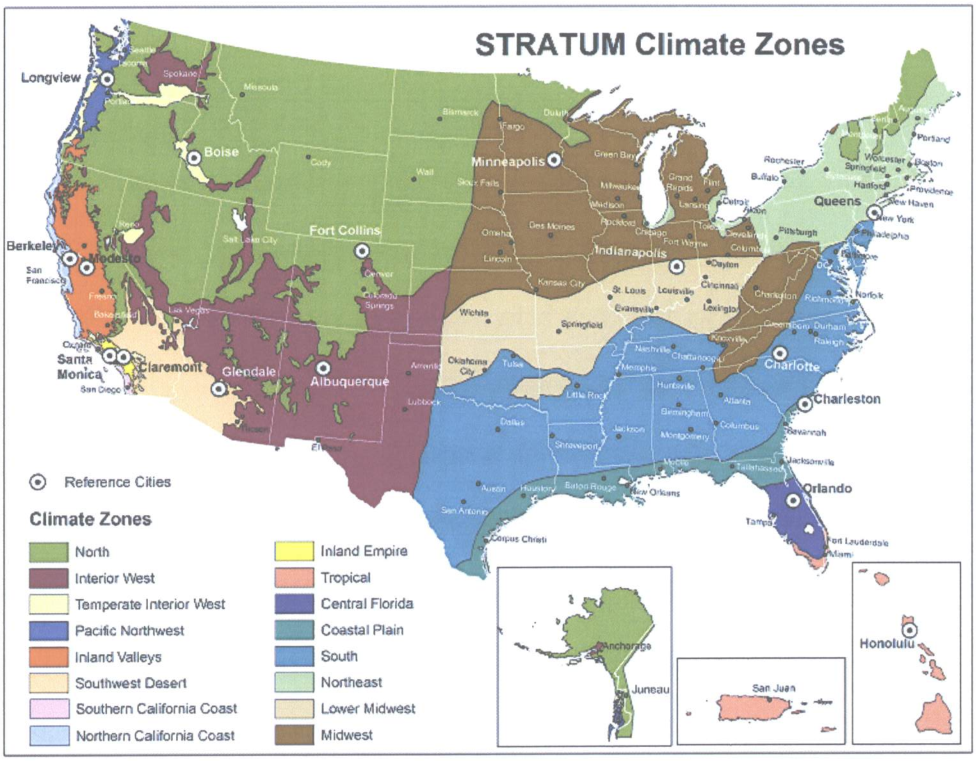


Figure 3.2: STRATUM climate zones (version 3.4)

SOURCE: i-Tree (2006)

In addition to tree-specific inputs, STRATUM requires regionally-specific data that describe the following costs: 1) electricity ($/kWh); 2) natural gas ($/Therm); 3) stormwater interception ($/gallon); 4) average home resale value ($); 5) NO_2 ($/lb); 6) SO_2 ($/lb); 7) VOC ($/lb); 8) CO_2 ($/lb); and, 9) PM_{10} ($/lb).

Average electricity and natural gas pricing for the City of Toronto was collected for the year 2007; these values were $0.0505/kWh and $1.1169/Therm respectively. The 2007 stormwater interception cost (average of all blocks paid on or before due date), was at $0.007298/gallon. The average home resale value ($462,392) for the Moss Park neighbourhood, as reported by 2006 Census, was used. Air pollutant abatement costs are used by STRATUM to estimate willingness-to-pay (i.e., if a company is willing, or obligated, to pay an average of $1/lb of treated and controlled pollutant to meet minimum standards, then the mitigation savings provided by a tree that intercepts 1 lb of pollution is $1) (McPherson et al., 2006). Unfortunately, despite much effort, this information could not be located for Canadian industries. Therefore, the values used in this study are those found in the Piedmont UFORE analysis (McPherson et al., 2006), which calculated average annual emissions and their monetary values by using utility-specific emissions factors for electricity and heating fuels. This emissions pricing was derived from models that calculated the marginal cost of controlling different pollutants to meet air quality standards (McPherson et al., 2006). Prices used in this study are as follows: 1) NO_2 ($6.55/lb); 2) SO_2 ($1.91/lb); 3) VOC ($6.23/lb); 4) CO_2 ($0.0075/lb); and, 5) PM_{10} ($2.31/lb). Maco and McPherson (2003) describe in detail the methods by which the urban forest structure, and ecological and aesthetic benefits are calculated by STRATUM.

STRATUM further required annual costs associated with managing AG's tree resource. During summer 2008, many attempts were made to contact the PFRD, and Urban Forestry department, with the goal of estimating annual costs ($) for the following park activities: planting, pruning, tree and stump removal, pest and disease control, irrigation, repair/mitigate infrastructure damage, litter/storm clean-up, litigation and settlements due to tree-related claims, expenditure for program administration, and tree inspection.

Eventually, it was learned that the City of Toronto does not collect data in the detail or format that would lend itself to this kind of reporting (D. Hart, personal communication, July 11th, 2008). However, this did not hinder STRATUM's ability to produce a benefit analysis, but it thwarted the ability to generate both a cost-benefit and net benefit analysis of AG's urban forest.

STRATUM has been applied as an urban forest management tool for street tree evaluation in various cities in the US (City of Cambridge, Massachusetts; Cortland, New York; and, City of Pittsburgh, Pennsylvania); however, it is important to note this study is the first of its kind to apply the STRATUM model to the scale of an urban park. At present, little evidence of forested urban park investigations is found in the literature, and even less concerning studies that focus on quantifying the ecological and aesthetic benefits provided by an urban forest confined to a park.

3.3 Soil Analysis

Measurement focused on physical properties of the soil that included texture, compaction, bulk density and soil-water permeability. Although this study could have benefited from soil chemistry analysis (e.g., pH, electrical conductivity, and nutrient analysis), additional research was limited by time and financial constraints.

3.3.1 Soil Sampling Design

Using Hawth's Tools (ArcGIS 9.2 extension), a grid with 20 m x 20 m cells was superimposed on an air photo of AG, for the purpose of producing a gridded random sampling design. After masking all cells containing impervious surfaces (i.e., walkways, buildings), a sample point was randomly assigned to each remaining grid cell; this totalled 117 locations. These locations were subsequently sited in AG using a precision GPS, a measuring wheel, and a sighting compass. Each point was marked with a 20 cm nail that secured 10 cm radius red plastic disk flush to the ground; each disk was labelled with a unique sampling location number. This form of marker was essential for visual recognition of sample sites so as to: 1) ensure minimal disturbance within the park; and, 2) ensure repeat sampling efforts obtained data from the exact location.

If the soil could not be sampled at the designated sampling point due to an obstruction (e.g., walkway, tree, or bench), the sampling point was relocated to a location within a radius of 1 m from the original point; these changes were then updated in the GIS. In the case of stolen sample site markers (10 out of 117 were either moved or lost during the study period); replacements were made and installed using a similar procedure. Within the newly constructed dog park, built during in the spring of 2008, 10 sample points were removed by contractors during the construction process; they were not replaced. On occasion, grass cutting efforts in the park obscured the locations of the sampling disks. In such circumstances, a metal detector was used to re-locate the sampling sites.

3.3.2 Methodology and Instrumentation

From the 117 soil samples sites, 40 were selected randomly using Hawth's Tools to investigate texture. Soil was removed from a depth of 15 to 20 cm at each of these locations using an auger. Urban locations often exhibit highly disturbed soil, so this project focused on analyzing soil texture within the A horizon, which is an important rooting zone for trees (Craul and Patterson, 1989). Soil samples were collected in individually numbered field bags, from which approximately 50 ml was sieved and added to 100 ml labelled sampling containers. After filling containers to the 100 ml mark with water, 1 ml of biodegradable soap was added to each as an emulsifying agent (Steila, 1976; Plante et al., 2006). The containers were then sealed and shaken vigorously for 60 seconds to ensure that the soil, water and soap mixed sufficiently. Following this, containers were carefully placed on a flat surface and the proportion of sand and silt content was measured after 6 hrs; clay was measured after 72 hrs (Steila, 1976; Plante et al., 2006). The percentage sand, silt and clay were used to estimate ideal bulk density following Saxton et al. (1986). Soil type for the 40 soil samples was then classified following Craul (1999).

Soil compaction measurements were taken during May 2007; this data collection occurred at all 117 sample sites. Compaction measurements were taken early in the springtime for two reasons: 1) the soil must be moist during compaction measurements for the instrument to function optimally; and, 2) taking measurements early in the spring avoided bias caused by increased foot and park vehicle traffic that occurs in mid- to-late summer (June, July, and August). A Field Scout SC-900 probe (Spectrum Technologies Inc.) was used for soil compaction measurements. A profile of depth 2.5 cm to 30 cm was collected at each sample site. This probe had a built-in data logger, which eliminated the need to record soil measurements manually. It was important to take compaction measurements at depths that could be correlated with soil-water infiltration data. The SC-900 probe recorded the soil depth using a sonic depth sensor, while compaction was measured using cone index values recorded by a load cell sensor and converted to pressure recorded in kilopascals (kPa). A total of three profiles was collected and averaged for each of the 117 sample locations. From the profiles, values at two measurement depths (7.6 cm and 20 cm) were retained for subsequent mapping purposes.

Using the methodology outlined by the USDA (1999), soil water permeability was measured at the 117 sample locations in July 2008. This was done by driving an open ended steel cylinder of 7.6 cm diameter into the soil surface using a hammer and a wooden block. The cylinder was situated within 20 cm of the sample marker, and all grass or vegetation captured within the cylinder was removed from the surface so as to reduce any factors that may impact the water percolation process. Using a calibrated measuring scoop, 60 ml of water was poured into the cylinder and left to infiltrate into the soil; this was referred to as the 'wetting' process. When this procedure was completed (i.e., all the water captured within the cylinder had run into the soil), another 60 ml of water was poured into the cylinder and the time taken for complete soil infiltration was recorded with a stopwatch. Permeability measurements are recommended to occur at soil conditions close to saturation (USDA, 1999); therefore, this method was an attempt to control the wetting condition rather than planning data collection to be reliant on a rainfall event. Any sample location that did not drain completely within one hour was considered to have poor soil-water infiltration capacity.

3.3.3 Geospatial Analysis

Geostatistics is a collection of methods for the analysis and estimation of data correlated in space or time (Bailey and Gatrell, 1995); this project used kriging, one of several geostatistical methods, for spatial interpolation of soil surfaces. Spatial interpolation with kriging assumes that locations close together are more similar than locations that are farther apart. This distance of correlation is called the range, beyond which observations (point data) are considered uncorrelated or spatially independent (Bailey and Gatrell, 1995); it is investigated using a semivariogram. A semivariogram is a mathematical function that describes spatial correlation in observations measured at sample locations (Bailey and Gatrell, 1995). It is usually illustrated in a graph format that plots the variance in measurement value with distance between all pairs of sampled locations (Johnston et al., 2001). Kriging required modelling the semivariogram to predict values for the same data type at unsampled locations (Bailey and Gatrell, 1995).

While continuous data, such as percentage sand/silt/clay, compaction, bulk density, and soil water permeability can be measured at any location in space, they were only available in a finite number for sampled points (40, or 117). Kriging was used in this project as an interpolation method; it incorporated statistical relationships among a group of measured points to create prediction surfaces (Johnston et al., 2001). Kriging is a linear predictor, meaning that predictions at any location were obtained as a weighted average of neighbouring data. It is based on the Regionalized Variable Theory, which assumes that the spatial variation of a variable represented at specific measurement locations is statistically homogeneous throughout the defined surface (Bailey and Gatrell, 1995; Johnston et al., 2001).

Kriging was carried out in this research project using ArcGIS 9.2 software and the Geostatistical Analyst extension. It is important to note here that, while soil surfaces were important to the assessment of overall park conditions in AG, the processing of these data using kriging was completed as part of a separate study conducted by Masters Student, Brahma Toleti, under the supervision of Dr. Andrew Millward (Principal Investigator, Ryerson's Urban Forest Research & Ecological Disturbance (UFRED) Group). Therefore, while this study actively contributed to the sampling design and data collection phase of AG soil measurements, the full explanation of kriging methods used to generate soil prediction surfaces is described in Toleti (2008).

4.0 RESULTS AND DISCUSSION

4.1 Allan Gardens 2008 Tree Inventory

For a downtown urban park, AG has a large tree population encompassing a wide range of species; of the 309 trees surveyed 45 species were recorded (Table 4.1; Figure 4.1). Nine of the tree species were in the *Acer* (Maple) genus (20% of total park species count). The next most common genera were *Fraxinus* (Ash) and *Quercus* (Oak), both with 4 species each (9% each of the total species count); these were followed by *Ulmus* (Elm) and *Tilia* (Linden), accounting for 7% and 5% of the total species count respectively.

The largest average Ca was measured for the Amur Cork (*Phellodendron amurense*) (571 m^2), and the largest average Cv was measured for the Freeman Maple (*Acer x freemanii* 'Jeffersed') (4134 m^3). The smallest average Ca and Cv were associated with the White Oak (*Quercus alba*) (11 m^2 and 5 m^3, respectively). The most common species found in AG was the North American native Sugar Maple (*Acer saccharum*), accounting for 19.1% of the total population of trees inventoried. This species had average Ca and Cv values of 125 m^2 and 593 m^3, respectively. Norway Maple (*Acer platanoides*) (13.3%) and Siberian Elm (*Ulmus pumila*) (7.4%) were the next most common species; they averaged 258 m^2 and 235 m^2 for Ca, and 1346 m^3 and 652 m^3 for Cv, respectively. It is important to point out that the average Cv of Norway Maples was nearly twice that measured for the Siberian Elm, despite being very similar with respect to Ca. This is attributable to the fact that Siberian Elms, despite being large trees in AG, have crowns that are shallower, and less layered than the Norway Maple; in other words, their crown depths were much less.

The canopy shading coefficients calculated in this study were compared with those reported by Nowak (1996), and first derived by McPherson (1984). Nowak (1996) reported shading coefficient values for 47 tree species, of which 25 were found in AG. However, this study attempted to improve upon Nowak's (1996) coefficients by directly investigating shading values specific to AG trees.

Botanical Name	Common Name	Average Ca (m^2)	Average Cv (m^3)	Sabir Shading Coefficient	Nowak Shading Coefficient	Average LAI
Acer ginnala	Amur Maple	37.67	63.46	0.76	0.91	2.47
Acer platanoides	Norway Maple	258.25	1346.47	0.84	0.88	2.41
Acer platanoides 'Columnare'	Columnar Norway Maple	123.53	216.54	0.65	x	3.14
Acer pseudoplatanus	Sycamore Maple	242.04	994.10	0.76	x	2.41
Acer rubrum	Red Maple	101.85	160.73	0.58	0.83	3.92
Acer saccharinum	Silver Maple	439.11	1802.39	0.81	0.83	1.34
Acer saccharum	Sugar Maple	125.21	593.68	0.86	0.84	4.66
Acer x freemanii	Freeman Maple	1078.75	4134.34	0.58	x	0.28
Acer x freemanii 'Jeffersred'	Autumn Blaze Maple	14.72	8.62	0.71	x	1.44
Aesculus hippocastanum	Horsechestnut	165.59	1308.55	0.86	0.88	2.31
Ailanthus altissima	Tree of Heaven	187.10	693.73	0.75	x	2.28
Catalpa speciosa 'Nana'	N. Catalpa 'Mophead'	23.72	22.26	0.78	0.76	2.19
Chamaecyparis nootkatensis	Alaska Cedar	99.07	89.17	0.60	x	2.89
Cladrastis kentukea	Kentucky Yellowwood	37.67	49.92	0.74	x	2.39
Crataegus sp.	Hawthorn	24.36	27.11	0.77	0.76	2.07
Fagus sylvatica	European Beech	40.03	1526.29	0.83	0.88	2.74
Fraxinus americana	White Ash	866.13	2893.18	0.64	x	0.26
Fraxinus excelsior	European Ash	259.59	1231.40	0.62	0.85	0.42
Fraxinus pennsylvanica	Red Ash	50.33	294.67	0.70	0.83	1.83
Fraxinus pennsylvanica var. lanceolata	Green Ash	58.81	137.57	0.70	0.83	2.39
Ginkgo bilboa	Maidenhair	188.07	2592.77	0.73	0.81	0.72
Gleditsia triacanthos var. inermis	Thornless Honeylocust	79.43	579.54	0.79	0.67	2.85
Gymnocladus dioicus	Kentucky Coffee Tree	287.34	1377.98	0.79	0.86	1.14
Juglans nigra	Black Walnut	561.14	2884.50	0.75	0.91	0.59
Malus cv.	Crabapple (Apple)	24.84	32.00	0.76	0.85	2.04
Metasequoia glyptostroboides	Dawn Redwood	106.42	116.09	0.58	x	4.87
Phellodendron amurense	Amur Cork	571.35	1591.71	0.76	x	0.58
Picea abies	Norway Spruce	82.09	82.86	0.57	x	1.49
Pinus nigra	Austrian Pine	111.51	136.05	0.70	x	2.50
Platanus x acerifolia	London Plane	537.93	1893.71	0.81	0.86	2.52
Populus tremula 'Erecta'	Upright European Aspen	157.35	208.64	0.46	0.74	1.41
Prunus avium	Sweet Cherry	119.51	672.72	0.57	x	0.87
Pyrus calleryiana 'Bradford'	Bradford Pear	79.65	474.81	0.70	0.8	1.93
Quercus alba	White Oak	10.94	5.07	0.82	0.75	2.84
Quercus macrocarpa	Bur Oak	20.32	13.48	0.71	x	1.67
Quercus robous 'Fastigiata'	Pyramidal English Oak	58.54	44.38	0.61	x	2.32
Quercus rubra	Red Oak	29.11	48.05	0.72	0.81	2.53
Sophora japonica	Japanese Pagodatree	139.16	891.01	0.75	0.78	1.81
Syringa reticulate	Japanese Tree Lilac	46.68	129.50	0.74	x	2.52
Taxus cuspidata	Japanese Yew	32.34	64.08	0.56	x	1.59
Tilia cordata	Littleleaf Linden	251.97	1104.25	0.82	0.88	3.30
Tilia x euchlora	Crimean Linden	150.22	866.08	0.84	x	2.87
Ulmus americana	White Elm	515.36	1541.54	0.72	0.87	1.15
Ulmus glabra	Scotch Elm	236.06	1744.16	0.78	x	1.18
Ulmus pumila	Siberian Elm	235.18	651.45	0.68	0.85	2.61

Table 4.1: Allan Gardens tree inventory summary

Average Ca – Average Crown Surface Area, Average Cv – Average Crown Volume, Sabir Shading Coefficients, Nowak (1996) Shading Coefficients, Average LAI – Average Leaf Area Index Values for Allan Gardens Tree Species. All occurrences of "x" within the Nowak Shading Coefficient column indicate that Sh values for these tree species were not made available by Nowak (1996). Refer to Appendix A for full inventory.

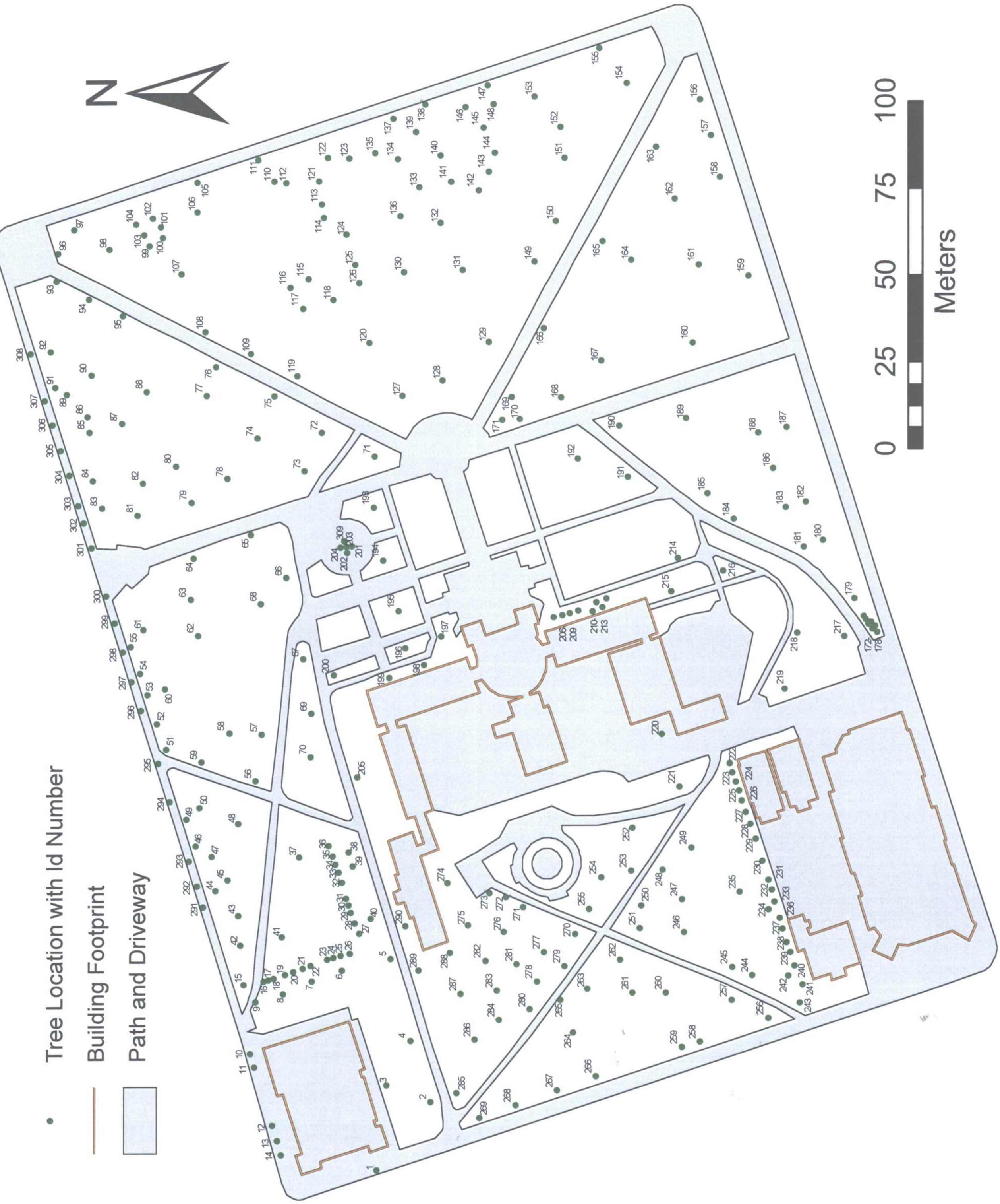


Figure 4.1: Tree locations in Allan Gardens with identification numbers
Refer to Appendix A for full tree details

A comparison to evaluate the difference between Nowak's (1996) 25 shading coefficients and those generated in this study was undertaken. Nowak's shading coefficients produced a mean of 0.83 (SD = 0.058), whereas this study found a lower shading coefficient mean of 0.75 (SD = 0.086). To evaluate if there was a significant difference between the means of the two groups, first, the normality distribution of both sets of data was tested using the Kolmogorov-Smirnov Test (Sabir shading coefficient's $p = 0.797$, and Nowak shading coefficient's $p = 0.573$; both were determined to be normally distributed), and second, a t-Test was performed using both data sets. The t-test null hypothesis was that no difference existed between the two group means. However, the t-Test (assuming equal variance confirmed by the Levene's Test) found that there was significant difference between the groups ($p = 0.001$). This test confirmed that the use of Nowak's (1996) shading coefficient values for the 25 tree species with Sabir's for the remaining 20 species would provide inconsistency in the resulting LAI values generated in Equation 2. It further supported the decision to collect and process the Sabir shading coefficients for all 45 species.

It should be pointed out that the value of this study's shading coefficient investigation is very important to future uses of Equation 2. Previous studies which employed Nowak's equation (Peper and McPherson, 2003) found that these shading coefficients may not always be in accordance with the tree's true values due to specific tree characteristics and conditions found in the study site. This study illustrated that there is value in obtaining site-specific Sh information, if LA is estimated using the logarithmic regression model.

The study estimation of LAI values for all the trees present in AG used Equation 2, however, it should be noted that although this equation takes into account the width, and height of a tree's crown, it does not directly consider crown condition. It estimates near-maximum leaf area for individual open-grown full canopy urban trees. Therefore, it is expected that in some cases, where a tree may be damaged or in decline, the model may tend to overestimate leaf area. LAI values are mapped in Figure 4.2 along with the footprint of each tree's dripline.

As can be seen in Table 4.1, average LAI values range between 0.26 and 4.87 for all tree species investigated. Deciduous trees have average LAI values that range between 0.26 and 4.66, whereas coniferous species have average LAI values ranging from between 1.49 and 4.87. The tree species measured to have the highest average LAI was the Dawn Redwood (*Metasequoia glyptostroboides*) (4.87), followed by three broadleaf deciduous trees that include Sugar Maple (*Acer saccharum*) (4.66), Red Maple (*Acer rubra*) (3.92), and Littleleaf Linden (*Tilia cordata*) (3.30). The fact that these three deciduous species have larger LAI values, and comparatively higher average crown height and width dimensions, establishes their importance to the urban environment. Trees

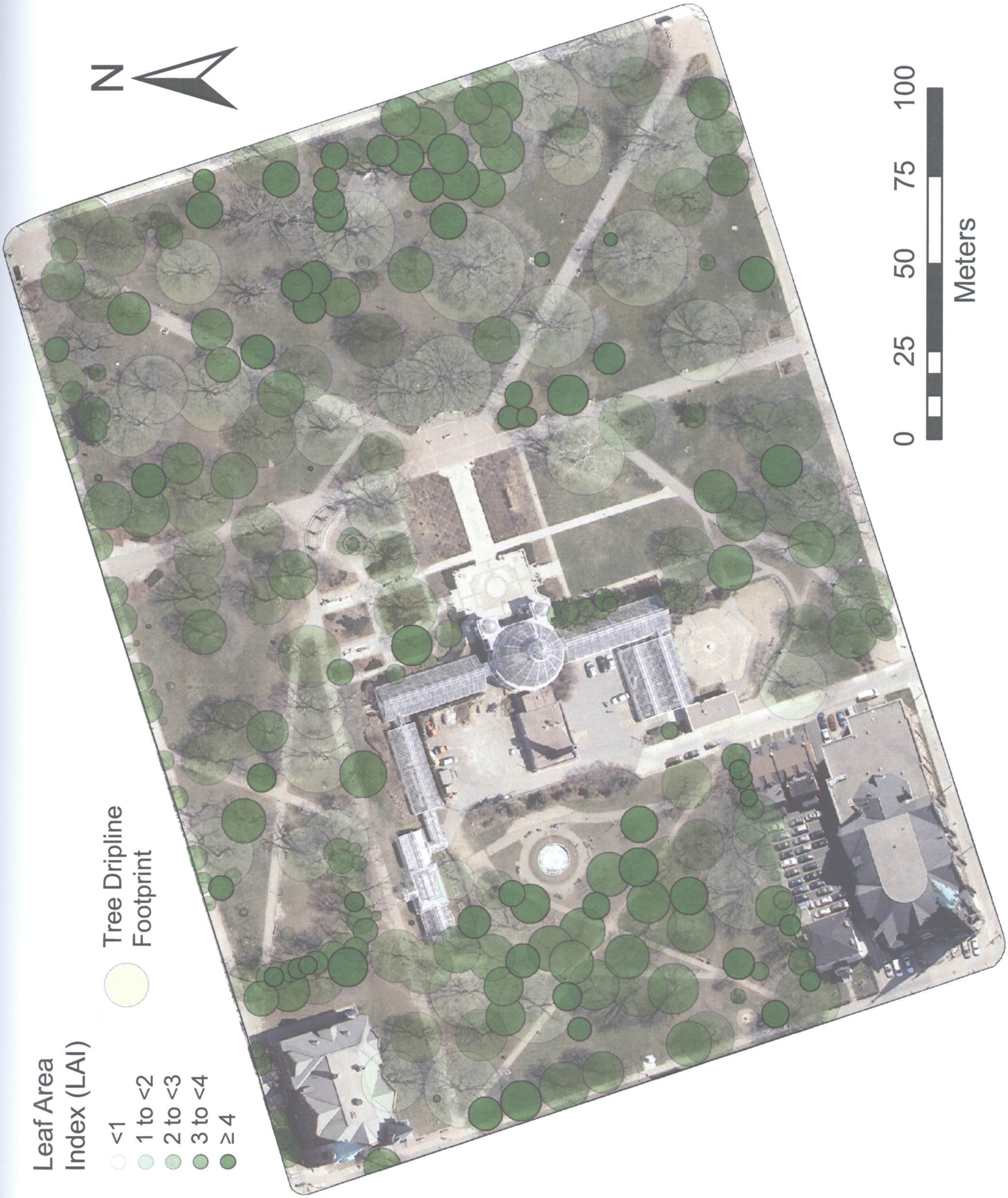


Figure 4.2: Tree dripline footprint classified by LAI values
Overlaid on a 2007 leaf-off air photo (Source: DMTI Canada)

with the lowest average LAI values were found to be Amur Cork (0.58), European Ash (0.42), Freeman Maple (0.28), and White Ash (0.26) (Table 4.1).

Tree canopy coverage is substantial in parts of AG, especially in the north western area of sections A, D, and E that support trees with higher canopy width (Figures 2.1 and 4.2). Many of the trees in these sections also have higher LAI values (LAI of 3 or greater) when compared to trees in other locations in AG. Sections B and C harbour many trees with low LAI values (less than 2) and small canopy sizes. Section A, however, is the most congested treed space in AG. Although composed of many trees in good health, the 2008 inventory reveals that some of the trees in this location are experiencing decline. This may be attributed to the soil conditions, old age, and to some degree competition between trees for available light.

The total LA in AG calculated using STRATUM was 75,633 m^2 (Appendix B3), whereas this study's independent collection of data for shading coefficient input into Equation 2 estimated 67,446 m^2 (Appendix A). When considering AG total plantable space (40,000 m^2), STRATUM output produced a LAD value of 1.89; this study's LAD was found to be 1.68. Because many of the trees in AG exceeded limits imposed by Equation 2 (190 trees fall into this category, approximately 61.5% of the tree population), restrictions on their various crown characteristics had to be adopted, thus producing lower leaf area estimations (D. Nowak, personal communication, October 28th, 2008).

4.2 STRATUM Tree Resource Reports for Allan Gardens

4.2.1 Tree Numbers

The 2008 AG tree inventory included 309 trees (Table 4.2). AG's tree population was found to be dominated by broadleaf deciduous species (92.6%), the coniferous evergreens accounted for the remainder. Broadleaf deciduous trees can grow larger in both structure and crown characteristics compared to coniferous trees. Because most ecological services provided by trees are directly related to leaf surface area, the high percentage of broadleaf trees in AG make a strong contribution to the ecological benefits provided by park trees.

Species (Common Name)	DBH class (cm)										
	0-8	8-15	15-30	30-46	46-61	61-76	76-91	91-107	>107	Total	% of total
BROADLEAF DECIDUOUS - LARGE											
Sugar Maple	6	1	25	20	4	3	0	0	0	59	19.1
Norway Maple	0	1	3	15	7	11	2	1	1	41	13.3
Siberian Elm	0	0	6	13	3	1	0	0	0	23	7.4
Red Ash	0	5	12	0	0	0	0	0	0	17	5.5
Columnar Norway Maple	0	1	12	2	0	0	0	0	0	15	4.9
Silver Maple	6	0	0	0	3	4	2	1	4	14	4.5
Black Walnut	0	0	0	0	0	1	4	0	1	6	1.9
Scotch Elm	0	0	0	0	1	1	3	0	1	6	1.9
Green Ash	0	0	5	0	0	0	0	0	0	5	1.6
Honeylocust	1	0	0	4	0	0	0	0	0	5	1.6
Northern Red Oak	4	0	1	0	0	0	0	0	0	5	1.6
Tree of Heaven	1	0	0	0	0	2	1	0	0	4	1.3
Dawn Redwood	0	0	2	1	0	0	0	0	0	3	1.0
Pyramidal English Oak	0	0	3	0	0	0	0	0	0	3	1.0
Freeman Maple	0	0	0	0	0	0	0	1	1	2	0.6
Horsechestnut	0	0	0	0	0	1	1	0	0	2	0.6
European Beech	0	1	0	0	0	0	0	1	0	2	0.6
Kentucky Coffeetree	0	0	0	0	1	1	0	0	0	2	0.6
London plane	0	0	1	0	0	0	0	1	0	2	0.6
White Oak	0	1	1	0	0	0	0	0	0	2	0.6
American Elm	0	0	0	0	0	1	0	0	1	2	0.6
Sycamore Maple	0	0	0	0	1	0	0	0	0	1	0.3
White Ash	0	0	0	0	0	0	1	0	0	1	0.3
European Ash	0	0	0	0	0	1	0	0	0	1	0.3
Maidenhair	0	0	0	0	0	0	1	0	0	1	0.3
Upright European Aspen	0	0	0	1	0	0	0	0	0	1	0.3
Bur Oak	0	0	0	0	0	0	0	0	0	1	0.3
Total	12	11	71	56	20	27	15	4	8	226	73.1
BROADLEAF DECIDUOUS - MEDIUM											
Crimean Linden	0	0	0	2	12	2	0	0	0	16	5.2
Littleleaf Linden	0	0	1	4	2	0	3	0	1	11	3.6
Autumn Blaze Maple	8	0	0	0	0	0	0	0	0	8	2.6
Red Maple	0	1	1	0	0	0	0	0	0	2	0.6
Northern Catalpa	0	0	1	0	0	0	0	0	0	1	0.3
Hawthorn	0	0	1	0	0	0	0	0	0	1	0.3
Amur Corktree	0	0	0	0	0	0	1	0	0	1	0.3
Sweet Cherry	0	0	0	1	0	0	0	0	0	1	0.3
Japanese Pagoda	0	0	0	1	0	0	0	0	0	1	0.3
Total	8	1	4	8	14	2	4	0	1	42	13.6
BROADLEAF DECIDUOUS - SMALL											
Amur Maple	0	7	0	0	0	0	0	0	0	7	2.3
Kentucky Yellowwood	4	1	0	0	0	0	0	0	0	5	1.6
Crabapple	0	0	3	0	0	0	0	0	0	3	1.0
Japanese Tree Lilac	0	1	1	0	0	0	0	0	0	2	0.6
Callery Pear	0	0	0	0	1	0	0	0	0	1	0.3
Total	4	9	4	0	1	0	0	0	0	18	5.8
CONIFER EVERGREEN LARGE											
Austrian Pine	0	0	3	3	1	1	1	0	0	9	2.9
Alaska Cedar	0	0	5	0	0	0	0	0	0	5	1.6
Norway Spruce	0	2	0	1	0	0	0	0	0	3	1.0
Total	0	2	8	4	1	1	1	0	0	17	5.5
CONIFER EVERGREEN - SMALL											
Japanese Yew	2	3	1	0	0	0	0	0	0	6	1.9
Total	2	3	1	0	0	0	0	0	0	6	1.9
AG-wide Total	26	26	88	68	36	30	20	5	10	309	100

Table 4.2: Tree species abundance by DBH class

Refer to Appendix B1 for full STRATUM report

4.2.2 Tree Species Composition and Diversity

In Table 4.2, tree species presence, relative to DBH size class, was described for all 45 species found in AG. The five dominant species include Sugar Maple (19.1%), Norway Maple (13.3%), Siberian Elm (7.4%), Red Ash (5.5%) and Crimean Linden (5.2%) (see Appendix B2 for STRATUM report). These five species constitute just over 50% of AG's tree population. The *Acer* (maple) genus alone constitutes over 48% of the total tree population. Tree dominance of this kind can be a management concern. This is due to the fact that having such a significant portion of trees in the same genus may enhance vulnerability in the event of a storm, drought, disease, pest, or other stressor (e.g., Dutch Elm Disease, Emerald Ash Borer). Such an event could have a catastrophic effect on AG and the ability of its trees to provide benefits to the City of Toronto in future.

4.2.3 Tree Species Importance

Importance values (IVal) are one method of measuring reliance on the functional capacity of a certain species. Each tree species's IVal was calculated as the sum of relative abundance (from percent of total trees), crown projection area (from percent of total leaf area), and leaf area (from percent of canopy cover), divided by three (Peper et al., 2001; 2007). The IVal provides a more robust indicator of species importance than does relative abundance or size alone (Peper et al., 2001). IVals range between 0-100, where a value approaching 100 suggests reliance on this species is high, indicating that a large fraction of an urban forest's benefits are supplied by this species. On the other hand, an IVal close to 0 suggests little or no reliance (Peper et al., 2007).

There may be a practical advantage to an urban tree population being composed of a few dominant species (i.e., an IVal > 25%), as this dominance may lead to lowered maintenance costs brought about by the efficiency of repetitive work. However, it is not desirable to rely so heavily on a few species, as this may equally incur large costs if disease or senescence becomes widespread, resulting in a large number of removals and/or replacements. In the case where IVals are more equally distributed across five to ten species, the risk of momentous loss of a single dominant species would be notably curbed. Leaf area, canopy coverage and IVals for the ten most prevalent species found in AG are presented in Table 4.3.

Table 4.3: Importance values (IVal) for the 9 dominant tree species in Allan Gardens Refer to Appendix B3 for full STRATUM report

Species	# of trees	% of total trees	LA (m^2)	% of total LA	Canopy cover (m^2)	% of Total canopy cover	Importance Value
Sugar Maple	59	19.1	8,472	11.2	2,615	11	13.8
Norway Maple	41	13.3	11,049	14.6	4,111	17.2	15
Siberian Elm	23	7.4	5,174	6.8	1,471	6.2	6.8
Red Ash	17	5.5	1,646	2.2	593	2.5	3.4
Crimean Linden	16	5.2	3,937	5.2	1,584	6.6	5.7
Columnar Norway Maple	15	4.9	910	1.2	535	2.2	2.8
Silver Maple	14	4.5	10,750	14.2	2,777	11.6	10.1
Littleleaf Linden	11	3.6	2,069	2.7	809	3.4	3.2
Austrian Pine	9	2.9	1,253	1.7	504	2.1	2.2
Other tree species	104	33.6	30,373	40.2	8,842	37.2	37
Total	309	100	75,633	100	23,841	100	100

The 9 most abundant AG tree species (Table 4.3) comprise 66% of the total AG population, 60% of the total leaf area, and 63% of the total canopy cover. Collectively, they produce an IVal of 63. AG was found to be most reliant on the functional capacity of Norway Maple trees (IVal = 15), despite accounting for only 13% of the total tree population. Because of the large canopy size of many AG Norway Maples, they provide high amounts of both leaf area and canopy cover. Results suggest that the Norway Maple is just over twice as significant, in terms of LA and canopy cover, as the Siberian Elm (IVal = 6.8), and four times more significant than Red Ash (IVal = 3.4). Of the 20 most prevalent species growing in AG (Appendix B3), the tree species that contributed the least benefit were the Kentucky Yellowwood, Japanese Yew, and Red Oak with IVals of 0.6, 0.7, and 0.7 respectively.

Silver Maples have a relatively high IVal of 10.1, yet they rank as the 7th most abundant species (4.5% of AG's total tree population). Siberian Elms, on the other hand, rank 3rd in population abundance but have an IVal of only 6.8. Compared to the Siberian Elm, Silver Maples's population is approximately 60% less, but due to its tree crown characteristics this species is more substantial in terms of both leaf area and canopy cover (2.08 and 1.89 times more, respectively). Therefore, if the number of Silver Maple trees was increased by new plantings to match the population abundance of Siberian Elm trees, Silver

Maple species' importance value would increase disproportionately as a function of tree structure and morphology.

4.2.4 Age Structure

The age distribution within a tree population influences present and future maintenance costs, as well as the flow of benefits (Peper et al., 2007). A population of non-uniform age allows managers to allocate annual maintenance costs uniformly over many years, and assures continuity in overall tree-canopy cover. An ideal age distribution would have a high proportion of new plantings (i.e., trees with DBH within the two ranges 0-8cm and 8-15cm) to offset establishment-related morality. For each species, 40% of its tree populations should be found in these first two DBH segments (Group One), and the remaining 60% of the population should be distributed across the larger and subsequent DBH classes. Under this scenario, 30% of AG's total tree population would occur in the next three DBH segments (Group Two: 15-30 cm, 30-46 cm and 46-61cm), followed by 25% in the subsequent two DBH segments (Group Three: 61-76 cm and 76-91cm), and the remaining 5% in the last two segments (Group Four: 91-107 cm and >107cm) (Peper et al., 2007). Some modifications to these classes are required on a species by species basis because not all trees have the ability to achieve the same size at maturity. Table 4.4 shows age data (relative to DBH size class) for the 10 most prevalent tree species found in AG.

Table 4.4: Relative age distribution (%) by DBH class for 10 dominant tree species in Allan Gardens
Refer to Appendix B4 for full STRATUM report

	DBH class (cm)								
Species	**0-8**	**8-15**	**15-30**	**30-46**	**46-61**	**61-76**	**76-91**	**91-107**	**>107**
Sugar Maple	10.17	1.69	42.37	33.9	6.78	5.08	0	0	0
Norway Maple	0	2.44	7.32	36.59	17.07	26.83	4.88	2.44	2.44
Siberian Elm	0	0	26.09	56.52	13.04	4.35	0	0	0
Red Ash	0	29.41	70.59	0	0	0	0	0	0
Crimean Linden	0	0	0	12.5	75	12.5	0	0	0
Columnar Norway Maple	0	6.67	80	13.33	0	0	0	0	0
Silver Maple	0	0	0	0	21.43	28.57	14.29	7.14	28.57
Littleleaf Linden	0	0	9.09	36.36	18.18	0	27.27	0	9.09
Austrian Pine	0	0	33.33	33.33	11.11	11.11	11.11	0	0
Autumn Blaze Maple	100	0	0	0	0	0	0	0	0
AG-wide total	8.41	8.41	28.48	22.01	11.65	9.71	6.47	1.62	3.24

The overall age structure for AG trees fails to meet, or even approach, the aforementioned ideal age distribution with exception of two DBH groups: 1) Group Two, which exceeded the ideal 30%; and, 2) Group Four, which came close to approaching the 5% ideal. When considering the 10 dominant AG tree species, five are represented in the smallest DBH size class, with only the Autumn Blaze Maple exceeding the 40% ideal of the first DBH size group (100% of its total population present). In the second DBH group, all 10 dominant tree species exceeded the 30% ideal with exception of the Silver Maple. In the third DBH group, the three species that exceeded the 25% ideal were Norway Maple (32%), Silver Maple (43%), and Littleleaf Linden (27%). In the fourth DBH group, the two tree species which exceeded the 5% ideal were Silver Maple (36%) and Littleleaf Linden (9%).

Of the species in Table 4.4, recent inventory records show that the percentage of young Autumn Blaze Maples was found to be high because there was a recent planting of this species in the western part of Section B (Figure 2.1). This is a hybrid of Red and Silver Maple that has only recently gained favour by the City of Toronto in its planting efforts. The Silver Maples in AG are, for the most part, a population of large old trees; none of this population is characterized as having small-to-medium sized stature, indicating that this species is vulnerable to loss if replanting is not encouraged.

It is important to note that the percentage of Sugar Maple trees is low within the DBH 8-15 cm segment, yet the percentage is comparatively higher in the 15-30 cm segment. This could mean that a number of newly planted Sugar Maple trees are not surviving into the higher segment for various reasons or that this species was favoured in the past and was planted with zeal. Young Sugar Maples could be facing relatively higher tree mortalities in AG due to pest damage, disease vulnerability, and competition for water and nutrients. Also, it may suggest that fewer Sugar Maple trees have been planted in AG recently, i.e. over the past decade. However, there are no planting records illustrating the planting patterns in AG to support this deduction.

In 2007, Ryerson's Urban Forest Research & Ecological Disturbance (UFRED) Group become aware of the problem concerning young Sugar Maple trees and AG's growing population of thirsty squirrels (Duncan, 2007). As AG is enclosed by 4 major streets, the majority of the Eastern Grey squirrel population is geographically restricted to the park, meaning that they are reliant on it for their sources of food and water. After an especially dry summer season in 2007, squirrels were observed to bark strip young Sugar Maple trees in search of moisture. They do this by removing (sometimes girdling) the young tree's outer bark to access the cambium, the transport location for sugars and water (Millward, 2007). However, by bark stripping in this manner squirrels can cause irrevocable damage to the tree, often instigating the death of the affected limb. This has lead to several young Sugar Maple tree deaths (e.g., Tree # 278, Appendix A) (Millward, 2007).

Distribution of tree DBH values can be used as an important point for comparison between the Sugar and Norway Maple. These species are somewhat similar in their tree structure and population number in AG, but the Norway Maple is known to have a quicker growth rate than the Sugar Maple. Even with a higher occurrence of Sugar Maples in the lower DBH classes, the population number drops dramatically after the 30 - 46 cm class (from 34% to 5 %); no Sugar Maples exist with a DBH greater than 76 cm. However, Norway Maple trees do exist in the higher DBH segments. Assuming that many of the now large trees in each species were planted around the same time, one explanation for Norway Maple size is that they grow more rapidly. Another explanation is that the Norway Maple is better adapted than the Sugar Maple to the urban growing conditions in AG. Unfortunately, planting records do not exist for AG, so these arguments cannot be fully substantiated. It is likely that the observed differences in these two species are a combination of both factors.

4.2.5 Tree Condition

Tree condition indicates both how well trees are managed and their relative performance given the growing environment within an urban park. The structural condition of trees (branches) in AG was found to be good, with 87% receiving a fair or better designation (Appendix 5B). Similarly, the functional condition (foliage) was also found to be sound, with 95% receiving a fair or better rating. The species in AG whose structure was determined to be deteriorating (i.e., very poor or dead condition) were the following: Japanese Yew (16.7%), Sugar Maple (8.5%), Silver Maple (7.1%), and Columnar Norway Maple (6.7%) (Appendix B5). Whereas, the species in AG whose foliage was found to be deteriorating (i.e., poor or dead condition) were the following: Green Ash (40%), Japanese Yew (33.4%), Siberian Elm (8.7%), Columnar Norway Maple (6.7%), and Sugar Maple (5.1%) (Appendix B6).

4.2.6 Tree Replacement Value

Replacement value should be distinguished from the value of annual benefits produced by an urban forest. The latter is discussed in Section 4.3, and is defined as a 'snapshot' of the benefits provided by the total tree population in AG for a single year. The replacement value of an urban forest reflects its current population number, stature, placement, and condition (Peper et al., 2007). Hence, replacement value accounts for the historical investment in trees over their lifetime. Therefore, the replacement value of the AG tree population would be expected to be many times greater than the value of annual benefits it produces. The STRATUM model employs a cost approach to evaluate the value of a tree and assumes that the replacement value of the tree equals the cost of production (i.e., the cost of replacing a tree in its current state) (McPherson et al., 2006; Peper et al., 2007). In Table 4.5, replacement values are described for the 10 most prevalent species found in AG. In instances where a replacement value of $0 is allocated for tree species throughout the DBH ranges, it indicates that, as of August 2008, there were no trees of this particular species existing within this size class.

Table 4.5: Replacement value, by DBH class, for the 10 most valuable tree species in Allan Gardens

All values are reported in CAD $. STRATUM reports replacement values in US $, exchange rate conversion was done at the average 2007 rate of 1.074 CAD $ to 1 US $. Values produced by STRATUM in Appendix B7 are retained in original US $ currency.

Species	DBH class (cm)									Total	% of total
	0-8	8-15	15-30	30-46	46-61	61-76	76-91	91-107	>107		
Norway Maple	$0	$560	$5,307	$69,317	$62,396	$159,870	$42,644	$28,168	$31,425	$399,687	19.49
Black Walnut	$0	$0	$0	$0	$0	$21,853	$127,253	$0	$46,968	$196,074	9.56
Crimean Linden	$0	$0	$0	$12,097	$139,185	$38,925	$0	$0	$0	$190,208	9.27
Littleleaf Linden	$0	$0	$2,245	$24,194	$23,544	$0	$84,948	$0	$41,787	$176,719	8.62
Silver Maple	$0	$0	$0	$0	$18,166	$33,779	$20,564	$18,892	$84,252	$175,654	8.56
Sugar Maple	$1,282	$57	$28,565	$62,935	$24,222	$29,702	$0	$0	$0	$146,764	7.16
Scotch Elm	$0	$0	$0	$0	$6,055	$9,901	$42,983	$0	$21,063	$80,002	3.90
Tree of Heaven	$138	$0	$0	$0	$0	$43,706	$31,813	$0	$0	$75,657	3.69
Austrian Pine	$0	$0	$6,021	$16,005	$10,343	$17,072	$24,819	$0	$0	$74,260	3.62
Siberian Elm	$0	$0	$7,373	$38,776	$18,166	$9,901	$0	$0	$0	$74,216	3.62
Other trees	$3,065	$12,359	$89,224	$57,006	$24,287	$63,508	$99,276	$77,274	$35,931	$461,930	22.52
AG-wide total	$4,485	$12,977	$138,736	$280,329	$326,365	$428,217	$474,300	$124,334	$261,427	$2,051,170	100.00

The average replacement value for a tree in AG was estimated at $6,638. Norway Maples account for approximately 19.5% of the total replacement cost, followed by Black Walnut (9.6%), Crimean Linden (9.3%), Littleleaf Linden (8.6%), and Silver Maple (8.6%). The DBH class with the greatest replacement cost was the 76–91 cm segment ($474,300). It is important to note that while Siberian Elms are among the larger trees on the study site, their replacement value does not rank as high as Norway Maple because they are found in fewer numbers (population of 23 trees), and have somewhat smaller crowns (average crown surface area of 225 m^2). Norway Maples are more abundant (population of 41 trees), have a more variant tree structure and crown dimensions (average crown surface area of 270 m^2).

On the whole, replacing AG's 309 public trees with ones of similar species, size, and condition should, for example, most trees be heavily damaged by a catastrophic event such as one similar to the 1998 ice storm, would cost approximately $2.05 million. Hence, AG trees are a considerable public asset and a significant component of City of Toronto's green infrastructure. However, it is important to realize that in the case of such a storm, trees of mature stature could never be replaced immediately.

4.3 Benefits Provided by Trees in Allan Gardens

In this section, the benefits of AG's public trees are evaluated. It should be noted that this is not a full accounting of all the benefits provided by this urban forest, because some benefits are intangible or otherwise difficult to measure (e.g., psychological). In addition, this is not an exhaustive accounting of all the environmental benefits provided by the urban forest, due to limitations of knowledge concerning the physical interactions between tree and pollutant. A full accounting of the benefits of an urban forest would take added account of the site-specific variability in tree species growth rates, and individual tree crown structure. Benefit estimates produced by STRATUM represent a general accounting of the benefits provided by AG public trees (Peper et al., 2007). They do, however, provide an important platform from which urban forest management decisions can be made.

4.3.1 Annual Energy Savings

Electricity and natural gas saved annually in the City of Toronto (Table 4.6), resulting from both shading and micro-climate related benefits produced by AG's urban forest amount to 84.8 GJ (valued at $1,190), and 936.5 GJ (valued at $9,914) respectively. This equated to a total annual energy saving of $11,104, or an average saving of $35.93/tree.

Table 4.6: Annual energy savings produced by 10 dominant tree species in Allan Gardens
Refer to Appendix C1 for full STRATUM report

Species	Total Electricity (GJ)	Electricity ($)	Total Natural Gas (GJ)	Natural Gas ($)	Total ($)	% of Total Trees	% of Total $	Avg. $/tree
Sugar Maple	10.3	145	131	1,387	1,532	19.1	13.8	25.97
Norway Maple	14.6	205	161	1,702	1,907	13.3	17.2	46.51
Siberian Elm	5.7	80	66	703	783	7.4	7.1	34.04
Red Ash	2.4	34	31	326	359	5.5	3.2	21.14
Crimean Linden	5.9	83	67	714	797	5.2	7.2	49.8
Columnar Norway Maple	2.1	29	28	295	325	4.9	2.9	21.66
Silver Maple	9.3	130	93	987	1,117	4.5	10.1	79.82
Littleleaf Linden	3.1	43	36	379	422	3.6	3.8	38.35
Austrian Pine	1.9	27	21	217	243	2.9	2.2	27.01
Other trees	29.5	414	302.6	3204	3619	33.6	32.5	x
AG-wide total	84.8	1,190	936.5	9,914	11,104	100	100	35.93

Norway Maple trees provide 17% of the energy savings and account for 13% of the total tree population; this was expected for a tree species with the highest IVal. Sugar Maples (14% of total energy savings) and Silver Maples (10% of total energy savings) make the next greatest contributions. On a per tree basis, Scotch Elm trees were the greatest contributors, providing energy savings of approximately $95/tree annually (Appendix C1). Black Walnuts and Silver Maples provide the next great savings on a per tree basis ($87 and $80, respectively) (Appendix C1). Scotch Elm, Black Walnut and Silver Maple were among the older and larger trees at the time of the inventory, explaining why their energy benefits per tree were higher than younger, yet large-growing, trees (e.g., Norway Maples provided an average energy savings of approximately $46.51/tree). As these younger species age and increase in size, their contributions to energy saving for the City of Toronto will increase accordingly.

4.3.2 Annual Atmospheric Carbon Dioxide (CO_2) Reduction

In addition to carbon sequestered by AG trees, other aspects that involve the carbon cycle in an urban ecosystem include CO_2 released when park personnel use machinery for maintenance and planting procedures (e.g., chain saws, vehicles). This CO_2 release is termed maintenance release (MR). Further, when a tree dies, all the carbon that accumulated in the woody biomass over the tree's lifetime is released back into the ecosystem as wood decomposes. This CO_2 release is referred to as decomposition release (DR). STRATUM considers these factors when estimating the CO_2 benefits of trees.

AG's urban forest was estimated to reduce atmospheric CO_2 by a net 51,895 kg annually (Table 4.7). This benefit was valued at $858, or $2.78/tree. Avoided CO_2 emissions from power plants totalled 32,193 kg, whereas CO_2 sequestered by trees totalled 27,201 kg. CO_2 released via MR and DR amounted to 7,500 kg, or a cost valued at $124. On a per tree basis, Scotch Elm ($9.93/tree), Silver Maple ($5.85/tree), Black Walnut ($5.79/tree), and Norway Maple ($5.39/tree) trees provide the greatest CO_2 removal benefits (Appendix C2). Due to their crown surface area and tree structure, Norway Maples provided the highest total benefits accounting for nearly 26% of AG's urban forest.

Table 4.7: Annual CO_2 reductions, releases, and net benefits produced by dominant tree species in Allan Gardens
Refer to Appendix C2 for full STRATUM report

Species	Sequestered (kg)	Sequestered ($)	DR (kg)	MR (kg)	Total Released ($)	Avoided (kg)	Avoided ($)	Net Total (kg)	Total ($)	% of Total trees	% of Total ($)	Avg. $/tree
Sugar Maple	3,119	52	-675	-202	-15	3,924	65	6,166	102	19.1	11.9	1.73
Norway Maple	9,005	149	-915	-263	-19	5,541	92	13,368	221	13.3	25.8	5.39
Siberian Elm	1,871	31	-467	-91	-9	2,152	36	3,465	57	7.4	6.7	2.49
Red Ash	326	5	-61	-40	-2	907	15	1,132	19	5.5	2.2	1.10
Crimean Linden	1,020	17	-780	-112	-15	2,254	37	2,382	39	5.2	4.6	2.46
Columnar Norway Maple	748	12	-158	-4	-3	796	13	1,341	22	4.9	2.6	1.48
Silver Maple	2,311	38	-720	-158	-15	3,521	58	4,954	82	4.5	9.6	5.85
Littleleaf Linden	402	7	-212	-68	-5	1,170	19	1,292	21	3.6	2.5	1.94
Austrian Pine	154	3	-44	-47	-2	717	12	780	13	2.9	1.5	1.43
Autumn Blaze Maple	33	1	-1	-4	0	15	0	43	1	2.6	0.1	0.09
Other trees	8,212	135	-1,986	-492	-39	11,196	185	16,972	281	31	33	x
AG-wide total	27,201	450	-6,019	-1,481	-124	32,193	532	51,895	858	100	100	2.78

4.3.3 Annual Air Quality Improvement

Approximately 133 kg of O_3, NO_2, PM_{10}, and SO_2 are annually intercepted either in the form of pollutant deposition or particle absorption by AG's trees (Table 4.8). This interception was valued at an annual saving of $1,520 for the City of Toronto.

Table 4.8: Pollutant deposition benefits produced by dominant tree species in Allan Gardens
Refer to Appendix C3 for full STRATUM report

Species	Deposition (kg) O_3	NO_2	PM_{10}	SO_2	Total Deposition (kg)	Total Deposition ($)	% of Total Trees	% of Total (kg)	% of Total ($)
Sugar Maple	7.1	3.1	3.5	1.2	14.9	170	19.1	11.2	11.2
Norway Maple	11.2	4.8	5.5	1.8	23.3	267	13.3	17.5	17.6
Siberian Elm	3.7	1.5	1.7	0.6	7.5	86	7.4	5.6	5.7
Red Ash	1.6	0.7	0.7	0.2	3.2	37	5.5	2.4	2.4
Crimean Linden	4.2	1.7	2.0	0.6	8.5	98	5.2	6.4	6.4
Columnar Norway Maple	1.5	0.6	0.7	0.2	3	35	4.9	2.3	2.3
Silver Maple	7.5	3.3	3.7	1.2	15.7	180	4.5	11.8	11.8
Littleleaf Linden	2.1	0.9	1.0	0.3	4.3	50	3.6	3.2	3.3
Austrian Pine	1.9	0.9	1.2	0.5	4.5	48	2.9	3.4	3.2
Autumn Blaze Maple	0.0	0.0	0.0	0.0	0	1	2.6	0.0	0.1
Other trees	23.1	9.8	11.4	3.9	48	548	31	36.1	36.1
AG-wide total	63.9	27.3	31.4	10.5	133	1,520	100.00	100.0	100.0

O_3 and PM_{10} were the pollutants deposited or absorbed in the greatest quantity by AG's trees. Due to its substantial leaf area, Norway Maples contribute the most to absorption and deposition of pollutants, removing a total of 23.3 kg annually, and accounting for almost 17.5% of the overall pollutant deposition and uptake benefits. Silver Maples were the second most important contributors, accounting for approximately 11.8% of the total benefits. The next most significant at pollution abatement in AG were found to be Sugar Maple (14.9 kg) and Crimean Linden (8.5 kg), each accounting for approximately 11.2% and 6.4% of the total amount saved annually from air pollutant emission reduction.

Offsets to energy demand provided by AG's urban forest (mostly a result of summertime cooling) causes a reduction in air emissions for the pollutants NO_2, PM_{10}, VOC, and SO_2. Collectively, a total of 148.2 kg of these pollutants are avoided annually, with an estimated value of $1,615 (Table 4.9). The largest avoided NO_2 emissions were provided by the Norway Maple (15.9 kg). Additionally, AG's Norway Maples provided the greatest overall impact on reducing pollutants, 25.6 kg otherwise emitted from power plants was avoided annually; this was valued at $278 for 2008. Sugar and Silver Maples were the next greatest contributors of benefits, contributing to the avoidance of 19 and 15.8 kg of air pollutants annually, and providing a saving of $208 and $170 respectively (Table 4.9).

Table 4.9: Avoided pollutant benefits provided by dominant tree species in Allan Gardens
Refer to Appendix C3 for full STRATUM report

Species	Avoided (kg)				Total Avoided (kg)	Total Avoided ($)	% of Total Trees	% of Total (kg)	% of Total ($)
	NO_2	PM_{10}	VOC	SO_2					
Sugar Maple	12.0	0.8	0.5	5.7	19	208	19.1	12.8	12.9
Norway Maple	15.9	1.0	0.6	8.1	25.6	278	13.3	17.3	17.2
Siberian Elm	6.4	0.4	0.2	3.1	10.1	111	7.4	6.8	6.9
Red Ash	2.8	0.2	0.1	1.3	4.4	49	5.5	3.0	3.0
Crimean Linden	6.6	0.4	0.3	3.3	10.6	114	5.2	7.2	7.1
Columnar Norway Maple	2.5	0.2	0.1	1.2	4	43	4.9	2.7	2.7
Silver Maple	9.7	0.6	0.4	5.1	15.8	170	4.5	10.7	10.5
Littleleaf Linden	3.4	0.2	0.1	1.7	5.4	60	3.6	3.6	3.7
Austrian Pine	2.0	0.1	0.1	1.0	3.2	36	2.9	2.2	2.2
Autumn Blaze Maple	0.1	0.0	0.0	0.0	0.1	1	2.6	0.1	0.1
Other trees	31.2	2.1	1.2	16.4	50	751	31	33.7	46.5
AG-wide total	92.6	6.0	3.6	46.9	148.2	1,615	100.00	100.0	100.0

Many trees species emit a small about of hydrocarbons from their leaves, such as isoprene and monoterpenes, into the atmosphere as biogenic volatile organic compounds (BVOCs) (Penuelas and Llusia, 2003; Manning, 2008). These BVOCs become a small part of the photochemical production cycle that produces O_3. Anthropogenically produced volatile organic compounds are referred to as VOCs. When both VOCs and BVOCs are added to the photochemical oxidant cycle, they react with O_2 to produce hydrocarbon free radicals, which further react with nitrogen oxides (NO_X). In sufficient quantities, VOC and BVOC emissions decrease the O_3 breakdown process; this can cause ground level O_3 concentrations to accumulate in the atmosphere (Penuelas and Llusia, 2003; Manning, 2008). Therefore, BVOC emissions from trees must be considered. It was found that AG's trees account for a total of 20.5 kg of BVOC produced annually; they offset about 7.2% of the air quality improvement and are estimated to have an annual cost to the City of $281 (Table 4.10). Austrian pine trees are the heaviest contributors of BVOCs, accounting for nearly 19% of AG's total emissions. Comparatively, Red Ash and Siberian Elm were determined to be the lowest emitters, with relatively undetectable contributions.

Table 4.10: BVOC emissions costs and net air quality benefits provided by dominant tree species in Allan Gardens
Refer to Appendix C3 for full report

Species	BVOC Emissions (kg)	BVOC Emissions ($)	Net Total Emissions (kg)	Net Total Emissions ($)	% of Total Trees	% of Total ($)	Avg. $/tree
Sugar Maple	-3.3	-45	30.5	333	19.1	11.7	5.64
Norway Maple	-2.0	-27	47	517	13.3	18.1	12.62
Siberian Elm	0.0	0	17.6	196	7.4	6.9	8.53
Red Ash	0.0	0	7.6	85	5.5	3.0	5.01
Crimean Linden	-2.1	-29	17	184	5.2	6.4	11.50
Columnar Norway Maple	-0.2	-2	6.8	76	4.9	2.7	5.04
Silver Maple	-2.8	-38	28.8	312	4.5	10.9	22.31
Littleleaf Linden	-1.1	-15	8.8	95	3.6	3.3	8.64
Austrian Pine	-3.9	-53	3.9	31	2.9	1.1	3.41
Autumn Blaze Maple	0.0	0	0.1	1	2.6	0.0	0.18
Other trees	-5.1	-72	92.9	1024	31	35.9	x
AG-wide total	-20.5	-281	261.0	2,854	100.00	100.0	9.24

Environment Canada (2008) estimated that the total VOC emissions in Canada for 2005 approximated 1.93 million tonnes (Environment Canada's definition of VOCs includes both anthropogenic and natural sourced emissions). The primary sources were found to be: 1) transportation (31%); 2) upstream oil and gas industry (26%); 3) industrial sources (e.g., petroleum refineries, pulp and paper, plastics manufacturing) (13%); 4) commercial and consumer products (e.g., solvent use, surface coating, printing) (12%); 5) residential wood combustion and incineration (8%); and, 6) all other sources (of which BVOCs are merely a fraction) accounted for the remaining 10% (Environment Canada, 2008). Therefore, it is important to note that anthropogenic caused VOC emissions from traffic alone in Canada are, comparatively, so high that BVOCs from trees have little effect on overall air quality. This statement is supported by a study conducted in the West Midlands metropolitan area of the UK that found BVOCs emissions were much lower than anthropogenic VOC estimates for the same area (Owen et al., 2003). These authors maintain that although urban tree canopies produce BVOCs, this is only a point of concern in areas that experience a high occurrence of NO_X emissions; in almost all cases, expanding urban tree canopy density is strongly advocated for its capacity to serve as a large sink for many air pollutants which far outweighs its contribution to the formation of O_3. Therefore, this should be considered a near negligible drawback to the urban forest, and does not constitute an argument for failing to protect and enhance AG's trees.

Net air pollutants removed, released, and avoided by AG's urban forest are also presented in Table 4.10. This total interaction with the atmosphere provided a net benefit valued at approximately \$2,854 annually, with an average benefit per tree of \$9.24. Trees vary dramatically in their inherent ability to produce net air quality benefits. Typically, trees supporting large canopies with large leaf surface areas, and that are not high BVOC emitters, produce the greatest benefits for urban air quality. Although Norway Maple trees are moderately high emitters of BVOCs, the large leaf surface area associated with this species counteracts the overall effect, reducing nearly 24 times the pollutants (47 kg) than they produce (2 kg) for a net total emissions benefit that was 18% of the total net air quality benefit produced by AG's trees. On a per tree basis, Norway Maples provided an average of \$12.62 of annual benefits, and ranked second to Silver Maple trees, which provided an average of \$22.31 in annual savings. Despite providing the highest benefits per tree, Silver Maple trees were the third highest remover of pollutants, extracting approximately 28.8 kg, and only producing 2.8 kg of BVOCs. Sugar Maples were the second best pollutant removers (30.5 kg) while being moderately high emitters of BVOCs (3.3 kg). Sugar Maples, mostly because of their comparatively smaller stature, accounted for only 11.7% of the overall air quality benefit produced by AG's urban forest.

4.3.4 Annual Stormwater Runoff Mitigation

AG's public trees intercept 1,920 m^3 of stormwater annually; the total value of this benefit to the city was determined to be \$3,701, or \$12/tree (Table 4.11). Certain species are far more successful at mitigating stormwater runoff than others (McPherson et al., 2006; Peper et al., 2007). Tree size, shape, leaf type, leaf area, branching pattern, and bark texture all affect the extent to which precipitation can be intercepted (Xiao and McPherson, 2002). The top three tree species to provide this benefit included Black Walnut (\$43.45/tree), Scotch Elm (\$39.94/tree), and Silver Maple (\$35.39/tree) (Appendix C4).

Table 4.11: Annual stormwater reduction benefits provided by dominant tree species in Allan Gardens
Please refer to Appendix C4 for STRATUM report

Species	Total rainfall interception (m^3)	Total ($)	% of Total Trees	% of Total ($)	Avg. $/tree
Sugar Maple	215	415	19.1	11.2	7.04
Norway Maple	313	603	13.3	16.3	14.71
Siberian Elm	114	220	7.4	5.9	9.57
Red Ash	43	83	5.5	2.2	4.91
Crimean Linden	111	214	5.2	5.8	13.38
Columnar Norway Maple	32	62	4.9	1.7	4.15
Silver Maple	257	495	4.5	13.4	35.39
Littleleaf Linden	57	111	3.6	3.0	10.07
Austrian Pine	49	95	2.9	2.6	10.52
Autumn Blaze Maple	1	2	2.6	0.1	0.21
Other trees	728	1,401	31	37.9	x
AG-wide total	1,920	3,701	100.00	100.0	11.98

As a percentage of overall stormwater interception benefits, the Norway Maple accounted for the highest contribution at 16%; Silver Maple trees accounted for 13%; and, Sugar Maples accounted for 11% (Table 4.11). Not surprisingly, trees that performed poorly at stormwater interception were characteristically small with relatively less leaf and stem area, such as Autumn Blaze Maple ($0.21/tree) and Amur Maple ($0.27/tree) (Appendix C4). The stormwater mitigation performance of other trees, such as Northern Red Oak and Autumn Blaze Maple is expected to improve as their younger cohort matures in size and structure. However, it is important to note that the Red Ash population rooted in the sidewalk cutouts, while small in stature, is not expected to grow much given the constraints of its growing medium; hence, its population's performance is not expected to improve significantly.

4.3.5 Annual Aesthetic and Other Benefits

To estimate the value of other intangible benefits, research has compared the difference in sale prices of houses to estimate the contribution associated with proximity to trees and park land (Peper et al., 2007). This difference in price reflects the willingness of buyers to pay for the perceived benefits associated with proximity to treed properties. STRATUM uses an approach designed to capture what house buyers perceive as both the benefits and costs of access to trees in a property sales price. One challenge to the application of this approach is the difficulty associated with extrapolating results from front-yard trees on residential properties to trees in other location s (e.g. urban park vs. commercial land).

With regard to aesthetic benefit, calculation is directly related to a tree's annual increase in leaf area (McPherson et al., 2006). When a tree is actively growing, leaf area increases annually. At maturity, there may be no net increase in leaf area from year to year, thus there is little or no incremental increase in annual aesthetic benefit from that year forward; instead, a comparatively high sustained aesthetic benefit exits. Because this project represents a 1-year snapshot of AG's tree population, benefits reflect the present leaf area for each tree for the year studied (Table 4.12). Therefore, one would expect that the young population of Autumn Blaze Maples would have a much greater annual increase in benefit than an equal number of mature Sugar Maples. However, the cumulative aesthetic value, based on leaf area, of the Sugar Maples would be much greater than that of the young Silver Maples.

Table 4.12: Annual aesthetic and other benefits provided by dominant tree species in Allan Gardens
Refer to Appendix C5 for full STRATUM report

Species	Total ($)	% of Total trees	% of Total $	Avg. $ / Tree
Sugar Maple	3,500	19.1	15.0	59.32
Norway Maple	4,669	13.3	20.0	113.88
Siberian Elm	2,791	7.4	11.9	121.36
Red Ash	1,054	5.5	4.5	62.02
Crimean Linden	583	5.2	2.5	36.41
Columnar Norway Maple	629	4.9	2.7	41.95
Silver Maple	1,004	4.5	4.3	71.68
Littleleaf Linden	387	3.6	1.7	35.14
Austrian Pine	266	2.9	1.1	29.60
Autumn Blaze Maple	602	2.6	2.6	75.22
Other trees	7,888	31	33.7	X
AG-wide total	23,373	100.00	100	75.64

The estimated total annual benefit associated with property value increases and other less tangible benefits was found to be $23,373, or $75.64/tree on average (Table 3.12). Trees which produced the highest average annual benefits include Scotch Elm ($208.36/tree), Tree of Heaven ($133.53/tree), Siberian Elm ($121.36/tree), and Norway Maple ($113.88/tree) (Appendix C5).

4.3.6 Annual Benefits of Allan Gardens Trees by Species

Of the dominant species in AG, Silver Maples were found to be the most valuable at providing benefits ($215/tree), followed by Norway Maple ($193/tree) and Siberian Elm ($176/tree) (Table 4.13). Columnar Maple ($74/tree) and Austrian Pine ($72/tree) were found to contribute the least on a per tree basis; however, it should be noted that although they contribute the least relative to the other eight dominant tree species, they are still responsible for a significant overall contribution of the benefits provided by AG's urban forest (Table 4.13). For non-dominant tree species, Scotch Elm ($385/tree), Black Walnut ($278/tree), and Tree of Heaven ($250/tree) produced the most significant benefits (Appendix C6).

Table 4.13: Average annual benefits ($/tree) of the dominant tree species in Allan Gardens
Refer to Appendix C6 for full STRATUM report

Species	Energy	CO_2	Air Quality	Stormwater	Aesthetic & Other	$/tree
Sugar Maple	25.97	1.73	5.64	7.04	59.32	99.70
Norway Maple	46.51	5.39	12.62	14.71	113.88	193.10
Siberian Elm	34.04	2.49	8.53	9.57	121.36	175.98
Red Ash	21.14	1.10	5.01	4.91	62.02	94.18
Crimean Linden	49.80	2.46	11.50	13.38	36.41	113.55
Columnar Norway Maple	21.66	1.48	5.04	4.15	41.95	74.29
Silver Maple	79.82	5.85	22.31	35.39	71.68	215.05
Littleleaf Linden	38.35	1.94	8.64	10.07	35.14	94.13
Austrian Pine	27.01	1.43	3.41	10.52	29.60	71.99
Autumn Blaze Maple	0.98	0.09	0.18	0.21	75.22	76.68

4.3.7 Total Annual Benefits Derived from Trees in Allan Gardens

Total annual benefits produced by AG's trees are estimated at $60,407; total environmental benefits approximated $18,517 (31% of the total annual benefits). Of these environmental benefits, energy savings ($11,104) accounted for 60% or 18% of the total annual benefits provided by AG's trees (Table 4.14). Stormwater reduction savings ($3,701) accounted for 20% of the environmental benefits, 6.1% of the total annual benefits, whereas air quality improvement ($2,854) accounted for 15% of the environmental benefits or 4.7% of total annual benefits. CO_2 reduction benefits ($858) account for 4.6% of the total environmental benefits (1.4% of the total). Finally, the effect on property value cultivated by AG's trees accounted for 69.3% of the total benefits provided by this forested urban park.

Table 4.14: Total annual benefits provided by dominant tree species in Allan Gardens
Refer to Appendix C7 for full STRATUM report

Species	Energy ($)	CO_2 ($)	Air Quality ($)	Stormwater ($)	Environmental Benefits ($)	% of Environmental Benefits	Aesthetic & Other ($)	Total Benefits ($)	% of Total Benefits
Sugar Maple	1,532	102	833	415	2,882	15.6	3,500	6,382	10.6
Norway Maple	1,907	221	517	603	3,248	17.5	4,669	7,917	13.1
Siberian Elm	783	57	196	220	1,256	6.8	2,791	4,047	6.7
Red Ash	359	19	85	83	546	2.9	1,054	1,600	2.6
Crimean Linden	797	39	184	214	1,234	6.7	583	1,817	3.0
Columnar Norway Maple	325	22	76	62	485	2.6	629	1,114	1.8
Silver Maple	1,117	82	312	495	2,006	10.8	1,004	3,010	5.0
Littleleaf Linden	422	21	95	111	649	3.5	387	1,036	1.7
Austrian Pine	243	13	31	95	382	2.1	266	648	1.1
Autumn Blaze Maple	8	1	1	2	12	0.1	602	614	1.0
Other trees	3,611	281	524	1,401	5,817	31.4	26,405	32,222	53.3
AG-wide total	11,104	858.0	2,854	3,701	18,517	100.0	41,890	60,407	100.0

4.4 Soil Analysis

Tree root growth can be limited by excessively dense soils which are resistant to penetration and restrictive to the influx of nutrients and water (Craul, 1999; Brady and Weil, 2008). Specifically, root penetration is dependent on soil strength, where variation in soil strength is due to three factors: 1) texture (% sand, silt and clay); 2) compaction levels; and, 3) water content.

4.4.1 Soil Texture

The soil texture analysis of AG found that the dominant soil type was sandy loam. Clay content in the soil was found to be reasonably low throughout the park at less than 5%. Locations within AG that had a greater sand content (greater than 70%), compared to other sections of the park, were mostly found in Sections C and D (Figure 4.3a). The areas which contained the least proportion of sand (less than 60%) were found in Sections A and F (Figure 4.3a). These areas with lower sand content were expected to have higher soil compaction levels. The prediction error map Figure 4.3b (one standard error) confirmed a higher confidence in the soil surface results for areas that were proximate to sampling locations. In areas that were close to park boundaries, there was less confidence in the soil surface map results. However, when the magnitude of error is inspected, prediction confidence is high for the majority of the park.

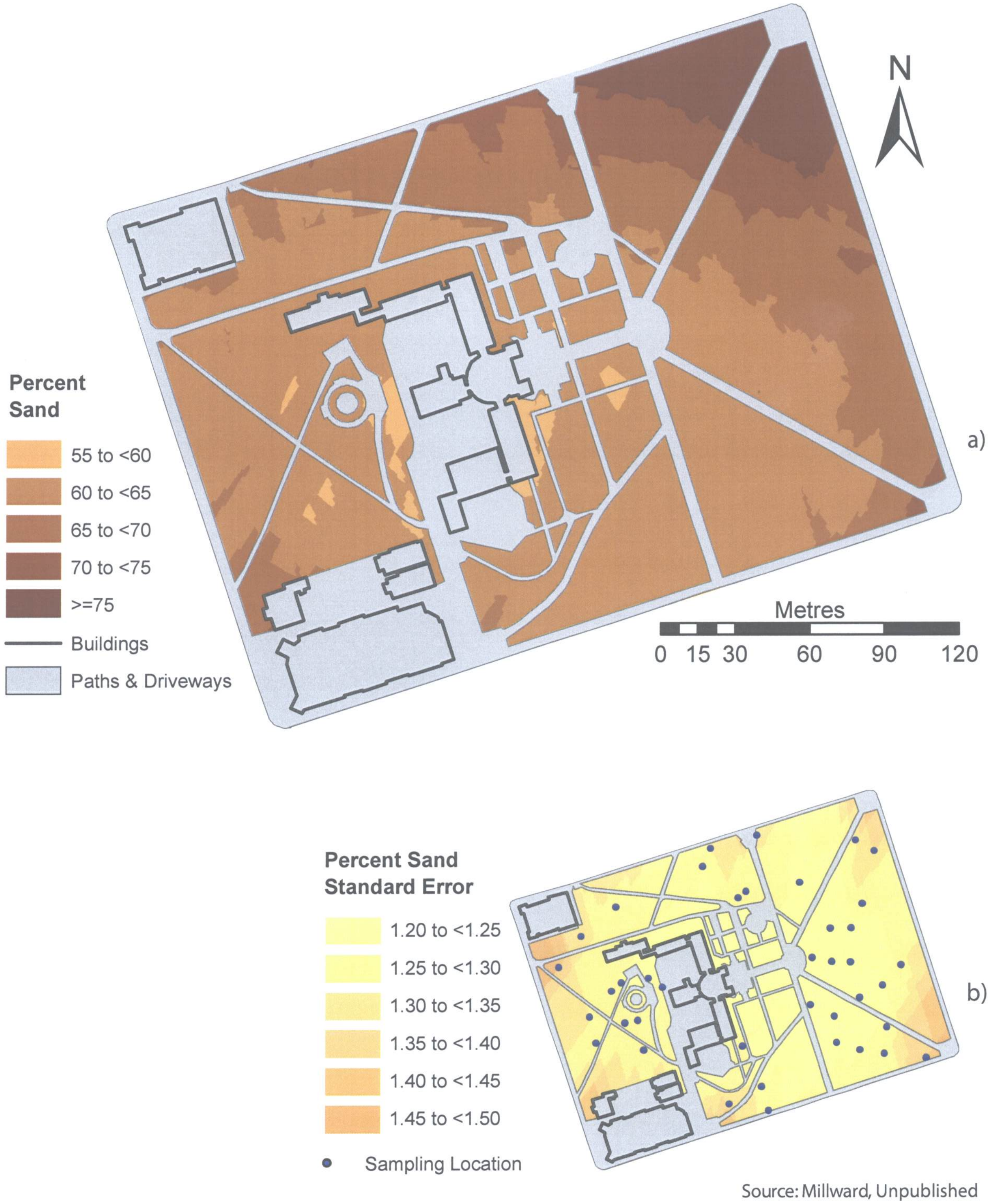


Figure 4.3: Percent of Allan Gardens' soil composed of sand

Sand particles in the soil range in size between 0.05 and 2 mm (Brady and Weil, 2008). Because the particles are relatively large (compared to silt and clay), the pores between them are large also. A soil with a high percentage of sand particles has low specific surface areas (i.e., low surface area for a given mass of particles), which means that it possesses lower capacity to hold water or nutrients (Brady and Weil, 2008). Therefore, while soils with a relatively high content of sand are expected to be well aerated and loose (i.e., experience little compaction), they are sometimes found to be infertile, and often very prone to drought stress (Brady and Weil, 2008). Silt particles are smaller than sand, ranging in size between 0.002 and 0.05 mm (Brady and Weil, 2008). Because these particles are smaller in size, they have more numerous pores between them. In general, soils with higher silt content will retain water when wet, and decelerate soil water drainage. However, due to a limited cohesiveness, soils with high silt content can be susceptible to both wind and water driven erosion (Brady and Weil, 2008).

Soils within AG that had the greater silt content (equal to or greater than 35%) were found in Sections A, E, and F (Figure 4.4a). The areas of the park that contained the least proportion of silt (less than 20%) were found in Sections C and D (Figure 4.4a). The prediction error map Figure 4.4b (one standard error) showed similar results to that produced for sand; locations proximate to sampling sites showed less overall error than those closer to park boundaries. In general, errors were found to be low and confirmed a sound sampling design.

4.4.2 Soil Compaction Analysis

Results show that the soil compaction in AG ranged from 1000 kPa to 1600 kPa at the 7.6 cm depth. The majority of AG was moderately compacted at levels ranging between 1200 and 1400 kPa. Soil at this depth was found to be most compacted (equal to, or greater than, 1400 kPa) in sections A, B, and somewhat in Section F (Figure 4.5a). Most of the highly compacted soil occurred in the vicinity of the conservatory buildings, with the greatest levels (1600 kPa) found Section B (Figure 4.5a). The least compacted soil (equal to, or less than, 1200 kPa) was found in AG Sections C, D, and E (Figure 4.5a).

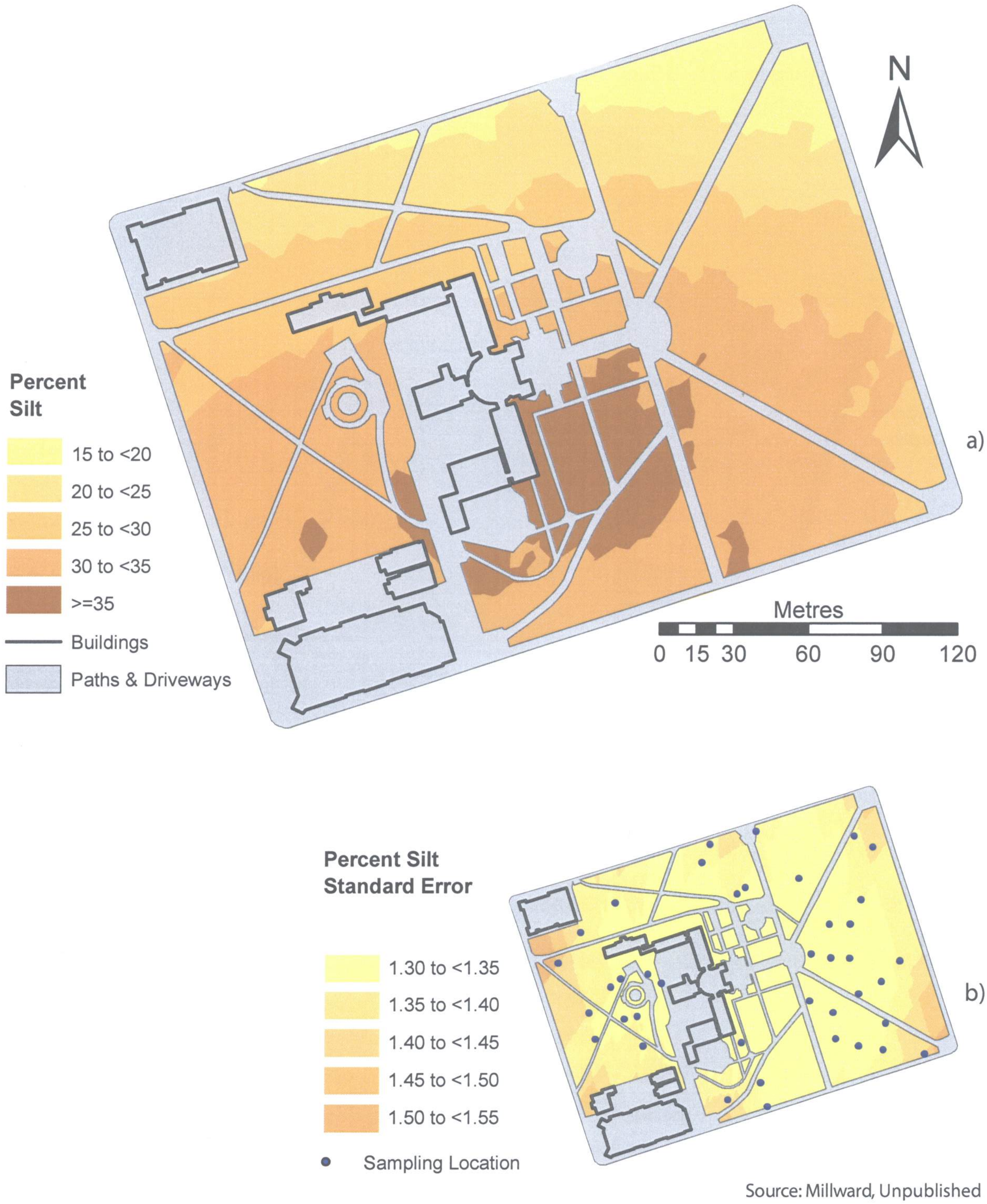
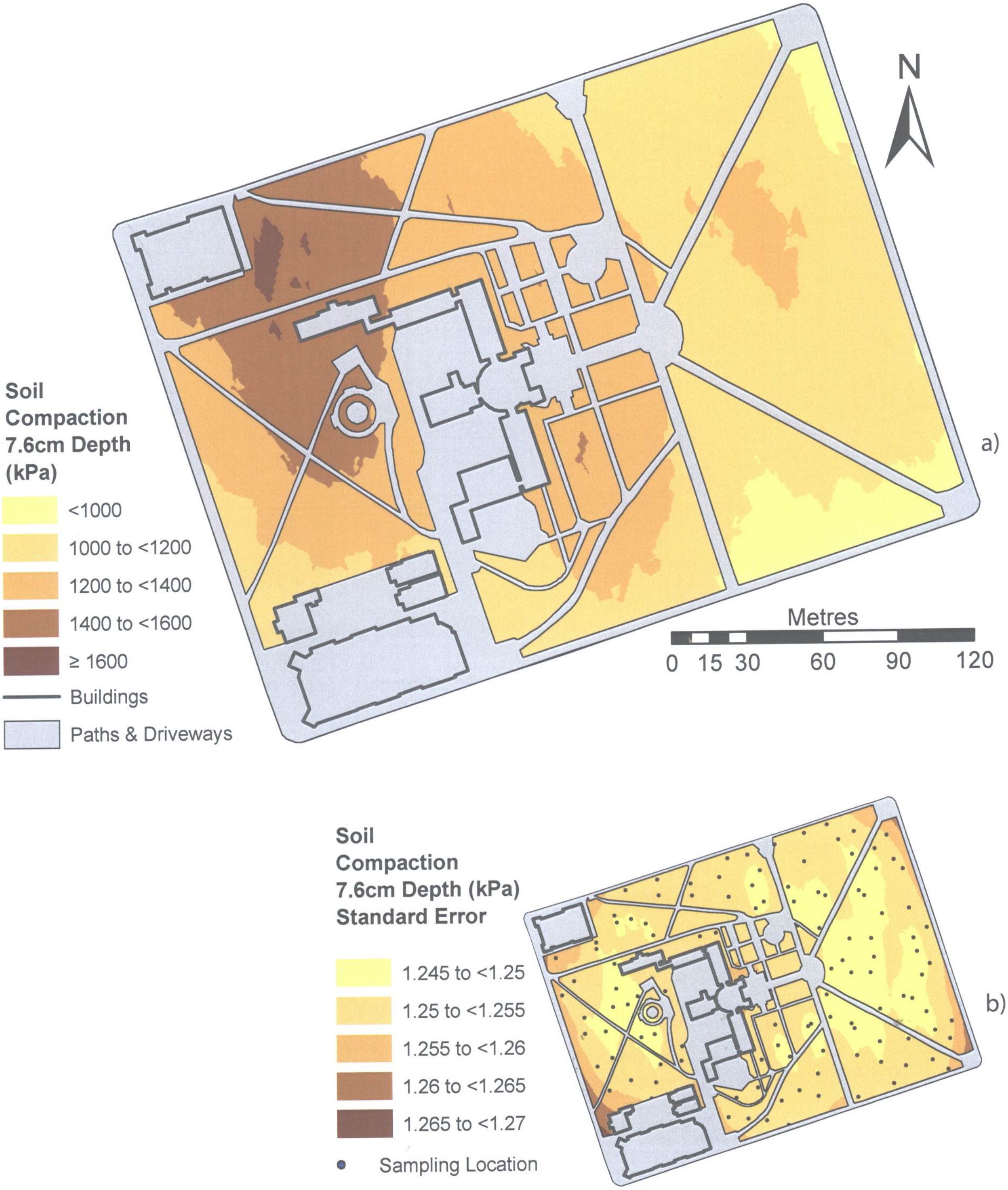


Figure 4.4: Percent of Allan Gardens' soil composed of silt



Source: Toleti, 2008

Figure 4.5: Soil compaction surface for Allan Gardens at 7.6 cm depth

The prediction standard error map (Figure 4.5b) showed strong confidence in compaction estimates for the park, with excellent prediction ability for Sections A, D, and E. This is partially due to the higher number of samples that were taken in this investigation (117 samples).

The results for soil compaction at the 20 cm depth show values that were much higher than those found at 7.6 cm, with ranges from 1000 kPa to greater than 2600 kPa. Soil compaction at the 20 cm depth revealed highly compacted areas in the same locations found for the 7.6 cm depth, Sections A, B, and F (Figure 4.6a). The highest compaction level (equal to or greater than 2600 kPa) was found in the centre of Section B (Figure 4.3a). Sections with lower compaction ranges (1000 – 1400 kPa) at the 20 cm depth were found in Sections D and E, with the lowest values in Section E. Moderate levels of compaction were found in Sections A, B, and F, similar to where high and moderate compaction patterns were found at the 7.6 cm depth (Figure 4.5a). The prediction standard error map (Figure 4.6b) showed relatively strong confidence in compaction estimates for the 20 cm depth. The highest prediction confidence was found in areas proximate to the sampling locations. In locations that were very close to the boundaries of the park, less confidence in the prediction surface was observed.

Section F of the park, which had low sand content, was found to have high compaction at the 20 cm depth. Whereas, Section C, which was composed of higher sand content, exhibited among the lowest compaction levels (Figures 4.3a, 4.4a, and 4.6a). Based on soil compaction at 20 cm depth, and the soil texture analysis, Section F of AG had a higher probability of causing tree root growth restrictions relative to other park locations.

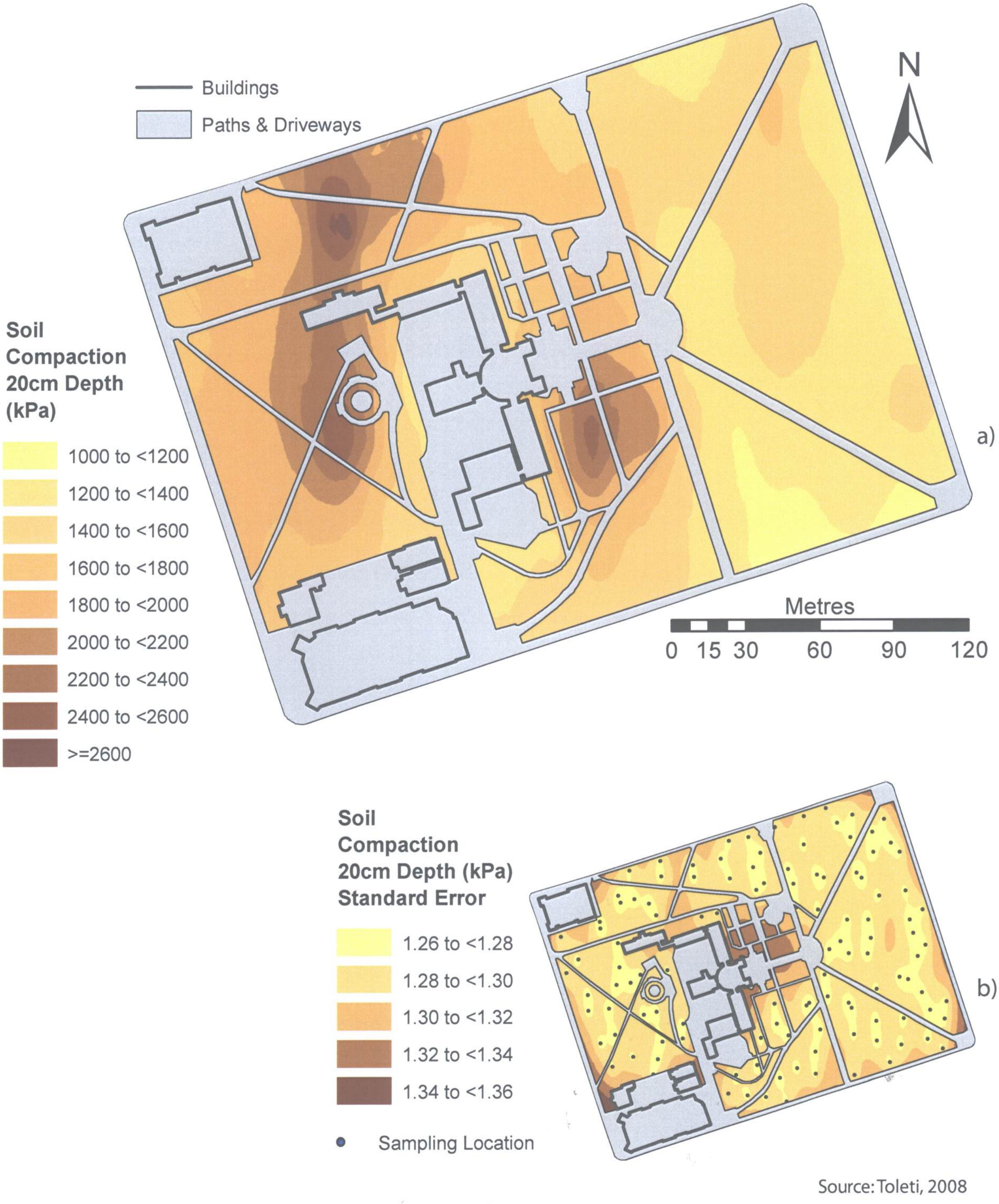


Figure 4.6: Soil compaction surface for Allan Gardens at 20 cm depth

4.4.3 Soil Bulk Density

In Toleti's (2008) analysis of AG soil, bulk density (BD) values were found to be highest (greater than 1.7 g/cm^3) in Section C (Figure 3.7a). The next highest BD range (1.675 to 1.7 g/cm^3) was also found in Section C and in the northern fraction of Section D (Figure 3.7a). Higher levels of BD were attributed to moderate pedestrian and vehicular (both AG park maintenance and police cars) traffic in these regions of the park. No locations within AG (as of 2007) exhibited BD measurements equal to, or greater than, the level at which root growth would be expected to be restricted (i.e., 1.8 g/cm^3) (Hanks and Lewandowski, 2003). However, BD that may cause potential harm to root growth was found; Toleti (2008) measured several areas throughout AG with BD values that exceeded the 1.63 g/cm^3 threshold (moderate risk of limiting tree root growth in sandy and sandy loam soils) (Jim 1998; Craul, 1999). These BD values were found in Sections C, D, and F. A conclusion that plant root growth is not currently restricted by bulk density should be approached with caution, as these values could climb in the near future if soil remediation actions are not undertaken in some of the identified areas of the park.

The area with the lowest values of BD (in the range of 1.525 to 1.55 g/cm^3) was found in Section A of AG (Figure 4.7a).This area of AG was also found to be least compacted, this is attributable to the fact that the park personnel have allocated this section as grounds for children's programming, thus discouraging other activities. This region of the park is fenced off and not accessible to regular park visitors. By limiting the amount of pedestrian and vehicular traffic in this region, compaction levels have been minimized, which in turn led to lower BD values. The lowest range of BD values (1.55 to 1.575 g/cm^3) was found in Sections A, B, D, E, and F (Figure 3.7a). Similar to the other mapped soil surfaces, the prediction error map Figure 3.7b (one standard error) showed higher confidence in the prediction surface results for areas that were proximate to the sampling locations. In areas that are close to the boundaries of the park, there is less confidence in the prediction surface map results.

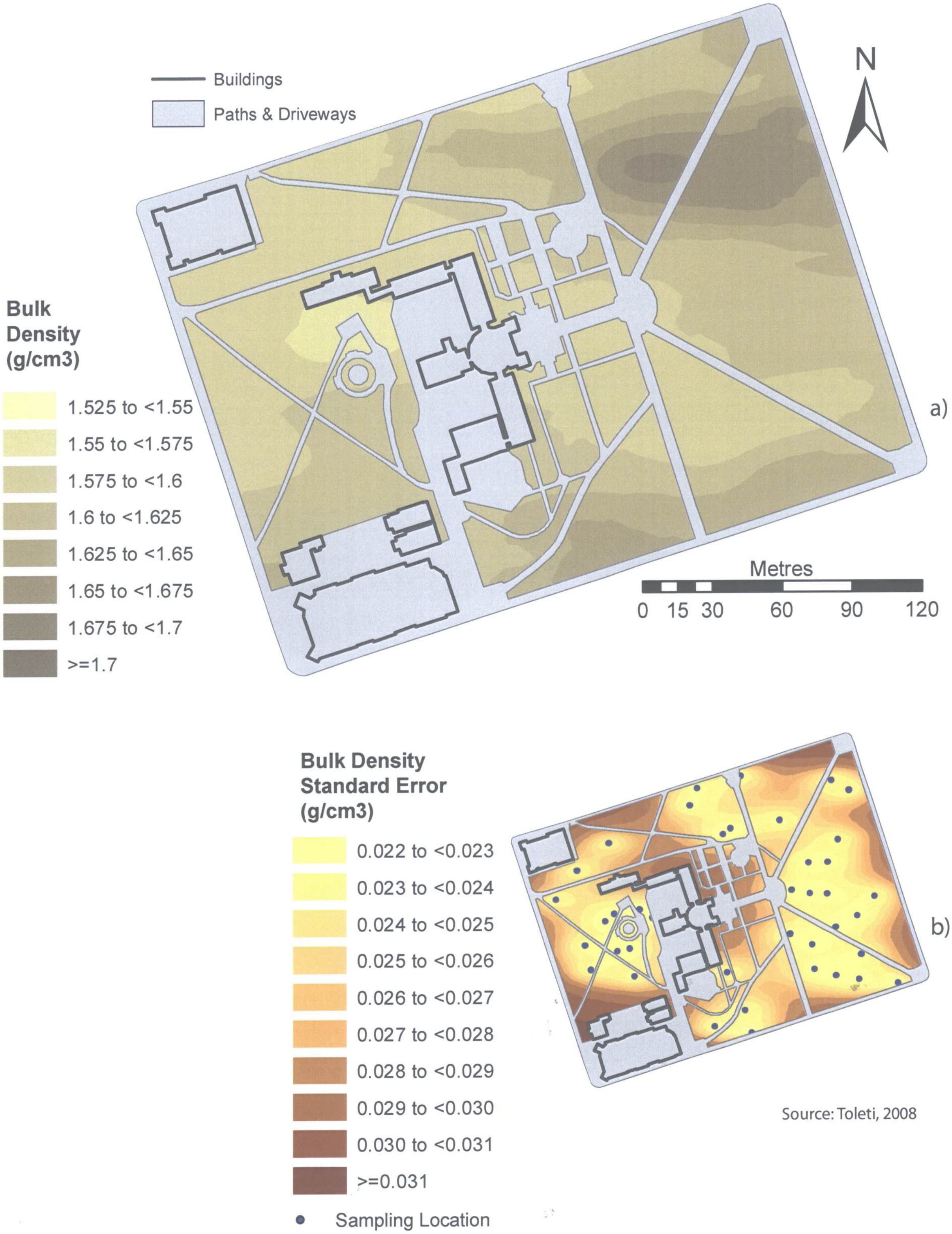


Figure 4.7: Soil bulk density surface for Allan Gardens

4.4.4 Soil Permeability

Genius Soil water content is often indirectly correlated with soil permeability. If soils allow for more water to infiltrate into their pores (i.e., harbouring high permeability levels), then the water content within the soil structure will increase. However, this assumes that the soil texture is such that water would not drain too rapidly, but rather would be retained by the soil and made available for plat root uptake. In cases where permeability may be high, the amount of water retained within the pores is dependent on the percentage silt and clay, as well as organic matter content, within the soil matrix. Low water content in fine textured soils tends to cause soil strength to increase, which consequently presents higher resistance to plant root growth and penetration.

This study found that water movement into the soil varied highly across AG, ranging from 20 mm/hr to 100 mm/hr. The higher the infiltration rate, the higher the permeability of the soil water; this contributes to raising the stormwater runoff mitigation capacity. Provided that soil water has a reasonable residence time, higher permeability may also mean more water availability for plants. The highest infiltration rates (i.e., fastest water permeability) were found in significant portions of Sections A, B (western side), C, D and F, and to some extent in Section E (Figure 4.8a). A high infiltration rate is attributable to the combination of soil texture (high percent sand, relative to other soil particles) and compaction (low compaction values at both surface and deeper sub-surface soil levels). Whereas, the slowest infiltration rates (i.e., the lowest water permeability) were found to be dominant in Sections B (eastern side), and in the centre location of Sections D and E (Figure 4.8a). Moderate water infiltration rates (60 to 80 mm/hr) were found in Sections A to E, and to a lesser degree in Section F. The locations in AG where high water infiltration rates were observed for over 25% of the studied section area were found A, B, and C (Figure 4.8a). Interpretation of the prediction error maps (Figure 4.8b) followed a similar pattern and explanation as was presented for Figure 4.7.

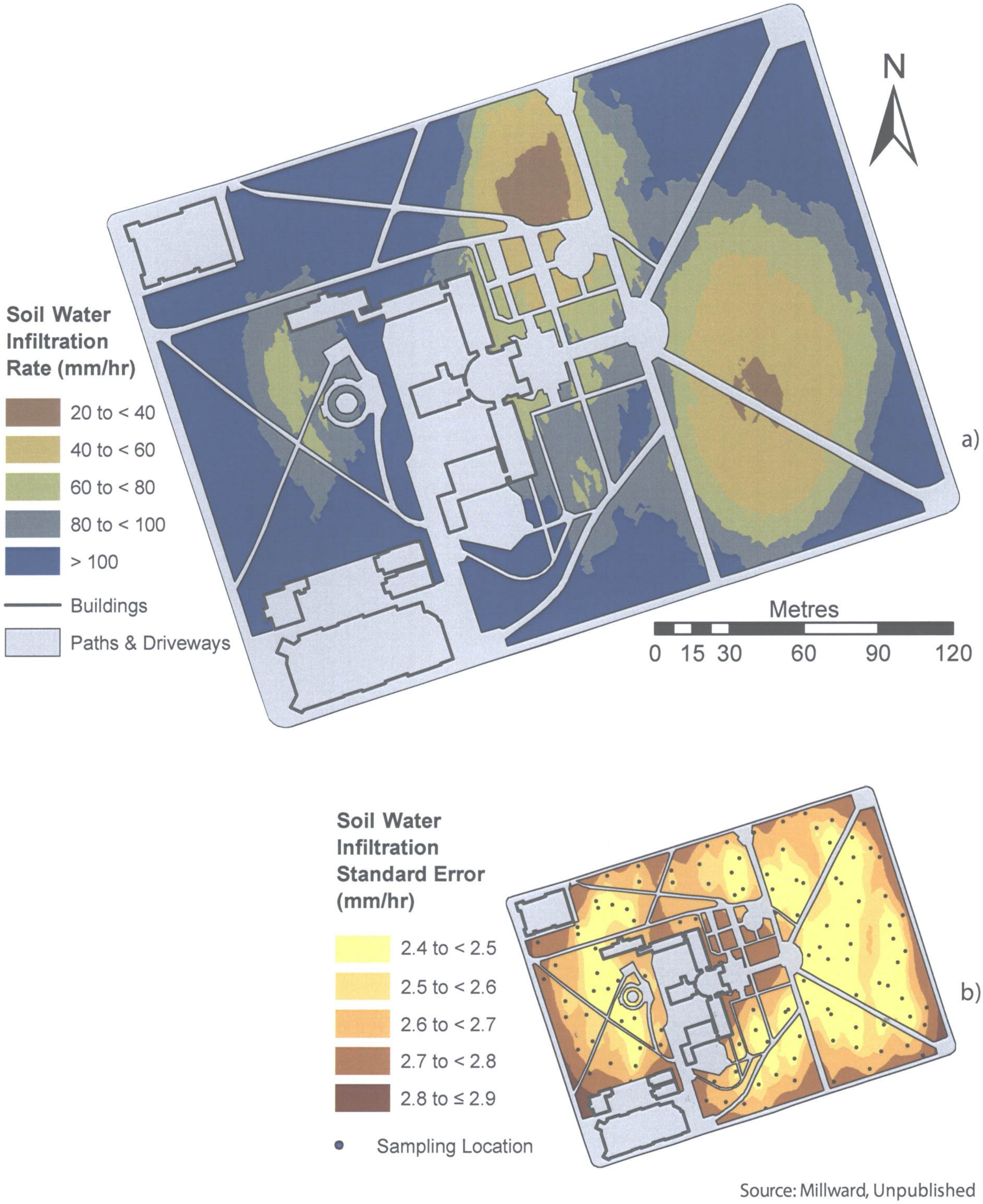


Figure 4.8: Soil water infiltration surface for Allan Gardens

5.0 Conclusions and Management Recommendations

This study has quantified many of the important benefits that AG's urban forest provides to the City of Toronto. To do this, it has produced a 'snapshot' of the current tree resources in the park, which will serve as important baseline data for future management considerations. Given the current status of AG's tree population, an informed discussion regarding the maintenance and management required to sustain, or even increase, the level of annual benefits can occur.

Data (tree resource complexity, tree resource extent, and soil condition), describing AG's urban forest, can assist in the refinement of broader tree management goals. Findings from this study support the City of Toronto shifting its focus away from simply increasing canopy cover toward attaining and meliorating conditions that promote urban forest sustainability. This would provide the City with the desired long-term benefits that accrue from an urban forest composed of a variety of species that are distributed well according to age. Also, it is important to note that the STRATUM analysis methodologies, results, and conclusions found by this study are unique and important, and are recommended for inclusion in future urban park tree management initiatives.

AG's 309 trees are an important asset to the City of Toronto, with a replacement value of $2.05 million and approximately $60,407 in annual benefits. Also, the number of species in AG (45) is remarkable for a downtown urban park considering the varying soil conditions measured across the site. Due to the potential for catastrophic tree loss resulting from disease or pests, the continued population dominance of two species (Sugar Maple and Norway Maples; constituting 19.1% and 13.3% of the total population respectively) is an important management concern. The recent plantings that have occurred in various sections of the park confirm City efforts to diversify and improve the age structure of this urban park's trees, however, the species selected for plantings were found to be limited to only two genera, *Quercus* (Oak) and *Acer* (Maple).

Among the dominant tree species in AG, this study found a total of 149 maples that collectively comprise 48% of the total population. The *Acer* genus, therefore, may be at some risk because it is one of the most preferred hosts for the Asian Long-horned Beetle (ALB), which has been responsible for catastrophic damage to Maple, Horsechestnut, and Poplar trees in forests of both New York City and Chicago (CDFA, 2008). The ALB was discovered in the City of Toronto in 2003. Since then, intensive protection and eradication programs have been implemented by the Canadian Food Inspection Agency (CFIA) to protect Maple, Birch, Elm, Horsechestnut, Willow, Poplar, Hackberry, London Plane and Ash tree species (TPFR, 2005). At present, 68% of AG's tree population are species at risk to the ALB.

There is a total of 24 *Fraxinus* (Ash) trees (Green, European, Red, and White), which comprise 7.8% of the total AG tree population. Red Ash, the predominant species, provides 2.5% of the total canopy cover and ranks sixth in overall importance of tree species within the park (IVal = 3.4). As Ash species have begun to fall victim to both the Emerald Ash Borer and ALB, plantings of these species have ceased in AG. It is important that the City strengthen and maintain its monitoring and eradication programs that aspire to protect the scale of benefits currently provided by its urban forests; selective diversification of tree species can ensure successful tree growth to maturity, which will maximize the benefits provided by this resource in the future.

Although AG's Norway Maples provide the City with annual benefits of $7,917, constitute 13% of the park's total tree population, provide 17% of total canopy cover, and rank first in overall importance (IVal = 15), they are now considered to be an invasive species in Ontario and the northeastern U.S. (Riley, 1989; Dunster, 1990). This is because Norway Maples are known to produce large numbers of seeds that, through wind dispersion, invade green spaces such as parks and ravines (Abbey, 2000). Also, like Silver Maple, Norway Maples are susceptible to storm damage because of their tree morphology (drooping crotch angles and lateral branching). In a forest setting, their dense canopies are found to inhibit the successful establishment of other trees in their proximity, reducing species diversity. Also, since Norway Maples have an aggressive and shallow root system, they out-compete other plants in their immediate landscape, and can cause pavement upheavals in urban settings (Abbey, 2000). In the last decade, no new Norway Maples have been planted in AG.

Recent plantings in AG include various Oak and Maple species. In particular, the Maple species found most commonly planted was the Autumn Blaze Maple (*Acer* x *freemanii* 'Jeffersred'). This tree was elected as the Urban Tree of the Year for 2003, and consecutively for 2004 by the Society of Municipal Arborists (a US-based professional affiliate of the International Society of Arboriculture). Autumn Blaze Maple is a cultivar created from the combination of two native species, Red Maple and Silver Maple (Nix, 2008). It is known for its superior fall colour, dense and healthy branching, high growth rates, drought resistance, insect and disease resistance, and a wide range of other soil and environmental adaptabilities (Nix, 2008). In addition, its rate of growth is significantly faster than Red Maple, reaching up to 18.3 m tall and 12.2 m wide (or 60 feet and 40 feet, respectively) at maturity. This tree is not as susceptible to storm damage as either the Norway or Silver Maple due to its branches' tighter crotch angles (Nix, 2008). Currently, the Autumn Blaze Maple population comprises 2.6% of AG's trees.

In general, AG would benefit from a shift away from planting new Maples to the introduction of new species and cultivars that will contribute to the diversification of genera in its urban forest ecosystem. Trees that are recommended for future planting include native species that grow large in stature and are less vulnerable to pests, wind and urban stresses; these include: *Carya* (Bitternut Hickory, and Shagbark Hickory), *Tsuga* (Eastern Hemlock), *Fagus* (American Beech), *Prunus* (Black Cherry), and *Larix* (Tamarack). Non-native species suggested for future plantings include *Ginkgo* (Maidenhair Tree), *Quercus* (Bur Oak, and Shumard Red Oak), and *Picea* (Serbian Spruce, and Blue Colorado Spruce) (Aboud and Associates Inc., 2006).

Leaf area was found to be the main contributing reason for AG's urban forest benefits. Many factors were found to affect the extent of leaf surface area, they include: 1) tree number; 2) tree age and structure; 3) canopy dimensions; and, 4) canopy health. As the number of dense-canopied trees increases, the amount of leaf area increases, and thus, the amount of canopy cover will increase. Tree age affects leaf area quantity to a certain extent; young trees that have the potential to achieve large statures will increase their contribution annually until they reach a mature status. Small trees provide more consistent benefits, in terms of leaf area, throughout their lives. If the tree population does not decrease in the near future, then the flow of benefits derived from the AG urban forest is expected to increase significantly. This is due to the fact that the trees planted in the past 5-10 years are a dynamic resource; they are all large-growing species whose tree stature and canopy dimensions are expected to increase significantly. Therefore, both AG's urban forest value and annual benefits are expected to increase as these newly planted trees mature, and as new trees are planted.

The greatest concern at this time for AG is that the park is on track to suffer a net loss in tree number and overall canopy cover due to the fact that many large trees are old, and are in declining states of health. The eventual loss of these trees will lead to an important, yet short-term, reduction in overall benefits. In addition to this anticipated tree loss, there is the issue of young tree mortality evident with certain species recently planted in AG. To maintain the flow of benefits that the City currently enjoys, it is imperative that planting efforts concentrate on replacement with medium and large stature trees, and that management and maintenance efforts are improved so as to reduce young tree mortality rates. It is further recommended that new tree plantings be planned with the goal of attaining close to the relative age distribution discussed in Section 4.2.4.

Each tree planted, that survives and grows to maturity, in AG will contribute to the improvement of the City of Toronto's air quality, urban micro-climate, stormwater runoff rates, and energy conservation. While street trees may be better positioned in the cityscape to provide environmental benefits, they seldom develop to their full potential due largely to inadequate growing conditions, especially soil quality and volume. Park trees have the potential to develop large, dense, and healthy canopies. Comprehensive and integrated planting and management efforts at park sites in Toronto's core are required to ensure tree benefits continue in the short- and long-term. Investment in park trees will pay much more in terms of dividends (ecosystem services) than a similar expenditure on street trees.

Tree canopy width and depth have a direct impact on AG's capacity to contribute to Toronto's environmental and socio-economic wellbeing. Mayor David Miller's plan to increase canopy cover in the City of Toronto to greater than 30 percent is an important goal; however, it should be noted that it is insufficient to simply plant more trees to achieve this outcome. The City must investigate the option of intensive maintenance programs that aim to prolong and improve the stature and lifespan of mature trees, as well as endeavour to reduce young tree mortality. To this end, urban forest managers can use canopy cover and LAD figures to assist in their identification and prioritization of available planting space, as well as for the selection of tolerant species suited to particular urban conditions.

While there was minor evidence of stressed trees in AG, this study did find important potential natural and anthropogenic vegetation-soil interactions that could significantly influence the park's future forest development and flow of benefits. Soil analysis results showed that a large amount of AG's soils were compacted in important tree rooting zones. The construction work recently undertaken to build the dog park in the western corner of Section B, the high traffic of people and dogs on a daily basis, and the park maintenance and police vehicles that do not adhere to allocated paved driveways, have all contributed to the degradation of soil conditions.

The variation in soil texture throughout the study site influences the degree of water retention and soil compaction, and correspondingly, the amount of water available for plant roots as well as the degree to which roots are able to penetrate the soil structure. AG's sandy soils rapidly drain water and are more prone to drought pressures. In contrast, sandy-loam soils, with more fine (silt and clay) content retain more water due to their smaller and more numerous pore spaces, but are more vulnerable to external compaction pressures. Areas in sections A, E and F were found to have higher silt content. Field observations found that two of these three sections (E and F) have large grown trees with dense and healthy canopies. Parts of Section A, however, also have large trees but many of these trees were in deteriorating health condition, likely a result (or partial result) of highly compacted soils.

At the 7.6 cm soil depth, compaction was found to be profound in parts of Sections A and B. Conflating this with the aforementioned soil texture information (higher silt content), trees that were observed to be in deteriorating health were the ones located in the region of Section A that had suffered from considerable soil compaction. Intense human and dog traffic may be the cause of this surface soil compaction in Section A, namely in the area around the fountain where the informal off-leash dog park was located for the past decade. Also, many of the young oak and maple trees growing in the western part of Section B were found to exhibit signs of failing health. Compaction levels in Section B may also be attributable to human foot traffic, as an entrance to one of the Conservatory buildings was found to face this section of the park. Further analyses at the depth of 20 cm revealed soil compaction levels in Sections A and B were even more severe than surface measurements. Where these occurred in Section B they were hypothesized to be a result of a building that existed on this site pre-1980 or to the construction of the Conservatory back in the early 2000s.

Water infiltration is crucial for successful tree establishment and growth. The ideal infiltration rate for AG's soil is site-specific and dependent upon texture, bulk density, and tree-specific water requirements. The areas of AG with the slowest water infiltration rates were found, not surprisingly, in the location with the most recent vehicular and maintenance disturbance (the new dog park), as well as in the vicinity of high soil silt content. These two sections of AG show a strong negative correlation between infiltration rate and soil compaction. Interestingly, retarded water infiltration rates were also encountered in the central portions of Sections D and E. This portion of AG was characterized by moderate surface soil compaction, but lower values at the 20 cm depth; its soil texture was composed of fairly high levels of silt. This portion of the park was also used regularly for leisure activities, demonstrating that lower infiltration rates are attributable to the combination of many interacting factors.

To protect and enhance AG's forest, the City of Toronto's maintenance priorities must include planting and caring for new trees, while maintaining and eventually removing aged and diseased ones. Particular maintenance attention should be paid to the newly planted trees so as to ensure that they survive and develop well-structured and healthy mature canopies. Norway Maples, which provide a substantial share of AG's forest benefits must continue to receive regular maintenance attention. However, in AG and other Toronto parks where this species is dominant, replacement plans should be composed of a diversity of species (preferably native to southern Ontario). It is recommended that new replacements be planted first in areas where removals are anticipated, and then, all subsequent planting efforts should be in areas that aim to reduce the City's reliance on the Norway Maple. With this in mind, all future planting efforts in AG should take into account the soil conditions and available growing space. While costly, soil remediation in strategic locations may be useful for lessening compaction. By heeding these recommendations, planners and urban forest managers ensure the right tree is planted in the right place, where final size matches site conditions and trees can grow to maturity providing maximum benefits.

References

Abbey, T. 2000. Invasive Plant Information Sheet: Norway Maples. Last Accessed on December 9th, 2008. Available at: <http://www.hort.uconn.edu/CIPWG/art_pubs/docs/norway_maple.pdf>

Aboud and Associates Inc. 2006. Tree Inventory and Management Strategy: Allan Gardens, City of Toronto. In: The Landplan Collaborative Ltd., Goldsmith Borgal & Company Ltd., Archaeological Services Inc., Valdor Engineering Inc., Aboud and Associates Inc., and MJS Consultants Inc. Allan Gardens Landscape Revitalization Strategy & Management Plan For the City of Toronto. Appendix 3.

Akbari, H., Davis, S., Dorsano, S., Huang, J., and Winnett, S. 1992. Cooling Our Communities: A Guidebook on Tree Planting and Light-Colored Surfacing. Washington, DC: U.S. Environmental Protection Agency. Pg 26

Akbari, H. and S. Konopacki. 2004. Energy Effects of Heat-Island Reduction Strategies in Toronto, Canada. Energy 29:191-210.

Anderson, L.M. and H.K.Cordel. 1988. Residential Property Values Improve by Landscaping With Trees. Southern Journal of Applied Forestry 9:162–166.

Bailey, T.C. and C. Gatrell. 1995. Interactive Spatial Data Analysis. New York: John Wiley & Sons.

Berry, B.J.L. 2008. Urbanization. In: Marzluff, J.M. (Ed), Urban Ecology: an International Perspective on the Interaction Between Humans and Nature (pp. 25-48). New York: Springer.

Brack, C. 1999. *Tree Crown*. Last accessed on: December 9th, 2008. Available at: <http://sres-associated.anu.edu.au/mensuration/crown.htm>

Brady, N.C. and R.R. Weil. 2008. The Nature and Properties of Soils. Upper Saddle River New Jersey: Pearson Education Inc.

California Department of Food and Agriculture. 2008. Asian Longhorned Beetle Pest Profile. Accessed on December 9th, 2008. Available at: <http://www.cdfa.ca.gov/phpps/pdep/target_pest_disease_profiles/asian_lhb_profile.html >

Carreiro, M.M. 2008. Introduction: the Growth of Cities and Urban Forestry. In: Carreiro, M., Y. Song and J. Wu (Eds), Ecology, Planning, and Management of Urban Forests International Perspectives (pp. 3-9). New York: Springer.

Chen, W.Y. and C.Y. Jim. 2008. Assessment and Valuation of the Ecosystem Services Provided by Urban Forests. In: Carreiro, M., Y. Song and J. Wu (Eds), Ecology, Planning, and Management of Urban Forests International Perspectives (pp. 53-83). New York: Springer.

Chiesura, A. 2004. The Role of Urban Parks for the Sustainable City. Landscape and Urban Planning 68:129–138.

City of Toronto. 2008. An Inventory of Toronto's Urban Forest Resource. Accessed on November 30th, 2008. Available at: <http://www.toronto.ca/trees/pdfs/UFORE.pdf>

Coder, K. 2000. Soil Compaction Impacts on Tree Roots. University of Georgia. Accessed on: November 30th, 2008. Available at: < http://www.wildcalifornia.org/cgi-files/0/pdfs/1206145859_Soil_Compaction_Impacts.pdf >

Conway, T.M. and L. Urbani. 2007. Variations in Municipal Urban Forest Policies: a Case Study of Toronto, Canada. Urban Forestry & Urban Greening 6:181-192.

Craul, P.J. and J.C. Patterson. 1989. The Urban Soil as a Rooting Environment. In: Proceedings of Fourth National Urban Forestry Conference, 15-19 October 1989 (pp. 97-102). St. Louis, Missouri.

Craul, P.J. 1999. Urban Soils: Applications and Practices. New York: John Wiley and Sons.

Daniels, W.L. and K.C. Haering. 2006. Concepts of Basic Soil Science. In: Mid-Atlantic Nutrient Management Handbook, Chapter 3. Accessed on November 30th, 2008. Available at: <http://www.mawaterquality.org/Publications/manmh/chapter3.pdf>

Duffy, N.M. 1999. Design Limitations to Potential Leaf Area Density in Urban Forests. M.Sc.F. Thesis, Faculty of Forestry, University of Toronto.

Duncan, D. 2007. To Turn Squirrels Into Tree Killers, Just Subtract Water. The Globe and Mail. Accessed on November 30th, 2008. Available at: <http://www.theglobeandmail.com%2Fservlet%2Fstory%2FLAC.20070915.WATER15%2FTPStory%2FTPEntertainment%2FOntario%2F&ord=72011188&brand=theglobeandmail&force_login=true >

Dunster, K. 1990. Exotic Plant Species Management Plan, Point Pelee National Park. Report Prepared for Parks Canada, Ontario Region.

Environment Canada, 2008. Main Emission Sources. Accessed on December 8th, 2008. Available at: < http://www.ec.gc.ca/cleanair-airpur/Main_Emission_Sources-WSD130165D-1_En.htm>

Escobedo, P.J., J.E. Wagner, D.J. Nowak, C.L. De la Maza, M. Rodriguez, and D.E. Crane. 2008. Analyzing the Cost Effectiveness of Santiago, Chile's Policy of Using Urban Forests to Improve Air quality. Journal of Environmental Management 86:148-157.

Farrar, J. 1995. Trees in Canada. Markham, ON: Fitzhenry and Whiteside Limited.

Given, S., L.H. Pendleton and A.B. Boehm. 2006. Regional Public Health Cost Estimates of Contaminated Coastal Waters: a Case Study of Gastroenteritis at Southern California Beaches. Environmental Science and Technology 40:4851-4858.

Grapentine, L., Q. Rochfort and J. Marsalek. 2008. Assessing Urban Stormwater Toxicity: Methodology Evolution from Point Observations to Longitudinal Profiling. Water Science and Technology 57:1375-81.

Hanks, D. and A. Lewandowski. 2003. Protecting Urban Soil Quality: Examples for Landscape Codes and Specifications. Washington DC: USDA-NRCS.

Hardin, P.J. and R.R. Jensen. 2007. The Effect of Urban Leaf Area on Summertime Urban Surface

Kinetic Temperatures: A Terre Haute Case Study. Urban Forestry & Urban Greening 6:63-72.

Hillel, D.L. 1982. Introduction to Soil Physics. New York: Academic Press.

Irvine, T. 2007. Toronto's Urban Forest is Ailing. The Toronto Star. Accessed on November 30th, 2008. Available at: < http://www.thestar.com/News/GTA/article/275384>

i-Tree. 2006. Assessing Street Tree Populations. Accessed November 30th, 2008. Available at: < http://www.itreetools.org/about_itree.shtm>

i-Tree. 2008. i-Tree Manual: Tools for Accessing and Managing Community Forests. Kent, OH: US Forest Service.

Jensen, R.R, J.R. Boulton and B.T. Harper. 2003. The Relationship Between Urban Leaf Area and Household Energy Usage in Terre Haute, Indiana. US Journal of Arboriculture 29:226-229.

Jim, C.Y. 1998. Soil Characteristics and Management in an Urban Park in Hong Kong. Environmental Management 22:683-695.

Johnston, K.J., M. VerHoef, K. Krivoruchko and N. Lucas. 2001. Using ArcGIS Geostatistical Analyst. New York: Environmental Systems Research Institute.

Johnston, M. and L.D. Shimada. 2004. Urban Forestry in a Multicultural Society. Journal of Arboriculture 30:185-192.

Jorgensen, E. 1970. Urban Forestry in Canada. In: Proceedings of the 46th International Shade Tree Conference. University of Toronto, Faculty of Forestry, Shade Tree Research Laboratory, Toronto.

Jorgensen, E. 1974. Towards an Urban Forestry Concept. Proceedings of the 10th Commonwealth Forestry Conference. Ottawa, Canada; Forestry Service.

Kenney, W.A. 2000. Leaf Area Density as an Urban Forestry Planning and Management Tool. The Forestry Chronicle 76: 235-239.

Kenney, W.A. 2008. Potential Leaf Area Index Analyses for the City of Toronto's Urban Forest. In: Carreiro, M., Y. Song and J. Wu (Eds), Ecology, Planning, and Management of Urban Forests International Perspectives (pp. 336-345). New York: Springer.

Knuth, L. 2005. Legal and Institutional Aspects of Urban and Peri-Urban Forestry and Greening. Food and Agriculture Organization of the United Nations. Accessed on November 19th, 2006. Available at: <http://www.fao.org/Legal/legstud/ls88/ls88e.pdf>

Konijnendijk, C.C., K. Nilsson, T.B. Randrup and J. Schipperijn (Eds.). 2005. Urban Forests and Trees. Springer, Heidelberg.

Kozlowski, T.T., P.J. Kramer and S.G. Pallardy. 1991. The Physiological Ecology of Woody Plants. Academic Press, San Diego, CA.

Kozlowski, T.T. and S.G. Pallardy, 1997. Physiology of Woody Plants, 2nd ed. Academic Press, San Diego.

Kozlowski, T.T. 1999. Soil Compaction and Growth of Woody Plants. Scandinavian Journal of Forest Research 14:596-619.

Lam, K., S. Ng, W. Hui and P. Chan. 2005. Environmental Quality of Urban Parks and Open Spaces in Hong Kong. Environmental Monitoring and Assessment 111:55-73.

Lovett, G.M., Traynor, M.M., Pouyat, R.V., Carreiro, M.M., Zhu, W., and Baxter, J.W. 2000. Atmospheric deposition to oak forests along an urban-rural gradient. Environmental Science and Technology 34:4294–4300.

Maco, S.E. and McPherson, G.E, 2003. A practical approach to assessing structure, function, and value of street tree populations in small communities. Journal of Arboriculture 29 (2): 84 – 97.

Manning, W.J. 2008. Plants in Urban Ecosystems: Essential Role of Urban Forests in Urban Metabolism and Succession Toward Sustainability. International Journal of Sustainable Development & World Ecology 15:362-370.

McLean, D.D., R.R. Jensen and A.R. Hurd. 2007. Seeing the Urban Forest Through the Trees: Building Depth Through Qualitative Research. Arboriculture and Urban Forestry 33:304-308.

McNeil, J., C. Vava and Town of Oakville. 2006. Oakville's Urban Forest: Our Solution to Our Pollution. Oakville, ON: Town of Oakville, Parks and Open Space Department, Forestry Section.

McPherson, E.G. 1984. Planting Design for Solar Control. In: McPherson, E.G. (Ed) Energy–conserving site design (pp. 141-164). Washington D.C.: American Society of Landscape Architecture.

McPherson, E.G., D. Nowak, G. Heisler, S. Grimmond, C. Souch, R. Grant and R. Rowntree. 1997. Quantifying Urban Forest Structure, Function, and Value: the Chicago Urban Forest Climate Project. Urban Ecosystems 1:49-61.

McPherson, E.G. 1998. Structure and Sustainability of Sacramento's Urban Forest. Journal of Arboriculture 24:174-190.

McPherson, E.G. and J.R. Simpson. 2002. A Comparison of Municipal Forest Benefits and Costs in Modesto and Santa Monica, California, USA. Urban Forestry & Urban Greening 1:61-74.

McPherson, E.G., J.R.Simpson, P.J. Peper, S.L. Gardner, K.E. Vargas, S.E. Maco and Q. Xiao. 2006. Piedmont Community Tree Guide: Benefits, Costs, and Strategic Planting. USDA Forest Service General Technical Report PSW-GTR-200.

McPherson, G E., J.R. Simpson, Q. Xiao and W. Chunxia. 2008. Los Angeles 1-Million Tree Canopy Cover Assessment. General Technical Report PSW-GTR-207. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Mertes, J.D. 1995. Park, Recreation, Open Space, and Greenway Guidelines. Arlington, VA:

Arlington: National Recreation and Park Association.

Millward, A.A. 2007. Field Notes from a Parched City. Spacing Toronto. Accessed November 30th, 2008. Available at: < http://spacing.ca/wire/?p=2301>

Morrison, H.J. 2008. Land Cover Distribution and Change in Toronto, Ontario, Canada from 1985-2005. MSA Thesis, Department of Geography, Ryerson University.

Nix, S. 2008. Autumn Blaze™ Maple - 2003 Urban Tree of the Year. Accessed December 9th, 2008. Available at: < http://forestry.about.com/cs/treeid/a/aut_blaze_mapl%20.htm>

Nix, S. 2009. What is a Dichotomous Tree Key? Last Accessed January 26th, 2009. Available at: <http://forestry.about.com/cs/treeid/f/Tree_ID_key.htm >

Nowak, D.J. 1991. Urban Forest Development and Structure: Analysis of Oakland, California. Ph.D. Thesis, University of California, Berkeley.

Nowak, D.J. 1994. Air Pollution Removal by Chicago's Urban Forest. In: McPherson, E.G., D.J. Nowak and R.A. Rowntree (Eds) Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project (pp. 63-82). USDA Forest. Service. General Technical Report NEGTR-186.

Nowak, D.J. 1996. Estimating Leaf Area and Leaf Biomass of Open-Grown Deciduous Urban Trees. Forest Science 42:504-507.

Nowak, D.J. and J.F.Dwyer. 2000. Understanding the Benefits and Costs of Urban Forest Ecosystems. In: Kuser, J.E. (Ed) Handbook of Urban and Community Forestry in the Northeast (pp. 11-25). New York: Kluwer Academic.

Nowak, D.J. and D.E. Crane. 2002. Carbon Storage and Sequestration by Urban Trees in the USA. Environmental Pollution 116: 381-389.

Nowak, D.J. 2006. Institutionalizing Urban Forestry as a "Biotechnology" to Improve Environmental Quality. Urban Forestry & Urban Greening 5:93-100.

Owen, S.M., A.R. MacKenzie, H. Stewart, H.Donovan and C.N. Hewitt. 2003. Biogenic Volatile Organic Compound (VOC) Emission Estimates From an Urban Tree Canopy. Ecological Applications. 13:927- 938.

Parikh, P., M.A.Taylor, T. Hoagland, H. Thurston and W. Shuster. 2005. Application of Market Mechanisms and Incentives to Reduce Stormwater Runoff: An Integrated Hydrologic, Economic and Legal Approach. Environmental Science & Policy 8:133-144.

Paudel, K. 2008. Urban Park Soil Restoration: Geostatistical Analysis of a Naturalization Strategy for Kew Gardens Park, Toronto. MSA Thesis, Department of Geography, Ryerson University.

Penuelas, J. and J. Llusia. 2003. BVOCs: Plant Defense Against Climate Warming? Trends in Plant Science 8:105-109.

Peper P.J., E.G.McPherson and S.M. Mori. 2001. Equations for Predicting Diameter, Height, Crown

Width and Leaf Area of San Joaquin Valley Street Trees. Journal of Arboriculture 27:306-317.

Peper, P.J. and E.G. McPherson. 2003. Evaluation of Four Methods for Estimating Leaf Area of Isolated Trees. Urban Forestry & Urban Greening 2:19-29.

Peper, P.J., E.G. McPherson, J.R. Simpson, S.L. Gardner, K.E. Vargas, and Q Xiao. 2007. New York City, New York Municipal Forest Resource Analysis. Accessed November 30th, 2008. Available at: <http://www.fs.fed.us/psw/programs/cufr/products/2/psw_cufr687_NYC_MFRA.pdf>

Plante, A.F., R.T. Conant, C.E. Stewart, K. Paustian, and J. Six. 2006. Impact of Soil Texture on the Distribution of Soil Organic Matter in Physical and Chemical Fractions. American Journal of Soil Sciences 70:287-296.

Riley, J.L. 1989. More Invasive Aliens. Seasons 29: 23.

Sæbø, A., T. Benedikz and T.B. Randrup. 2003. Selection of Trees for Urban Forestry in the Nordic Countries. Urban Forestry & Urban Greening 2:101-114.

Sanders, R.A. 1986. Urban Vegetation Impacts on the Urban Hydrology of Dayton Ohio. Urban Ecology 9:361-376.

Saxton, K.E., W.J. Rawls, J.S. Romberger and R.I. Papendick. 1986. Estimating Generalized Soil-Water Characteristics from Texture. Soil Science Society of America Journal 50:1031-1036.

Steila, D. 1976. Geography of Soils: Formation, Distribution and Management. Englewood Cliff, NJ: Prentice-Hall.

Stoffberg, G.H., M.W. Rooyen, M.J. van der Linde and H.T. Groeneveld. 2008. Predicting the Growth in Tree Height and Crown Size of Three Street Species in the City of Tshwane, South Africa. Urban Forestry & Urban Greening 7:259- 264.

Thaiutsa, B., L. Puangchit, R. Kjelgren and W. Arunpraparut. 2008. Urban Green Space, Street Tree and Heritage Large Tree Assessment in Bangkok, Thailand. Urban Forestry & Urban Greening 7:219-229.

Toleti, V.M.R B. 2008. Urban Forest Soil Characteristics: a Geostatistical Analysis of Allan Gardens Park, Toronto, Canada. MSA Thesis. Department of Geography, Ryerson University.

Trowbridge, P.J. and N.L. Bassuk. 2004. Trees in the Urban Landscape. Hoboken, New Jersey: John Wiley and Sons.

Toronto Parks, Forestry and Recreation. 2005. Asian Long-horned Beetle. Accessed December 9th, 2008. Available at: <http://www.toronto.ca/trees/pdfs/factsheets/Asian_Long-horned_Beetle_fs.pdf>

Ulrich, R.S. 1984. View Through a Window May Influence Recovery from Surgery. Science 224: 420–421.

United States Department of Agriculture. 1999. Soil Quality Test Kit Guide. Washington D.C.: Agricultural Research Service, Natural Resources conservation Services, Soil Quality Institute.

United States Department of Agriculture Forest Service. 2003. About Us. Accessed November 29th,2008. Available at: <http://www.fs.fed.us/ne/syracuse/About/about.htm>

Whitlow, R. 1995. Basic Soil Mechanics, Third Edition. Harlow, Essex, England: Longman Scientific & Technical.

Wittig, R. Principles for Guiding Eco-City Development. 2008. In: Carreiro, M., Y. Song and J. Wu (Eds), Ecology, Planning, and Management of Urban Forests International Perspectives (pp. 29-34). New York: Springer.

Wu, C., Q. Xiao and E.G. McPherson. 2008. A Method for Locating Potential Tree-Planting Sites in Urban Areas: A Case Study of Los Angeles, USA. Urban Forestry & Urban Greening 7:65-76.

Wu, J. 2008. Toward a Landscape Ecology of Cities: Beyond Buildings, Trees, and Urban Forests. In: Carreiro, M., Y. Song and J. Wu (Eds), Ecology, Planning, and Management of Urban Forests International Perspectives (pp. 10-28). New York: Springer.

Wu, R.W., T. Harnera and M.L. Diamond. 2008. Evolution Rates and PCB Content of Surface Films that Develop on Impervious Urban Surfaces. Atmospheric Environment 42:6131-6143.

Xiao, Q., E.G. McPherson, S.L. Ustin and M.E. Grismer. 2000. A New Approach to Modeling Tree Rainfall Interception. Journal Geophysical Research (Atmospheres) 105:29173-29188.

Xiao, Q. and G.E. McPherson. 2002. Rainfall Interception by Santa Monica's Municipal Urban Forest. Urban Ecosystems 6:291-302.

Appendix A – 2008 Tree Inventory

2005 Tree #	2008 Tree #	Tree Species	CRN Shape	DBH	Tree Height	CRN Depth	Live CRN Ratio	CRN Width	Loc.	Recomm.	Ca	Cv	LAI / notes
1	1	Tilia x euchlora	P	50.13	13.37	10.71	0.80	10.56	S	Mature: R	111.71	468.69	3.81
1a	2	Acer saccharum	P	5.73	4.51	2.38	0.53	2.18	P	Young: NONE	10.42	4.42	3.90
2	3	Ulmus glabra	P	114.59	22.17	19.23	0.87	18.13	P	Mature: R	46.81	2481.61	0.88
3	4	Tilia x euchlora	P	48.22	16.61	14.62	0.88	14.53	P	Mature: None	103.56	1211.48	1.93
4	5	Acer platanoides	P	37.56	17.38	15.20	0.87	15.62	P	Mature: R	70.99	1456.59	1.74
5	6	Tilia cordata	P	46.00	17.74	16.03	0.90	11.30	P	Mature: I	216.75	803.64	4.07
6	7	Acer platanoides	P	50.77	24.96	22.06	0.88	15.33	P	Mature: R	290.29	2035.97	1.80
7	8	Tilia cordata	P	33.10	18.44	16.20	0.88	12.19	P	Mature: I	209.21	945.06	3.21
8	9	Acer Platanoides	P	33.42	12.47	9.59	0.77	10.35	P	Mature: I	92.41	403.45	3.95
9	10	Fraxinus pennsylvanica var. lanceolata	P	20.29	10.93	6.73	0.62	4.96	S	Mature: I	58.25	64.92	2.69
10	11	Fraxinus pennsylvanica var. lanceolata	P	20.45	13.03	7.59	0.58	7.09	S	Mature: R	77.44	149.75	2.75
11	12	Fraxinus pennsylvanica var. lanceolata	P	22.20	9.33	6.09	0.65	7.47	S	Mature: I	56.90	133.20	2.24
12	13	Fraxinus pennsylvanica var. lanceolata	P	18.70	8.39	5.78	0.69	7.15	S	Mature: I	53.56	116.02	2.17
13	14	Fraxinus pennsylvanica var. lanceolata	P	26.82	9.93	6.39	0.64	9.45	S	Mature: R	47.88	223.95	2.12
14	15	Ulmus pumila	P	43.61	22.40	20.23	0.90	12.27	P	Mature: R	307.07	1195.13	1.43
15	16	Ulmus pumila	P	34.38	18.91	16.47	0.87	7.93	P	Mature: R	217.03	406.09	2.60
16	17	Ulmus pumila	P	25.62	16.54	13.80	0.83	5.79	P	Mature: I	145.82	181.64	4.88
17	18	Ulmus pumila	P	34.06	19.10	17.20	0.90	7.93	P	Mature: R	229.04	424.31	2.60
18	19	Ulmus pumila	P	31.99	21.26	18.90	0.89	6.52	P	Mature: R	226.33	315.51	3.85
19	20	Ulmus pumila	P	28.65	23.00	7.57	0.33	6.25	P	Mature: I	74.96	116.11	4.81
20	21	Ulmus pumila	P	33.10	20.62	19.42	0.94	5.64	P	Mature: R	208.59	242.11	5.15
21	22	Ulmus pumila	P	21.80	15.03	11.97	0.80	6.86	P	Mature: I	136.90	220.89	3.48
22	23	Ulmus pumila	P	35.81	21.95	17.01	0.78	8.84	P	Mature: R	236.59	522.00	2.09
23	24	Ulmus pumila	P	41.70	21.01	16.22	0.77	12.88	P	Mature: R	196.79	1056.12	0.99
24	25	Ulmus pumila	P	42.97	26.88	19.09	0.71	11.51	P	Mature: R	285.40	992.31	1.24
25	26	Ulmus pumila	P	20.69	15.14	12.36	0.82	7.24	P	Mature: R	146.04	254.13	3.09
26	27	Ulmus pumila	P	26.74	19.26	16.87	0.88	7.31	P	Mature: I	214.11	354.49	3.06
27	28	Ulmus pumila	P	42.49	23.64	16.21	0.69	7.92	P	Mature: R	212.96	399.85	2.60
28	29	Ulmus pumila	P	53.48	22.49	20.98	0.93	10.21	P	Mature: I	325.49	858.71	1.57
29	30	Ulmus pumila	P	23.24	18.72	6.43	0.34	5.79	P	Mature: I	59.74	84.71	5.80
30	31	Ulmus pumila	P	44.56	27.97	17.59	0.63	10.36	P	Mature: R	255.20	741.87	1.52
31	32	Ulmus pumila	P	31.51	24.23	16.46	0.68	9.75	P	Mature: I	231.35	614.80	1.72
32	33	Ulmus pumila	P	54.11	24.75	22.94	0.93	10.52	P	Mature: R	369.75	995.83	1.48

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33	34	Ulmus pumila	P	33.42	22.45	11.93	0.53	7.47	P	Mature: I	141.46	261.28	2.94
34	35	Ulmus pumila	P	42.34	23.05	20.54	0.89	8.69	P	Mature: I	298.11	608.73	2.17
35	36	Ulmus pumila	C	66.53	24.64	21.55	0.87	19.81	P	Mature: R	738.02	2214.09	0.42
36	37	Ulmus pumila	P	55.23	21.43	18.76	0.88	16.15	P	Mature: R	152.51	1922.63	0.63
37	38	Quercus robur 'Fastigiata'	P	22.60	13.74	10.73	0.78	3.96	P	Mature: R	82.37	66.12	2.86
38	39	Quercus robur 'Fastigiata'	P	19.10	10.12	7.87	0.78	4.27	P	Mature: R	62.59	56.29	2.09
39	40	Quercus robur 'Fastigiata'	P	22.12	11.02	8.17	0.74	2.83	P	Mature: R	30.67	10.73	2.03
40	41	Fraxinus pennsylvanica	P	10.03	6.39	4.48	0.70	3.81	P	Mature: R	31.25	25.51	1.87
41	42	Quercus macrocarpa	P	7.80	5.18	3.35	0.65	3.20	P	Young: R	20.32	13.48	1.67
42	43	Quercus alba	P	7.96	4.82	2.31	0.48	2.36	P	Young: I	10.94	5.07	2.84
43	44	Ailanthus altissima	P	27.85	11.80	9.25	0.78	7.31	P	Mature: R	101.22	194.43	4.38
44	45	Acer platanoides 'columnare'	P	17.03	8.96	6.63	0.74	4.95	P	Mature: R	57.24	63.89	1.98
45	46	Acer platanoides 'columnare'	N/A	12.57	6.81	0.00	0.00	0.00	P	N/A	0.00	0.00	Tree removed
46	47	Juglans nigra	C	79.58	23.83	18.39	0.77	20.95	P	Mature: R	696.74	2114.33	0.57
47	48	Acer saccharum	P	46.00	18.54	15.14	0.82	12.88	P	Mature: R	169.34	985.70	3.46
48	49	Acer platanoides	N/A	105.04	24.02	0	0	0	P	N/A	0.00	0.00	Tree removed
48a	50	Acer x freemanii 'Jeffersed'	P	4.93	4.32	2.78	0.64	1.90	P	Young: NONE	10.71	3.95	2.00
48b	51	Acer x freemanii 'Jeffersed'	P	5.25	4.59	3.25	0.71	2.25	P	Young: NONE	14.58	6.46	1.94
48c	52	Acer x freemanii 'Jeffersed'	P	5.25	4.80	3.54	0.74	2.45	P	Young: NONE	17.12	8.33	1.96
48d	53	Acer x freemanii 'Jeffersed'	P	5.57	5.45	4.14	0.76	1.90	P	Young: NONE	15.95	5.87	2.57
48e	54	Acer x freemanii 'Jeffersed'	P	5.57	4.38	3.06	0.70	2.35	P	Young: NONE	14.28	6.64	1.80
48f	55	Acer x freemanii 'Jeffersed'	P	4.77	4.03	2.91	0.72	1.90	P	Young: NONE	11.20	4.13	2.06
49	56	Acer platanoides	P	44.40	25.30	14.37	0.57	8.53	P	Mature: R	187.74	411.06	5.82
50	57	Acer platanoides	P	68.60	20.50	17.38	0.85	11.96	P	Mature: I	241.06	977.01	2.96
51	58	Tilia cordata	P	86.74	21.04	19.60	0.93	17.22	P	Mature: R	120.37	2282.53	1.21
52	59	Acer platanoides	P	62.23	21.14	18.52	0.88	14.93	P	Mature: R	198.55	1622.00	1.90
52a	60	Quercus rubra	P	4.93	4.82	3.14	0.65	2.67	P	Young: NONE	16.36	8.76	1.83
53	61	Quercus rubra	P	4.14	3.90	2.68	0.69	1.22	P	YOUNG: R	6.76	1.57	3.09
54	62	Acer platanoides	P	66.21	19.59	17.53	0.89	13.03	P	Mature: R	226.82	1168.58	2.96
55	63	Acer saccharinum	P	81.33	25.13	19.69	0.78	13.87	P	Mature: I	265.29	1486.95	1.87
56	64	Acer platanoides	P	51.57	20.71	18.93	0.91	15.24	P	Mature: R	198.93	1726.54	1.82
57	65	Acer platanoides	P	43.93	15.58	13.93	0.89	15.40	P	Mature: R	45.26	1297.50	1.79
58	66	Aesculus hippocastanum	P	71.30	19.65	16.53	0.84	14.20	P	Mature: R	168.23	1309.27	2.32

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59	67	Acer platanoides	C	49.34	13.62	10.76	0.79	17.94	P	Mature: R	394.86	906.97	1.37
60	68	Ulmus glabra	P	81.49	20.09	15.70	0.78	14.10	P	Mature: R	148.92	1225.30	1.46
61	x	Acer platanoides	N/A	x	x	x	x	x	x	x	x	x	Tree removed
62	69	Juglans nigra	P	70.03	21.75	20.09	0.92	16.70	P	Mature: R	166.45	2200.08	0.89
63	70	Acer platanoides	C	81.17	18.77	17.43	0.93	22.75	P	Mature: R	743.89	2362.23	0.82
64	71	Sophora japonica	P	36.13	16.09	13.85	0.86	12.80	P	Mature: R	139.16	891.01	1.81
65	72	Acer saccharinum	C	120.00	22.74	16.57	0.73	20.88	P	Mature: R	642.33	1891.17	0.80
65a	73	Acer saccharum	P	4.77	4.08	2.03	0.50	1.22	P	Young: NONE	5.13	1.18	6.38
66	74	Acer platanoides	C	71.30	18.76	14.13	0.75	18.44	P	Mature: R	488.69	1257.78	1.25
67	75	Acer platanoides	P	42.18	18.90	16.85	0.89	13.49	P	Mature: R	198.31	1203.91	2.56
68	76	Acer platanoides	P	33.74	12.48	10.20	0.82	10.36	P	Mature: R	104.09	430.25	3.94
69	77	Fraxinus americana	C	81.49	24.38	21.58	0.89	22.63	P	Mature: R	866.13	2893.18	0.26
70	78	Acer platanoides	P	37.88	12.56	10.72	0.85	13.56	P	Mature: R	39.49	774.45	2.57
71	79	Acer platanoides	P	69.87	27.20	25.26	0.93	20.50	P	Mature: NONE	75.57	4167.25	1.01
72	80	Acer pseudoplatanus	P	51.73	19.69	17.47	0.89	12.04	P	Mature: R	242.04	994.10	2.41
73	81	Acer saccharum	P	46.15	18.29	15.58	0.85	14.86	P	Mature: R	116.75	1350.77	2.14
74	82	Gleditsia triacanthos var. inermis	P	31.83	14.28	11.46	0.80	9.75	P	Mature: R	134.16	428.02	4.84
75	83	Acer saccharum	P	43.93	18.13	15.55	0.86	14.02	P	Mature: R	147.41	1200.44	2.41
75a	84	Acer saccharum	P	3.50	4.01	2.43	0.61	2.13	P	Young: NONE	10.46	4.35	4.01
76	85	Pinus nigra	C	33.26	9.33	7.39	0.79	7.01	P	Mature: I	90.09	95.11	2.67
77	86	Pinus nigra	C	47.43	13.58	11.65	0.86	10.06	P	Mature: R	200.48	308.55	2.75
78	87	Acer platanoides	C	85.47	23.31	21.21	0.91	21.33	P	Mature: R	795.74	2527.87	0.93
79	88	Tilia cordata	C	80.69	18.26	16.45	0.90	20.27	P	Mature: I	615.15	1769.24	0.88
80	89	Pinus nigra	C	26.58	9.12	7.78	0.85	6.40	P	Mature: R	84.55	83.40	2.91
81	90	Pinus nigra	C	19.42	7.01	6.03	0.86	4.95	P	Mature: R	50.70	38.72	2.35
82	91	Acer platanoides	P	40.43	14.98	12.74	0.85	14.93	P	Mature: R	34.63	1116.13	1.90
83	x	Juglans nigra	N/A	x	x	x	x	x	x	x	x	x	Tree removed
84	92	Acer platanoides	P	15.76	9.21	7.40	0.80	7.16	P	Mature: R	75.02	149.16	6.03
85	x	Acer platanoides	N/A	x	x	x	x	x	x	x	x	x	Tree removed
86	93	Ulmus glabra	P	56.34	18.42	14.64	0.79	12.72	P	Mature: R	160.70	931.21	2.22
87	94	Acer platanoides	P	72.42	19.97	17.67	0.88	15.16	P	Mature: R	164.42	1594.98	1.84
88	95	Acer platanoides	P	42.97	18.85	16.34	0.87	12.50	P	Mature: R	207.50	1002.25	3.47
89	96	Syringa reticulata	P	1.59 - 12.41	5.97	5.04	0.84	7.70	P	Young: R	42.63	117.18	2.43

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90	97	Tilia cordata	C	52.20	17.11	15.47	0.90	18.52	P	Mature: R	524.41	1388.70	1.05
91	98	Acer platanoides	C	52.20	17.67	15.62	0.88	17.37	P	Mature: R	487.67	1233.98	1.40
92	99	Taxus cuspidata	N/A	6.37	3.33	0.00	0.00	0.00	P	Young: I	0.00	0.00	Tree dead
92a	100	Taxus cuspidata	P	4.93 - 15.92	5.12	4.64	0.91	7.62	P	Young: R	38.24	105.80	2.19
92b	101	Taxus cuspidata	P	4.77 - 7	4.79	4.45	0.93	6.17	P	Young: R	38.86	66.63	1.49
92c	102	Taxus cuspidata	P	4.77 - 10.19	4.98	4.86	0.98	7.16	P	Young: R	42.36	98.00	1.80
92d	103	Taxus cuspidata	P	2.71 - 7.89	3.50	2.31	0.66	2.82	P	Young: R	12.77	7.20	0.84
92e	104	Taxus cuspidata	P	7.96 & 10.50	4.12	3.52	0.85	5.56	P	Young: R	29.46	42.77	1.65
93	105	Acer saccharum	P	22.92	12.67	10.49	0.83	6.48	P	Mature: R	113.48	172.84	11.27
94	106	Acer saccharum	P	37.40	15.68	13.20	0.84	10.82	P	Mature: None	159.85	606.89	4.04
95	107	Fraxinus excelsior	C	62.39	15.02	12.19	0.81	18.97	P	Mature: R	460.37	1148.92	0.33
96	108	Acer platanoides	P	38.36	14.90	12.57	0.84	12.12	P	Mature: None	124.76	724.32	3.86
97	109	Acer platanoides	P	29.44	10.50	7.55	0.72	10.06	P	Mature: R	59.09	300.03	4.88
98	x	Ulmus glabra	N/A	x	x	x	x	x	x	x	x	x	Tree removed
99	x	Ulmus pumila	N/A	x	x	x	x	x	x	x	x	x	Tree removed
100	x	Quercus alba	N/A	x	x	x	x	x	x	x	x	x	Tree removed
101	110	Acer saccharum	P	18.78	11.16	9.05	0.81	10.82	P	Mature: None	74.88	416.15	4.43
102	111	Acer platanoides	P	75.60	26.06	23.43	0.90	18.59	P	Mature: R	163.42	3180.43	1.23
103	112	Acer saccharum	N/A	16.55	9.56	0.00	0.00	0.00	P	Mature: I	0.00	0.00	Tree dead
104	113	Acer saccharum	P	18.30	12.48	9.85	0.79	9.07	P	Mature: None	108.94	318.03	5.75
105	114	Acer saccharum	P	18.46	12.68	10.68	0.84	9.60	P	Mature: None	120.61	386.60	5.13
106	115	Tilia cordata (cultivar)	P	39.31	17.75	15.41	0.87	9.45	P	Mature: None	210.32	540.22	6.15
107	116	Tilia cordata (cultivar)	P	38.04	17.43	15.25	0.88	9.14	P	Mature: None	206.47	500.83	6.52
108	117	Tilia cordata (cultivar)	P	36.61	16.17	14.37	0.89	9.52	P	Mature: None	190.61	512.05	6.06
109	118	Gleditsia triacanthos var. inermis	P	38.36	13.43	11.07	0.82	11.73	P	Mature: R	99.16	598.36	3.10
110	119	Acer platanoides	P	54.59	18.52	16.17	0.87	16.53	P	Mature: R	50.61	1735.74	1.55
111	120	Tilia x euchlora	P	70.98	20.66	18.25	0.88	15.85	P	Mature: R	151.60	1800.54	1.62
112	121	Acer saccharum	P	27.53	12.96	10.39	0.80	7.24	P	Mature: R	117.27	213.70	9.02
113	122	Acer saccharum	P	23.71	13.57	11.39	0.84	8.15	P	Mature: R	136.14	297.27	7.11
114	123	Ulmus americana	P	63.66	22.21	20.59	0.93	10.74	P	Mature: R	320.16	933.29	1.80
115	x	Ulmus americana	N/A	x	x	x	x	x	x	x	x	x	Tree removed
116	124	Juglans nigra	C	89.76	25.60	22.90	0.89	23.93	P	Mature: R	971.04	3432.10	0.44
117	125	Picea abies	C	13.85	6.87	4.33	0.63	4.04	P	Mature: I	30.29	18.47	0.86

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118	126	Picea abies	C	14.48	9.55	7.91	0.83	6.40	P	Mature: R	85.80	84.84	1.44
119	127	Juglans nigra	P	79.10	25.63	22.75	0.89	19.66	P	Mature: R	53.49	3453.18	0.65
120	128	Juglans nigra	C	111.41	23.21	20.20	0.87	24.69	P	Mature: R	917.96	3222.83	0.41
121	129	Acer platanoides	P	65.57	18.29	16.12	0.88	13.56	P	Mature: R	176.81	1164.60	2.50
122	130	Gleditsia triacanthos var. inermis	P	37.56	17.46	14.26	0.82	13.11	P	Mature: None	141.54	962.11	2.13
123	131	Acer saccharinum	C	110.61	25.37	23.34	0.92	31.93	P	Mature: R	1418.22	6229.17	0.34
124	132	Acer saccharum	P	27.69	15.87	13.28	0.84	10.52	P	Mature: None	164.40	576.42	4.28
125	133	Acer saccharum	P	30.56	17.37	14.81	0.85	9.98	P	Mature: None	198.63	579.56	4.75
126	134	Acer saccharum	P	33.26	17.81	15.09	0.85	10.52	P	Mature: None	202.22	655.17	4.28
127	135	Acer saccharum	P	26.10	14.22	11.99	0.84	9.30	P	Mature: None	146.34	406.94	5.47
128	136	Quercus rubra	P	6.53	5.57	3.71	0.67	2.29	P	Young: R	16.92	7.62	2.32
129	137	Acer saccharum	P	31.19	15.94	12.45	0.78	11.73	P	Mature: None	129.77	673.01	3.43
130	138	Acer saccharinum	C	53.48	20.73	18.82	0.91	18.67	P	Mature: R	616.07	1717.25	1.01
131	139	Acer saccharum	P	31.35	17.10	14.75	0.86	13.33	P	Mature: None	147.57	1030.01	3.00
132	140	Acer saccharum	P	38.04	20.15	17.89	0.89	11.89	P	Mature: None	254.10	992.85	4.59
133	141	Acer saccharum	P	41.06	19.62	15.39	0.78	12.19	P	Mature: None	189.88	898.45	4.22
134	142	Acer saccharum	P	30.08	18.14	15.07	0.83	10.90	P	Mature: R	199.23	702.68	3.98
135	143	Fraxinus excelsior	P	69.07	17.59	14.26	0.81	15.32	P	Mature: R	58.82	1313.89	0.50
136	144	Acer saccharum	P	43.93	20.57	16.69	0.81	12.95	P	Mature: None	206.84	1099.52	3.38
137	145	Acer saccharum	P	37.08	18.65	15.91	0.85	12.50	P	Mature: None	196.79	975.62	3.87
138	146	Acer saccharum	P	27.69	13.95	11.54	0.83	10.97	P	Mature: None	122.96	545.79	3.98
139	147	Acer platanoides	P	43.13	16.72	14.66	0.88	13.56	P	Mature: R	138.41	1058.97	2.50
140	148	Acer platanoides	P	34.06	17.39	15.89	0.91	12.65	P	Mature: R	193.36	998.60	3.32
141	149	Acer saccharum	P	6.68	6.71	5.36	0.80	4.50	P	Mature: R	42.44	42.51	5.37
142	150	Acer saccharum	N/A	8.59	7.56	0.00	0.00	0.00	P	Mature: I	0.00	0.00	Tree dead
143	151	Ginkgo biloba	P	77.35	24.66	21.88	0.89	17.37	P	Mature: R	188.07	2592.77	0.72
144	152	Pinus nigra	C	63.18	7.01	5.09	0.73	11.28	P	Mature: R	134.54	169.41	1.88
145	153	Phellodendron amurense	C	84.83	16.42	13.95	0.85	20.88	P	Mature: R	571.35	1591.71	0.58
146	154	Tilia cordata	P	77.03	23.99	22.67	0.94	14.17	P	Mature: R	341.79	1787.91	1.79
147	155	Acer platanoides	C	116.02	25.77	24.41	0.95	23.62	P	Mature: R	1006.25	3566.04	0.76
148	156	Tilia x euchlora	P	53.95	14.75	12.74	0.86	12.34	P	Mature: R	123.67	762.30	3.49
149	157	Tilia x euchlora	C	57.93	9.71	8.00	0.82	14.02	P	Mature: R	234.29	411.79	2.35
150	158	Tilia x euchlora	P	58.41	10.87	9.35	0.86	12.12	P	Mature: I	53.35	539.15	3.60

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2005 Tree #	2008 Tree #	Tree Species	CRN Shape	DBH	Tree Height	CRN Depth	Live CRN Ratio	CRN Width	Loc.	Recomm.	Ca	Cv	LAI / notes
151	159	Platanus x acerifolia	P	27.37	11.14	9.41	0.84	10.13	P	Mature: None	91.71	379.46	4.37
152	160	Acer saccharinum	C	128.60	25.30	21.79	0.86	24.08	P	Mature: R	941.63	3307.58	0.60
153	161	Crataegus sp.	P	23.55	5.44	3.09	0.57	4.72	P	Young: I	24.36	27.11	2.07
154	x	Acer platanoides	N/A	x	x	x	x	x	x	x	x	x	Tree removed
155	162	Gymnocladus dioicus	C	53.48	16.12	14.25	0.88	16.92	P	Mature: R	440.21	1067.15	1.06
156	163	Acer x freemanii	C	116.82	27.78	21.39	0.77	29.72	P	Mature: R	1215.56	4944.19	0.22
157	164	Acer saccharinum	C	120.64	24.64	23.47	0.95	28.04	P	Mature: R	1204.09	4830.77	0.45
158	165	Acer saccharum	P	6.84	5.77	4.23	0.73	3.81	P	Mature: R	29.46	24.13	4.47
159	166	Acer x freemanii	C	106.00	25.31	21.36	0.84	24.38	P	Mature: R	941.95	3324.48	0.33
160	167	Acer saccharum	P	26.42	12.60	7.67	0.61	8.99	P	Mature: R	72.63	243.59	5.85
161	168	Acer saccharum	P	37.08	18.13	15.57	0.86	11.58	P	Mature: None	203.35	820.41	4.97
162	169	Metasequoia glyptostroboides	C	33.10	12.26	9.55	0.78	7.92	P	Mature: None	128.65	156.93	4.60
163	170	Metasequoia glyptostroboides	C	26.42	11.12	9.07	0.82	5.87	P	Mature: None	87.83	81.71	5.28
164	171	Metasequoia glyptostroboides	C	25.94	10.80	8.90	0.82	6.86	P	Mature: None	102.77	109.61	4.72
165	172	Acer ginnala	P	10.19	5.17	3.06	0.59	5.71	P	Young: R	25.93	39.28	2.01
165a	173	Acer ginnala	P	13.85	5.20	4.25	0.82	6.40	P	Young: R	36.75	68.40	2.47
165b	174	Acer ginnala	P	10.66	5.95	4.17	0.70	5.56	P	Young: R	35.41	50.69	2.40
165c	175	Acer ginnala	P	8.59	4.06	2.37	0.58	2.29	P	Young: R	10.85	4.86	2.09
165d	176	Acer ginnala	P	11.62 & 14.48	9.45	6.79	0.72	7.31	P	Mature: R	66.61	142.65	2.66
165e	177	Acer ginnala	P	11.46	7.19	5.43	0.76	5.03	P	Mature: R	45.97	53.94	2.98
165f	178	Acer ginnala	P	9.87 & 10.66	6.78	4.78	0.71	6.71	P	Mature: R	42.19	84.38	2.68
166	179	Acer platanoides	C	50.61	16.64	15.36	0.92	17.83	P	Mature: R	497.43	1278.48	1.33
167	180	Acer saccharinum	P	82.76	27.93	24.13	0.86	17.07	P	Mature: R	281.83	2760.44	1.20
168	181	Acer saccharinum	P	72.57	28.77	22.31	0.78	13.64	P	Mature: R	342.66	1629.93	2.02
169	182	Acer saccharinum	P	72.42	20.21	19.02	0.94	15.01	P	Mature: R	210.39	1682.82	1.55
170	183	Acer saccharinum	P	91.51	26.21	20.45	0.78	17.68	P	Mature: R	120.26	2509.50	1.12
171	184	Aesculus hippocastanum	P	77.35	18.07	16.40	0.91	14.25	P	Mature: I	162.95	1307.82	2.30
172	185	Acer platanoides	P	36.92	12.05	10.10	0.84	12.50	P	Mature: R	59.33	619.57	3.45
173	186	Acer saccharum	P	33.10	26.17	22.05	0.84	12.19	P	Mature: R	352.72	1286.97	4.22
174	187	Acer platanoides	C	53.16	15.09	13.24	0.88	16.00	P	Mature: R	388.89	887.68	1.65
175	188	Acer platanoides	P	75.28	21.30	19.27	0.91	16.53	P	Mature: I	149.00	2069.34	1.55
176	189	Picea abies	C	33.26	12.86	11.29	0.88	7.01	P	Mature: I	130.20	145.28	2.16
177	190	Acer platanoides	P	72.26	20.25	17.84	0.88	16.46	P	Mature: I	107.26	1897.29	1.56

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2005 Tree #	2008 Tree #	Tree Species	CRN Shape	DBH	Tree Height	CRN Depth	Live CRN Ratio	CRN Width	Loc.	Recomm.	Ca	Cv	LAI / notes
178	191	Quercus rubra	P	4.46	4.17	2.43	0.58	0.99	P	Young: I	5.00	0.94	1.90
179	192	Platanus x acerifolia	C	98.36	27.98	24.91	0.89	22.86	P	Mature: R	984.15	3407.96	0.66
180	193	Ulmus americana	C	159.15	20.68	19.55	0.95	20.50	P	Mature: I	710.56	2149.79	0.50
181	194	Gymnocladus dioicus	P	61.75	19.73	17.46	0.88	15.70	P	Mature: None	134.47	1688.82	1.23
182	195	Acer platanoides	C	10.35	19.98	16.19	0.81	18.29	P	Mature: R	534.11	1417.46	1.27
183	196	Acer platanoides	P	73.21	15.93	12.25	0.77	11.73	P	Mature: R	125.41	662.50	4.28
184	197	Syringa reticulata	P	12.73 - 22.76	7.93	5.75	0.73	7.92	P	Mature: R	50.73	141.83	2.62
185	198	Malus cv.	P	15.92	3.21	1.80	0.56	3.89	P	Mature: I	14.14	10.65	1.65
186	199	Malus cv.	P	13.85 & 20.53	5.53	4.16	0.75	5.71	P	Mature: R	35.53	53.36	2.42
187	200	Quercus rubra	P	24.35	10.47	9.15	0.87	7.85	P	Mature: None	100.51	221.39	3.52
188	201	Cladrastis kentukea	P	5.89 - 7	4.08	2.95	0.72	3.58	P	Young: R	19.53	14.87	1.76
188a	202	Cladrastis kentukea	P	4.14 - 9.87	5.94	4.23	0.71	4.88	P	Young: R	34.16	39.46	2.18
188b	203	Cladrastis kentukea	P	4.46 & 5.89	6.89	4.45	0.65	3.58	P	Mature: R	29.68	22.41	2.41
188c	204	Cladrastis kentukea	P	3.50 - 7.48	8.29	6.09	0.73	5.79	P	Mature: R	55.92	80.17	2.96
188d	309[1]	Cladrastis kentukea	P	2.39 - 7.48	7.38	5.37	0.73	6.629	P	Mature: R	49.04	92.67	2.63
189	x	Sorbus aucuparia	N/A	x	x	x	x	x	x	x	x	x	Tree removed
190	205	Ailanthus altissima	C	64.14	12.77	3.46	0.27	13.56	P	Mature: R	162.23	166.82	3.42
191	206	Pinus nigra	C	35.97	11.66	8.32	0.71	8.00	P	Mature: R	115.97	139.36	2.79
192	207	Pinus nigra	C	27.37	9.96	7.16	0.72	5.49	P	Mature: R	66.04	56.38	2.78
193	208	Pinus nigra	C	39.15	10.76	7.72	0.72	8.23	P	Mature: R	113.04	136.80	2.57
194	209	Chamaecyparis nootkatensis	C	20.37	11.83	10.74	0.91	5.57	P	Mature: R	97.12	87.30	2.86
194a	210	Chamaecyparis nootkatensis	C	21.01	12.71	11.27	0.89	6.02	P	Mature: R	110.31	106.93	2.82
194b	211	Chamaecyparis nootkatensis	C	20.21	14.03	12.67	0.90	6.25	P	Mature: R	128.12	129.57	3.31
194c	212	Chamaecyparis nootkatensis	C	22.92	13.32	11.99	0.90	4.88	P	Mature: R	93.79	74.75	3.11
194d	213	Chamaecyparis nootkatensis	C	16.55	10.39	9.25	0.89	4.42	P	Mature: R	66.03	47.31	2.36
195	214	Acer platanoides	C	78.15	17.21	9.31	0.54	16.53	P	Mature: R	323.40	666.42	1.69
196	215	Pinus nigra	C	77.35	10.90	5.40	0.50	11.80	P	Mature: R	148.22	196.74	1.78
197	216	Acer saccharum	C	35.49	14.61	7.94	0.54	13.11	P	Mature: None	211.97	357.13	3.37

[1] Note - The Kentucky Yellowwood tree #188f was missed in the initial 2008 inventory count, so when reintroduced into the inventory it was assigned the next number after all the trees were numbered, i.e. tree # 309. Therefore, the next tree planted in AG will be assigned the number 310 and so on.

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2005 Tree #	2008 Tree #	Tree Species	CRN Shape	DBH	Tree Height	CRN Depth	Live CRN Ratio	CRN Width	Loc.	Recomm.	Ca	Cv	LAI / notes
198	217	Tilia x euchlora	P	49.02	15.23	11.07	0.73	14.17	P	Mature: None	24.47	873.03	2.09
199	218	Tilia x euchlora	C	47.75	15.55	10.84	0.70	14.93	P	Mature: R	308.82	633.06	1.90
200	219	Ailanthus altissima	C	90.08	21.07	17.46	0.83	19.73	P	Mature: R	621.65	1780.04	0.63
201	X	Amelanchier laevis	N/A	X	x	x	x	x	P	x	x	x	Tree removed
202	220	Fagus sylvatica	P	11.94	5.44	4.44	0.82	4.95	P	Young: R	36.36	42.80	3.73
203	221	Gleditsia triacanthos var. inermis	P	42.97	12.92	10.74	0.83	14.55	P	Mature: R	0.09	893.61	1.53
204	222	Acer platanoides 'columnare'	P	34.22	14.03	11.96	0.85	8.23	P	Mature: R	145.66	318.01	3.02
205	223	Acer platanoides 'columnare'	P	27.06	16.10	14.12	0.88	5.71	P	Mature: R	148.28	181.10	4.34
206	224	Acer platanoides 'columnare'	P	26.10	14.78	12.69	0.86	5.71	x	Mature: R	131.50	162.80	4.34
207	225	Acer platanoides 'columnare'	P	19.58	15.03	8.21	0.55	4.80	P	Mature: R	71.33	74.25	2.67
208	226	Acer platanoides 'columnare'	P	17.19	13.56	10.80	0.80	5.18	P	Mature: R	102.38	113.89	4.05
209	227	Acer platanoides 'columnare'	P	20.85	12.64	8.24	0.65	6.32	P	Mature: R	83.62	129.43	2.37
210	228	Ulmus glabra	P	67.80	19.89	11.34	0.57	14.86	P	Mature: R	1.20	983.29	1.34
211	229	Ulmus glabra	P	86.74	22.31	17.48	0.78	17.75	P	Mature: R	14.22	2163.17	0.92
212	230	Acer platanoides 'columnare'	P	19.42	9.00	6.94	0.77	7.77	P	Mature: R	67.89	164.73	1.84
212a	231	Acer x freemanii 'Jeffersed'	P	4.30 & 4.77	4.13	2.40	0.58	2.90	P	Young: None	13.55	7.90	1.51
212b	232	Ailanthus altissima	P	3.82	3.22	0.91	0.28	1.50	P	Young: None	3.19	0.80	1.96
213	233	Acer platanoides 'columnare'	P	22.92	11.64	9.38	0.81	5.64	P	Mature: R	92.15	117.13	3.01
214	234	Tilia cordata	P	29.44	14.35	12.13	0.84	11.73	P	Mature: R	122.59	655.67	3.64
215	235	Ulmus glabra	C	115.55	22.01	18.91	0.86	24.15	P	Mature: R	851.47	2889.09	0.50
216	236	Acer platanoides 'columnare'	P	29.92	15.91	10.95	0.69	8.08	P	Mature: R	128.95	280.60	2.78
217	237	Acer platanoides 'columnare'	P	24.83	17.76	14.59	0.82	6.25	P	Mature: R	163.79	223.74	4.18
218	238	Acer platanoides 'columnare'	P	39.47	17.62	15.18	0.86	10.36	P	Mature: None	204.92	640.26	1.99
219	239	Populus tremula ' erecta'	P	40.58	23.62	14.30	0.61	6.10	P	Mature: I	157.35	208.64	1.41
220	240	Acer platanoides 'columnare'	P	29.60	14.77	13.87	0.94	8.08	P	Mature: R	176.28	355.34	3.11
221	241	Acer platanoides 'columnare'	P	22.92	16.34	14.14	0.87	6.10	P	Mature: R	155.39	206.36	4.28
222	242	Malus cv.	N/A	18.14	7.57	0.00	0.00	0.00	P	Mature: I	0.00	0.00	Tree dead
223	243	Fagus sylvatica	P	93.58	22.63	21.12	0.93	19.05	P	Mature: R	43.71	3009.78	1.74
224	244	Acer rubrum	P	10.50	8.95	7.38	0.82	5.64	P	Mature: R	69.53	92.11	3.01
225	245	Tilia x euchlora	C	34.06	14.78	13.48	0.91	9.30	P	Mature: None	208.20	304.94	4.72
226	246	Acer saccharum	P	30.88	13.99	11.74	0.84	13.94	P	Mature: R	50.34	896.53	2.48
227	247	Acer saccharum	P	28.01	11.44	8.07	0.71	11.12	P	Mature: R	50.33	392.01	4.85
228	248	Acer saccharinum	C	52.52	17.67	15.36	0.87	17.75	P	Mature: R	494.77	1267.57	1.11

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2005 Tree #	2008 Tree #	Tree Species	CRN Shape	DBH	Tree Height	CRN Depth	Live CRN Ratio	CRN Width	Loc.	Recomm.	Ca	Cv	LAI / notes
229	249	Tilia cordata	P	63.34	13.32	11.43	0.86	14.63	P	Mature: I	14.03	960.88	1.71
230	250	Acer saccharum	P	34.06	16.03	13.23	0.83	12.42	P	Mature: R	133.57	801.65	3.96
231	251	Ulmus glabra	C	53.48 & 61.12	19.35	17.67	0.91	16.84	P	Mature: R	517.63	1311.42	1.02
232	252	Acer platanoides	C	28.33	11.00	9.01	0.82	10.74	P	Mature: R	177.09	272.39	4.80
233	253	Acer saccharum	P	38.04	14.62	12.09	0.83	11.28	P	Mature: R	129.89	603.78	5.38
234	254	Acer saccharum	P	38.52	13.76	11.41	0.83	12.88	P	Mature: R	78.38	743.27	3.47
235	255	Acer saccharum	P	28.81	13.15	9.71	0.74	8.08	P	Mature: R	109.13	248.70	7.25
236	256	Acer saccharum	P	21.65	12.95	10.88	0.84	8.15	P	Mature: None	127.92	284.03	7.11
237	257	Catalpa speciosa ‘Nana’	P	21.33	4.81	3.23	0.67	4.19	P	Young: R	23.72	22.26	2.19
238	258	Ailanthus altissima	P	73.53	17.10	14.12	0.83	15.47	P	Mature: R	47.23	1326.57	1.03
239	259	Tilia x euchlora	P	60.00	17.77	15.53	0.87	13.11	P	Mature: None	173.72	1047.63	2.79
240	260	Acer saccharum	P	54.11	20.55	17.37	0.85	14.71	P	Mature: None	173.79	1475.14	2.19
241	261	Ulmus glabra	P	78.94	23.46	18.85	0.80	16.31	P	Mature: R	147.50	1968.21	1.09
242	262	Acer saccharum	P	32.31	17.32	14.38	0.83	12.72	P	Mature: R	154.23	914.54	3.62
243	263	Acer saccharum	P	35.33	16.53	13.33	0.81	14.78	P	Mature: None	57.54	1144.20	2.16
244	264	Acer rubrum	P	24.19	15.25	11.63	0.76	7.09	P	Mature: None	134.18	229.35	4.84
245	265	Acer saccharum	C	22.92	16.00	13.08	0.82	8.38	P	Mature: R	164.83	360.72	6.73
246	266	Tilia x euchlora	P	54.75	18.30	17.03	0.93	12.27	P	Mature: None	228.12	1006.18	2.71
247	267	Tilia x euchlora	P	65.09	16.99	15.23	0.90	14.17	P	Mature: None	133.51	1201.55	2.03
248	268	Tilia x euchlora	P	52.04	16.34	14.49	0.89	11.58	P	Mature: R	178.59	763.37	4.29
249	269	Tilia x euchlora	P	43.13	15.75	12.75	0.81	9.75	P	Mature: R	158.82	476.13	4.29
250	270	Acer saccharum	P	29.76	13.68	10.78	0.79	13.33	P	Mature: R	48.85	752.56	3.06
251	271	Acer saccharum	P	31.51	13.52	10.96	0.81	11.51	P	Mature: R	101.47	569.76	4.93
252	272	Acer saccharum	P	21.80	11.58	9.22	0.80	7.62	P	Mature: R	101.39	210.26	8.14
253	273	Pyrus calleryiana ‘Bradford’	P	50.93	11.50	9.64	0.84	11.20	P	Mature: R	79.65	474.81	1.93
254	274	Prunus avium	P	41.70	13.99	12.12	0.87	11.89	P	Mature: R	119.51	672.72	0.87
255	275	Acer saccharum	P	23.55	13.10	11.14	0.85	9.68	P	Mature: R	128.73	409.79	5.05
256	276	Acer saccharinum	C	55.39	21.12	17.51	0.83	19.66	P	Mature: R	620.15	1771.88	0.91
257	277	Acer saccharum	P	28.97	14.92	12.19	0.82	13.11	P	Mature: None	90.16	822.32	3.23
258	278	Acer saccharum	N/A	28.81	15.46	0.00	0.00	0.00	P	Mature: I	0.00	0.00	Tree dead
259	279	Acer saccharum	P	30.08	14.93	12.09	0.81	12.88	P	Mature: None	94.50	787.43	3.46
260	280	Acer saccharinum	C	69.07	22.54	18.78	0.83	22.10	P	Mature: R	756.36	2400.95	0.72
261	281	Acer saccharum	P	24.67	13.41	9.23	0.69	9.91	P	Mature: None	91.10	355.78	4.82

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262	282	Acer platanoides	P	35.81	14.80	13.36	0.90	13.72	P	Mature: R	99.89	987.16	2.38
263	283	Acer saccharum	P	28.01	14.09	10.75	0.76	11.28	P	Mature: R	101.32	536.96	3.72
264	284	Acer saccharum	P	24.35	16.67	13.28	0.80	11.51	P	Mature: R	152.31	690.14	3.57
265	285	Acer platanoides	C	73.37	22.09	20.23	0.92	22.33	P	Mature: R	810.38	2640.19	0.85
266	286	Tilia x euchlora	P	53.64	17.78	14.69	0.83	15.24	P	Mature: None	74.54	1339.63	1.76
267	287	Acer saccharinum	C	73.05	22.47	19.49	0.87	22.25	P	Mature: R	784.43	2526.41	0.71
268	288	Tilia x euchlora	P	48.86	17.10	14.41	0.84	13.41	P	Mature: R	136.61	1017.82	2.53
269	289	Acer platanoides	C	36.61	12.02	9.28	0.77	15.70	P	Mature: R	299.67	598.62	1.87
269a	290	Acer saccharum	P	4.30	4.65	3.29	0.71	1.37	P	Young: R	9.27	2.43	6.44
270	291	Fraxinus pennsylvanica	P	15.12	8.18	5.83	0.71	4.50	S	Mature: R	46.66	46.30	2.34
271	292	Fraxinus pennsylvanica	P	18.62	7.62	5.18	0.68	6.25	S	Mature: R	46.76	79.43	2.01
272	293	Fraxinus pennsylvanica	P	14.96	8.24	5.67	0.69	7.39	S	Mature: R	51.69	121.71	2.14
273	294	Fraxinus pennsylvanica	P	16.39	7.83	5.56	0.71	7.16	S	Mature: R	50.82	112.07	2.11
274	295	Fraxinus pennsylvanica	P	16.87	7.56	5.99	0.79	5.79	S	Mature: R	54.87	78.93	2.29
275	296	Fraxinus pennsylvanica	P	19.89	8.13	5.54	0.68	8.99	S	Mature: R	40.23	175.81	2.02
276	297	Fraxinus pennsylvanica	P	23.24	10.30	8.00	0.78	9.14	S	Mature: R	76.85	262.77	2.46
277	298	Fraxinus pennsylvanica	P	12.57	6.55	3.72	0.57	3.73	S	Mature: R	25.41	20.39	1.61
278	299	Fraxinus pennsylvanica	P	26.26	9.46	7.74	0.82	10.36	S	Mature: R	57.81	326.21	2.11
279	300	Fraxinus pennsylvanica	P	25.46	10.97	8.84	0.81	9.37	S	Mature: R	89.20	304.88	2.56
280	301	Fraxinus pennsylvanica	P	25.62	10.44	8.07	0.77	9.60	S	Mature: R	73.68	292.16	2.36
281	302	Fraxinus pennsylvanica	P	16.39	6.94	4.69	0.68	5.87	S	Mature: I	41.00	63.35	1.86
282	303	Acer x freemanii 'Jeffersed'	P	5.41	4.85	2.84	0.58	2.90	S	Young: R	15.88	9.34	1.37
283	304	Fraxinus pennsylvanica	P	12.89	5.92	3.73	0.63	5.33	S	Young: I	30.91	41.64	1.58
284	305	Fraxinus pennsylvanica	P	16.07	8.26	5.86	0.71	6.93	S	Mature: I	54.80	110.57	2.20
285	306	Fraxinus pennsylvanica	P	18.14	7.78	4.91	0.63	6.86	S	Mature: I	43.44	90.59	1.94
286	307	Gleditsia triancanthos var inermis	P	7.32	5.86	3.53	0.60	3.35	S	Young: R	22.22	15.59	2.65
287	x	Fraxinus pennsylvanica	N/A	15.60	6.69	0	0	0	S	Mature: I	0.00	0.00	Tree removed
288	308	Fraxinus pennsylvanica	P	17.51	6.34	4.86	0.77	4.95	S	Mature: I	40.26	46.86	1.92

Appendix A – 2008 Tree Inventory

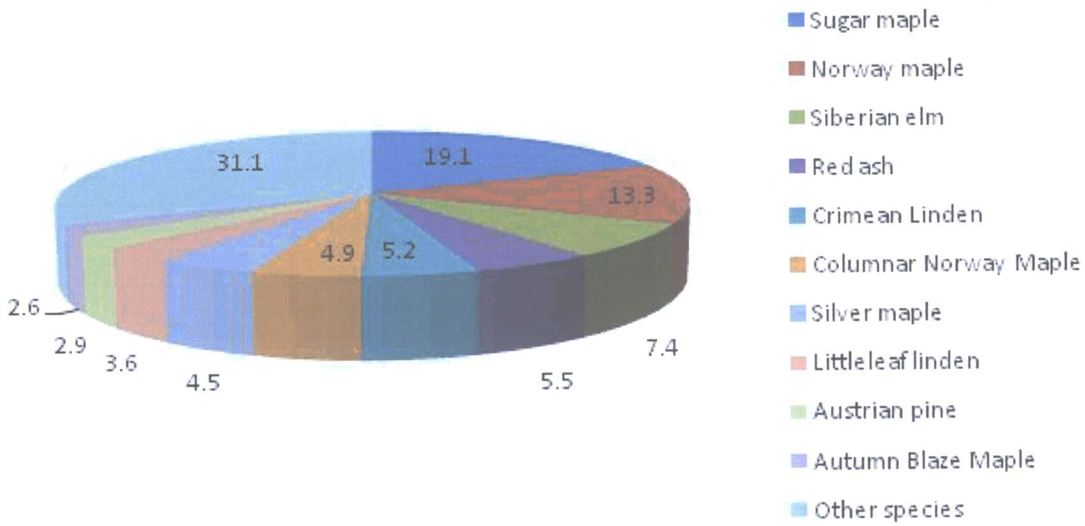
Where:

1. CRN shape:
    - P – Parabolic shape,
    - C – Conoid shape.
2. Loc: Location:
    - P – Park,
    - S – Sidewalk.
3. Recomm.: Recommended attention:
    - Mature: Mature tree – tree height ≥ 5.48m, requiring either
        - R - Regular maintenance or,
        - I – Immediate attention and maintenance.
    - Young: Young tree – tree height < 5.48m, requiring either
        - R - Regular maintenance or,
        - I – Immediate attention and maintenance.
4. Any occurrences of "x" indicate that the tree has been removed sometime between the 2006 inventory and this study's 2008 inventory. Therefore, at the time of this study's investigation this tree did not exist in AG.
5. Any occurrences of "0" in the crown measurements indicate that though this tree still stands in AG (as of 2008), it no longer leafs out. Thus, it has no canopy dimensions.

Appendix B1 – Complete Population of Public Trees

	0-8	8-15	15-30	30-46	46-61	61-76	76-91	91-107	>107	Total
BROADLEAF DECIDUOUS - LARGE										
Sugar Maple	6	1	25	20	4	3	0	0	0	59
Norway Maple	0	1	3	15	7	11	2	1	1	41
Siberian Elm	0	0	6	13	3	1	0	0	0	23
Red Ash	0	5	12	0	0	0	0	0	0	17
Columnar Norway Maple	0	1	12	2	0	0	0	0	0	15
Silver Maple	6	0	0	0	3	4	2	1	4	14
Black Walnut	0	0	0	0	0	1	4	0	1	6
Scotch Elm	0	0	0	0	1	1	3	0	1	6
Green Ash	0	0	5	0	0	0	0	0	0	5
Honeylocust	1	0	0	4	0	0	0	0	0	5
Northern Red Oak	4	0	1	0	0	0	0	0	0	5
Tree of Heaven	1	0	0	0	0	2	1	0	0	4
Dawn Redwood	0	0	2	1	0	0	0	0	0	3
Pyramidal English Oak	0	0	3	0	0	0	0	0	0	3
Freeman Maple	0	0	0	0	0	0	0	1	1	2
Horsechestnut	0	0	0	0	0	1	1	0	0	2
European Beech	0	1	0	0	0	0	0	1	0	2
Kentucky Coffeetree	0	0	0	0	1	1	0	0	0	2
London plane	0	0	1	0	0	0	0	1	0	2
White Oak	0	1	1	0	0	0	0	0	0	2
American Elm	0	0	0	0	0	1	0	0	1	2
Sycamore Maple	0	0	0	0	1	0	0	0	0	1
White Ash	0	0	0	0	0	0	1	0	0	1
European Ash	0	0	0	0	0	1	0	0	0	1
Maidenhair	0	0	0	0	0	0	1	0	0	1
Upright European Aspen	0	0	0	1	0	0	0	0	0	1
Bur Oak	0	0	0	0	0	0	0	0	0	1
Total	12	11	71	56	20	27	15	4	8	226
BROADLEAF DECIDUOUS - MEDIUM										
Crimean Linden	0	0	0	2	12	2	0	0	0	16
Littleleaf Linden	0	0	1	4	2	0	3	0	1	11
Autumn Blaze Maple	8	0	0	0	0	0	0	0	0	8
Red Maple	0	1	1	0	0	0	0	0	0	2
Northern Catalpa	0	0	1	0	0	0	0	0	0	1
Hawthorn	0	0	1	0	0	0	0	0	0	1
Amur Corktree	0	0	0	0	0	0	1	0	0	1
Sweet Cherry	0	0	0	1	0	0	0	0	0	1
Japanese Pagoda	0	0	0	1	0	0	0	0	0	1
Total	8	1	4	8	14	2	4	0	1	42
BROADLEAF DECIDUOUS - SMALL										
Amur Maple	0	7	0	0	0	0	0	0	0	7
Kentucky Yellowwood	4	1	0	0	0	0	0	0	0	5
Crabapple	0	0	3	0	0	0	0	0	0	3
Japanese Tree Lilac	0	1	1	0	0	0	0	0	0	2
Callery Pear	0	0	0	0	1	0	0	0	0	1
Total	4	9	4	0	1	0	0	0	0	18
CONIFER EVERGREEN LARGE										
Austrian Pine	0	0	3	3	1	1	1	0	0	9
Alaska Cedar	0	0	5	0	0	0	0	0	0	5
Norway Spruce	0	2	0	1	0	0	0	0	0	3
Total	0	2	8	4	1	1	1	0	0	17
CONIFER EVERGREEN - SMALL										
Japanese Yew	2	3	1	0	0	0	0	0	0	6
Total	2	3	1	0	0	0	0	0	0	6
AG-wide Total	26	26	88	68	36	30	20	5	10	309

Appendix B2 – Species Distribution of Public Trees (%)

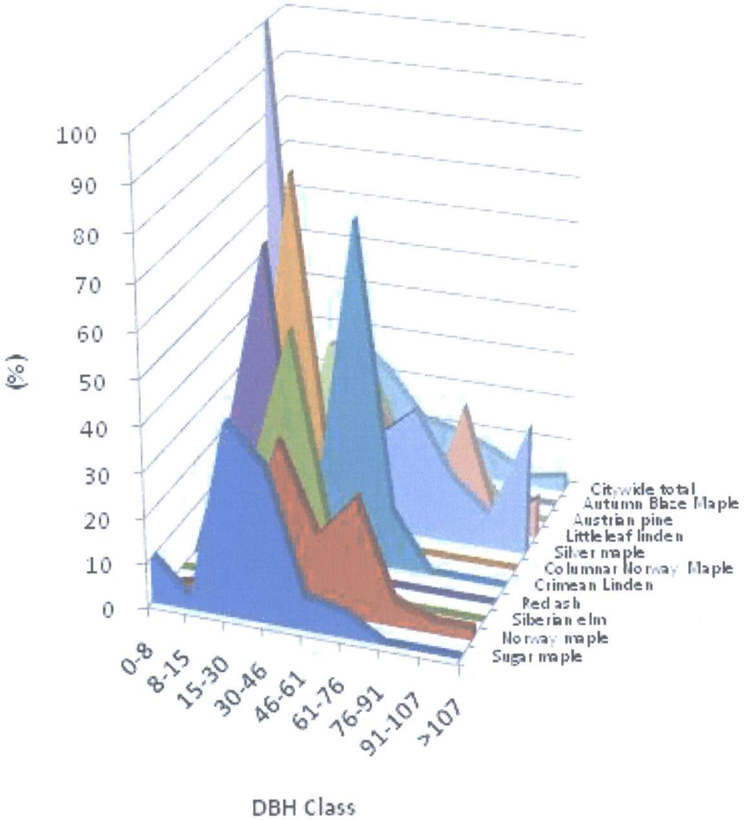


Species	Percent
Sugar Maple	19.1
Norway Maple	13.3
Siberian Elm	7.4
Red Ash	5.5
Crimean Linden	5.2
Columnar Norway maple	4.9
Silver Maple	4.5
Littleleaf Linden	3.6
Austrian Pine	2.9
Autumn Blaze Maple	2.6
Other Species	31.1
Total	100

Appendix B3 – Importance Values for Most Abundant Public Trees

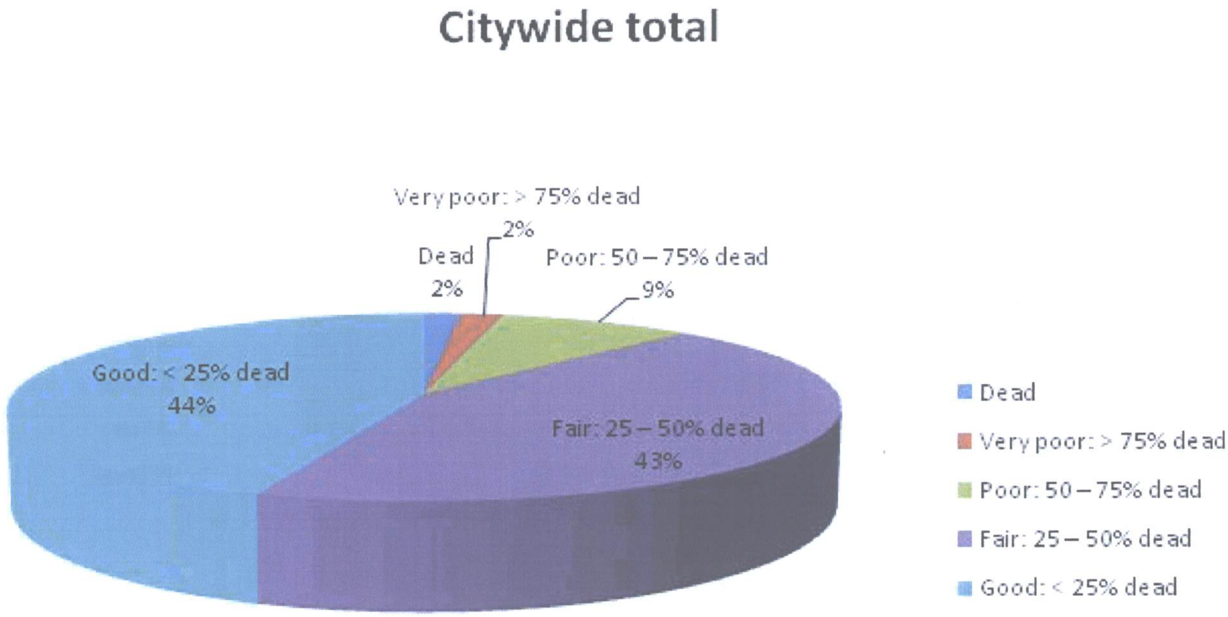
Species	Number of Trees	% of Total Trees	Leaf Area (m^2)	% of Total Leaf Area	Canopy Cover (m^2)	% of Total Canopy Cover	Importance Value
Sugar maple	59	19.1	8,472	11.2	2,615	11.0	13.8
Norway maple	41	13.3	11,049	14.6	4,111	17.2	15.0
Siberian elm	23	7.4	5,174	6.8	1,471	6.2	6.8
Red ash	17	5.5	1,646	2.2	593	2.5	3.4
Crimean Linden	16	5.2	3,937	5.2	1,584	6.6	5.7
Columnar Norway Maple	15	4.9	910	1.2	535	2.2	2.8
Silver maple	14	4.5	10,750	14.2	2,777	11.6	10.1
Littleleaf linden	11	3.6	2,069	2.7	809	3.4	3.2
Austrian pine	9	2.9	1,253	1.7	504	2.1	2.2
Autumn Blaze Maple	8	2.6	35	0.0	10	0.0	0.9
Amur maple	7	2.3	40	0.1	11	0.0	0.8
Black walnut	6	1.9	6,140	8.1	1,501	6.3	5.5
Japanese Yew	6	1.9	96	0.1	26	0.1	0.7
Scotch Elm	6	1.9	5,344	7.1	1,677	7.0	5.3
Alaska Cedar	5	1.6	426	0.6	154	0.6	0.9
Kentucky Yellowwood	5	1.6	28	0.0	16	0.1	0.6
Green Ash	5	1.6	678	0.9	242	1.0	1.2
Honeylocust	5	1.6	582	0.8	265	1.1	1.2
Northern red oak	5	1.6	169	0.2	59	0.2	0.7
Tree of heaven	4	1.3	2,611	3.5	676	2.8	2.5
Other trees	42	13.6	14,224	18.8	4,205	17.6	16.7
Total	309	100.0	75,633	100.0	23,841	100.0	100.0

Appendix B4 – Relative Age Distribution of Top 10 Tree Species (%)



	DBH class (cm)								
Species	0-8	8-15	15-30	30-46	46-61	61-76	76-91	91-107	>107
Sugar maple	10.17	1.69	42.37	33.90	6.78	5.08	0.00	0.00	0.00
Norway maple	0.00	2.44	7.32	36.59	17.07	26.83	4.88	2.44	2.44
Siberian elm	0.00	0.00	26.09	56.52	13.04	4.35	0.00	0.00	0.00
Red ash	0.00	29.41	70.59	0.00	0.00	0.00	0.00	0.00	0.00
Crimean Linden	0.00	0.00	0.00	12.50	75.00	12.50	0.00	0.00	0.00
Columnar Norway	0.00	6.67	80.00	13.33	0.00	0.00	0.00	0.00	0.00
Silver maple	0.00	0.00	0.00	0.00	21.43	28.57	14.29	7.14	28.57
Littleleaf linden	0.00	0.00	9.09	36.36	18.18	0.00	27.27	0.00	9.09
Austrian pine	0.00	0.00	33.33	33.33	11.11	11.11	11.11	0.00	0.00
Autumn Blaze Maple	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Citywide total	8.41	8.41	28.48	22.01	11.65	9.71	6.47	1.62	3.24

Appendix B5 – Structural (Woody) Condition of Public Trees by Species (%)



Species	Dead	Very poor: > 75% dead	Poor: 50 – 75% dead	Fair: 25 – 50% dead	Good: < 25% dead
Sugar maple	3.4	5.1	13.6	52.5	25.4
Norway maple	0.0	0.0	2.4	31.7	65.9
Siberian elm	0.0	0.0	8.7	39.1	52.2
Red ash	0.0	0.0	0.0	58.8	41.2
Crimean Linden	0.0	0.0	0.0	12.5	87.5
Columnar Norway	6.7	0.0	0.0	40.0	53.3
Silver maple	0.0	7.1	21.4	50.0	21.4
Littleleaf linden	0.0	0.0	0.0	63.6	36.4
Austrian pine	0.0	0.0	0.0	100.0	0.0
Autumn Blaze Maple	0.0	0.0	0.0	12.5	87.5
Amur maple	0.0	0.0	0.0	0.0	100.0
Black walnut	0.0	0.0	0.0	50.0	50.0
Japanese Yew	16.7	0.0	16.7	66.7	0.0
Scotch Elm	0.0	0.0	0.0	83.3	16.7
Alaska Cedar	0.0	0.0	0.0	0.0	100.0
Kentucky Yellowwood	0.0	0.0	0.0	0.0	100.0
Green Ash	0.0	0.0	60.0	40.0	0.0
Honeylocust	0.0	0.0	20.0	60.0	20.0
Northern red oak	0.0	0.0	0.0	0.0	100.0
Tree of heaven	0.0	0.0	0.0	25.0	75.0
Citywide total	1.6	1.9	8.7	43.4	44.3

Appendix B6 – Functional (Foliage) Condition of Public Trees by Species (%)

Species	Dead or Dying	Poor	Fair	Good
Sugar maple	3.4	1.7	20.3	74.6
Norway maple	0.0	0.0	4.9	95.1
Siberian elm	0.0	8.7	56.5	34.8
Red ash	0.0	0.0	17.6	82.4
Columnar Norway	6.7	0.0	0.0	93.3
Crimean Linden	0.0	0.0	13.3	86.7
Silver maple	0.0	0.0	50.0	50.0
Littleleaf linden	0.0	0.0	27.3	72.7
Austrian pine	0.0	0.0	44.4	55.6
Autumn Blaze Maple	0.0	0.0	0.0	100.0
Amur maple	0.0	0.0	0.0	100.0
Black walnut	0.0	0.0	0.0	100.0
Japanese Yew	16.7	16.7	66.7	0.0
Scotch Elm	0.0	0.0	16.7	83.3
Alaska Cedar	0.0	0.0	100.0	0.0
Kentucky Yellowwood	0.0	0.0	0.0	100.0
Green Ash	0.0	40.0	20.0	40.0
Honeylocust	0.0	0.0	20.0	80.0
Northern red oak	0.0	0.0	0.0	100.0
Tree of heaven	0.0	0.0	0.0	100.0
Citywide total	1.6	2.6	21.4	74.4

Appendix B7 – Replacement Value for Public Trees by Species

	DBH Class (cm)											
Species	0-8	8-15	15-30	30-46	46-61	61-76	76-91	91-107	>107	Total	Standard Error	% of Total
Sugar maple	1,193	53.27	26,577.74	58,556.43	22,536.38	27,635.62	0.00	0.00	0.00	136,552.05	(±0)	7.16
Norway maple	0	521.47	4,937.29	64,494.09	58,054.26	148,747.00	39,676.59	26,208.34	29,238.62	371,877.66	(±0)	19.49
Siberian elm	0	0.00	6,860.14	36,077.76	16,902.28	9,211.87	0.00	0.00	0.00	69,052.05	(±0)	3.62
Red ash	0	2,607.34	19,749.17	0.00	0.00	0.00	0.00	0.00	0.00	22,356.51	(±0)	1.17
Crimean Linden	0	0.00	0.00	11,255.38	129,501.19	36,216.79	0.00	0.00	0.00	176,973.36	(±0)	9.27
Columnar Norway	0	61.35	19,749.17	8,599.21	0.00	0.00	0.00	0.00	0.00	28,409.73	(±0)	1.49
Silver maple	0	0.00	0.00	0.00	16,902.28	31,428.74	19,133.40	17,577.34	78,390.12	163,431.88	(±0)	8.56
Littleleaf linden	0	0.00	2,089.24	22,510.77	21,905.68	0.00	79,037.82	0.00	38,879.71	164,423.20	(±0)	8.62
Austrian pine	0	0.00	5,602.50	14,890.95	9,623.15	15,884.26	23,092.12	0.00	0.00	69,092.98	(±0)	3.62
Autumn Blaze Maple	1,022	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1,021.99	(±0)	0.05
Amur maple	0	3,650.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3,650.28	(±0)	0.19
Black walnut	0	0.00	0.00	0.00	0.00	20,332.52	118,399.05	0.00	43,700.25	182,431.81	(±0)	9.56
Japanese Yew	306	935.29	758.82	0.00	0.00	0.00	0.00	0.00	0.00	1,999.97	(±0)	0.10
Scotch Elm	0	0.00	0.00	0.00	5,634.09	9,211.87	39,991.93	0.00	19,597.53	74,435.43	(±0)	3.90
Alaska Cedar	0	0.00	9,337.50	0.00	0.00	0.00	0.00	0.00	0.00	9,337.50	(±0)	0.49
Kentucky Yellowwood	928	452.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1,380.65	(±0)	0.07
Green Ash	0	0.00	5,886.03	0.00	0.00	0.00	0.00	0.00	0.00	5,886.03	(±0)	0.31
Honeylocust	169	0.00	0.00	19,854.60	0.00	0.00	0.00	0.00	0.00	20,024.03	(±0)	1.05
Northern red oak	428	0.00	2,532.71	0.00	0.00	0.00	0.00	0.00	0.00	2,960.32	(±0)	0.16
Tree of heaven	128	0.00	0.00	0.00	0.00	40,665.05	29,599.76	0.00	0.00	70,392.55	(±0)	3.69
Crabapple	0	0.00	3,405.44	0.00	0.00	0.00	0.00	0.00	0.00	3,405.44	(±0)	0.18
Dawn redwood	0	0.00	4,621.94	6,291.73	0.00	0.00	0.00	0.00	0.00	10,913.68	(±0)	0.57
Norway spruce	0	1,111.64	0.00	4,963.65	0.00	0.00	0.00	0.00	0.00	6,075.29	(±0)	0.32
English oak	0	0.00	6,853.21	0.00	0.00	0.00	0.00	0.00	0.00	6,853.21	(±0)	0.36
Freeman Maple	0	0.00	0.00	0.00	0.00	0.00	0.00	17,577.34	13,833.55	31,410.89	(±0)	1.65
Red maple	0	624.53	2,310.97	0.00	0.00	0.00	0.00	0.00	0.00	2,935.50	(±0)	0.15
Horsechestnut	0	0.00	0.00	0.00	0.00	9,211.87	13,330.64	0.00	0.00	22,542.52	(±0)	1.18
European beech	0	624.53	0.00	0.00	0.00	0.00	0.00	39,154.83	0.00	39,779.36	(±0)	2.08
Kentucky coffeetree	0	0.00	0.00	0.00	8,670.02	20,332.52	0.00	0.00	0.00	29,002.54	(±0)	1.52
London Plane	0	0.00	2,089.24	0.00	0.00	0.00	0.00	15,165.36	0.00	17,254.59	(±0)	0.90
White oak	0	319.60	1,202.29	0.00	0.00	0.00	0.00	0.00	0.00	1,521.89	(±0)	0.08
Japanese tree lilac	0	452.76	1,202.29	0.00	0.00	0.00	0.00	0.00	0.00	1,655.05	(±0)	0.09
American elm	0	0.00	0.00	0.00	0.00	9,211.87	0.00	0.00	19,597.53	28,809.40	(±0)	1.51
Sycamore maple	0	0.00	0.00	0.00	8,293.47	0.00	0.00	0.00	0.00	8,293.47	(±0)	0.43
Northern catalpa	0	0.00	2,310.97	0.00	0.00	0.00	0.00	0.00	0.00	2,310.97	(±0)	0.12
Hawthorn	0	0.00	1,005.95	0.00	0.00	0.00	0.00	0.00	0.00	1,005.95	(±0)	0.05

Appendix B7 – Replacement Value for Public Trees by Species

	DBH Class (cm)											
Species	0-8	8-15	15-30	30-46	46-61	61-76	76-91	91-107	>107	Total	Standard Error	% of Total
White ash	0	0.00	0.00	0.00	0.00	0.00	19,838.29	0.00	0.00	19,838.29	(±0)	1.04
Europeam Ash	0	0.00	0.00	0.00	0.00	20,332.52	0.00	0.00	0.00	20,332.52	(±0)	1.07
Ginkgo	0	0.00	0.00	0.00	0.00	0.00	29,599.76	0.00	0.00	29,599.76	(±0)	1.55
Amur corktree	0	0.00	0.00	0.00	0.00	0.00	29,599.76	0.00	0.00	29,599.76	(±0)	1.55
Upright European	0	0.00	0.00	2,738.75	0.00	0.00	0.00	0.00	0.00	2,738.75	(±0)	0.14
Sweet cherry	0	0.00	0.00	4,299.61	0.00	0.00	0.00	0.00	0.00	4,299.61	(±0)	0.23
Callery pear	0	0.00	0.00	0.00	5,634.09	0.00	0.00	0.00	0.00	5,634.09	(±0)	0.30
Bur Oak	0	658.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	658.88	(±0)	0.03
Japanese pagoda tree	0	0.00	0.00	6,291.73	0.00	0.00	0.00	0.00	0.00	6,291.73	(±0)	0.33
Citywide total	4,173	12,073.69		260,824.67	303,656.88	398,422.51	441,299.12	115,683.21	243,237.30	1,908,453.12	(±0)	100.00

Appendix C1 – Annual Energy Benefits of Public Trees by Species

Species	Total Electricity (GJ)	Electricity ($)	Total Natural Gas (GJ)	Natural Gas ($)	Total ($)	Standard Error	% of Total Trees	% of Total $	Avg. $/tree
Sugar maple	10.3	145	131.0	1,387	1,532	(N/A)	19.1	13.8	25.97
Norway maple	14.6	205	160.8	1,702	1,907	(N/A)	13.3	17.2	46.51
Siberian elm	5.7	80	66.4	703	783	(N/A)	7.4	7.1	34.04
Red ash	2.4	34	30.8	326	359	(N/A)	5.5	3.2	21.14
Crimean Linden	5.9	83	67.4	714	797	(N/A)	5.2	7.2	49.80
Columnar Norway Maple	2.1	29	27.9	295	325	(N/A)	4.9	2.9	21.66
Silver maple	9.3	130	93.3	987	1,117	(N/A)	4.5	10.1	79.82
Littleleaf linden	3.1	43	35.8	379	422	(N/A)	3.6	3.8	38.35
Austrian pine	1.9	27	20.5	217	243	(N/A)	2.9	2.2	27.01
Autumn Blaze Maple	0.0	1	0.7	7	8	(N/A)	2.6	0.1	0.98
Amur maple	0.0	1	0.7	7	8	(N/A)	2.3	0.1	1.13
Black walnut	4.5	63	43.1	457	520	(N/A)	1.9	4.7	86.60
Japanese Yew	0.1	1	1.3	14	16	(N/A)	1.9	0.1	2.60
Scotch Elm	5.2	73	47.1	499	572	(N/A)	1.9	5.2	95.37
Alaska Cedar	0.6	8	6.7	71	79	(N/A)	1.6	0.7	15.87
Kentucky Yellowwood	0.1	1	1.1	12	13	(N/A)	1.6	0.1	2.56
Green Ash	1.0	14	12.5	133	146	(N/A)	1.6	1.3	29.27
Honeylocust	1.0	15	12.6	133	148	(N/A)	1.6	1.3	29.57
Northern red oak	0.2	3	3.2	33	37	(N/A)	1.6	0.3	7.36
Tree of heaven	2.1	30	21.1	223	253	(N/A)	1.3	2.3	63.24
Other street trees	14.6	205	152.5	1,614	1,819	(N/A)	13.6	16.4	43.31
Citywide total	84.8	1,190	936.5	9,914	11,104	(N/A)	100.0	100.0	35.93

Appendix C2 – Annual CO_2 Benefits of Public Trees by Species

Species	Sequestered (kg)	Sequestered ($)	Decomposition Release(kg)	Maintenance Release(kg)	Total Released ($)	Avoided (kg)	Avoided ($)	Net Total (kg)	Total Standard ($) Error	% of Total Trees	% of Total $	Avg. $/tree
Sugar maple	3,119	52	-675	-202	-15	3,924	65	6,166	102 (N/A)	19.1	11.9	1.73
Norway maple	9,005	149	-915	-263	-19	5,541	92	13,368	221 (N/A)	13.3	25.8	5.39
Siberian elm	1,871	31	-467	-91	-9	2,152	36	3,465	57 (N/A)	7.4	6.7	2.49
Red ash	326	5	-61	-40	-2	907	15	1,132	19 (N/A)	5.5	2.2	1.10
Crimean Linden	1,020	17	-780	-112	-15	2,254	37	2,382	39 (N/A)	5.2	4.6	2.46
Columnar Norway	748	12	-158	-44	-3	796	13	1,341	22 (N/A)	4.9	2.6	1.48
Silver maple	2,311	38	-720	-158	-15	3,521	58	4,954	82 (N/A)	4.5	9.6	5.85
Littleleaf linden	402	7	-212	-68	-5	1,170	19	1,292	21 (N/A)	3.6	2.5	1.94
Austrian pine	154	3	-44	-47	-2	717	12	780	13 (N/A)	2.9	1.5	1.43
Autumn Blaze Maple	33	1	-1	-4	0	15	0	43	1 (N/A)	2.6	0.1	0.09
Amur maple	24	0	-2	-4	0	17	0	35	1 (N/A)	2.3	0.1	0.08
Black walnut	741	12	-277	-66	-6	1,703	28	2,100	35 (N/A)	1.9	4.1	5.79
Japanese Yew	25	0	-1	-3	0	37	1	58	1 (N/A)	1.9	0.1	0.16
Scotch Elm	2,072	34	-386	-66	-7	1,983	33	3,603	60 (N/A)	1.9	6.9	9.93
Alaska Cedar	93	2	-18	-16	-1	225	4	284	5 (N/A)	1.6	0.6	0.94
Kentucky Yellowwood	14	0	-1	-3	0	26	0	37	1 (N/A)	1.6	0.1	0.12
Green Ash	131	2	-25	-16	-1	370	6	461	8 (N/A)	1.6	0.9	1.52
Honeylocust	213	4	-40	-13	-1	394	7	554	9 (N/A)	1.6	1.1	1.83
Northern red oak	59	1	-11	-5	0	92	2	134	2 (N/A)	1.6	0.3	0.44
Tree of heaven	474	8	-239	-31	-4	800	13	1,004	17 (N/A)	1.3	1.9	4.15
Other street trees	4,368	72	-986	-231	-20	5,550	92	8,701	144 (N/A)	13.6	16.8	3.43
Citywide total	27,201	450	-6,019	-1,481	-124	32,193	532	51,895	858 (N/A)	100.0	100.0	2.78

Appendix C3 – Annual Air Quality Benefits of Public Trees by Species

Species	Deposition (kg)				Total Depos. ($)	Avoided (kg)				Total Avoided ($)	BVOC Emissions (kg)	BVOC Emissions ($)	Total Emissions	Total Standard ($) Error	% of Total Trees	Avg. $/tree
	O_3	NO_2	PM_{10}	SO_2		NO_2	PM_{10}	VOC	SO_2							
Sugar maple	7.1	3.1	3.5	1.2	170	12.0	0.8	0.5	5.7	208	-3.3	-45	30.5	333 (N/A)	19.1	5.64
Norway maple	11.2	4.8	5.5	1.8	267	15.9	1.0	0.6	8.1	278	-2.0	-27	47.0	517 (N/A)	13.3	12.62
Siberian elm	3.7	1.5	1.7	0.6	86	6.4	0.4	0.2	3.1	111	0.0	0	17.6	196 (N/A)	7.4	8.53
Red ash	1.6	0.7	0.7	0.2	37	2.8	0.2	0.1	1.3	49	0.0	0	7.6	85 (N/A)	5.5	5.01
Crimean Linden	4.2	1.7	2.0	0.6	98	6.6	0.4	0.3	3.3	114	-2.1	-29	17.0	184 (N/A)	5.2	11.50
Columnar Norway Maple	1.5	0.6	0.7	0.2	35	2.5	0.2	0.1	1.2	43	-0.2	-2	6.8	76 (N/A)	4.9	5.04
Silver maple	7.5	3.3	3.7	1.2	180	9.7	0.6	0.4	5.1	170	-2.8	-38	28.8	312 (N/A)	4.5	22.31
Littleleaf linden	2.1	0.9	1.0	0.3	50	3.4	0.2	0.1	1.7	60	-1.1	-15	8.8	95 (N/A)	3.6	8.64
Austrian pine	1.9	0.9	1.2	0.5	48	2.0	0.1	0.1	1.0	36	-3.9	-53	3.9	31 (N/A)	2.9	3.41
Autumn Blaze Maple	0.0	0.0	0.0	0.0	1	0.1	0.0	0.0	0.0	1	0.0	0	0.1	1 (N/A)	2.6	0.18
Amur maple	0.0	0.0	0.0	0.0	1	0.1	0.0	0.0	0.0	1	0.0	0	0.1	2 (N/A)	2.3	0.23
Black walnut	3.9	1.7	1.9	0.6	93	4.6	0.3	0.2	2.5	81	0.0	0	15.7	174 (N/A)	1.9	29.00
Japanese Yew	0.1	0.0	0.1	0.0	2	0.1	0.0	0.0	0.1	2	-0.2	-2	0.2	2 (N/A)	1.9	0.36
Scotch Elm	4.2	1.7	2.0	0.6	98	5.2	0.3	0.2	2.9	92	0.0	0	17.2	190 (N/A)	1.9	31.63
Alaska Cedar	0.6	0.3	0.4	0.2	15	0.7	0.0	0.0	0.3	11	-1.3	-18	1.1	8 (N/A)	1.6	1.61
Kentucky Yellowwood	0.0	0.0	0.0	0.0	1	0.1	0.0	0.0	0.0	2	0.0	0	0.2	3 (N/A)	1.6	0.52
Green Ash	0.6	0.3	0.3	0.1	15	1.1	0.1	0.0	0.5	20	0.0	0	3.1	35 (N/A)	1.6	6.96
Honeylocust	0.7	0.3	0.3	0.1	15	1.2	0.1	0.0	0.6	21	-0.3	-4	3.0	32 (N/A)	1.6	6.48
Northern red oak	0.2	0.1	0.1	0.0	4	0.3	0.0	0.0	0.1	5	-0.1	-2	0.6	7 (N/A)	1.6	1.32
Tree of heaven	1.8	0.7	0.9	0.3	42	2.2	0.1	0.1	1.2	39	0.0	0	7.2	81 (N/A)	1.3	20.13
Other street trees	11.1	4.7	5.4	1.8	264	15.6	1.0	0.6	8.1	272	-3.3	-46	45.0	491 (N/A)	13.6	11.69
Citywide total	63.9	27.3	31.4	10.5	1,520	92.6	6.0	3.6	46.9	1,615	-20.5	-281	261.7	2,854 (N/A)	100.0	9.24

Appendix C4 – Annual Stormwater Benefits of Public Trees by Species

Species	Total rainfall interception (cu.m.)	Total ($)	Standard Error	% of Total Trees	% of Total $	Avg. $/tree
Sugar maple	215	415	(N/A)	19.1	11.2	7.04
Norway maple	313	603	(N/A)	13.3	16.3	14.71
Siberian elm	114	220	(N/A)	7.4	6.0	9.57
Red ash	43	83	(N/A)	5.5	2.3	4.91
Crimean Linden	111	214	(N/A)	5.2	5.8	13.38
Columnar Norway Maple	32	62	(N/A)	4.9	1.7	4.15
Silver maple	257	495	(N/A)	4.5	13.4	35.39
Littleleaf linden	57	111	(N/A)	3.6	3.0	10.07
Austrian pine	49	95	(N/A)	2.9	2.6	10.52
Autumn Blaze Maple	1	2	(N/A)	2.6	0.0	0.21
Amur maple	1	2	(N/A)	2.3	0.1	0.27
Black walnut	135	261	(N/A)	1.9	7.1	43.45
Japanese Yew	3	6	(N/A)	1.9	0.2	1.02
Scotch Elm	124	240	(N/A)	1.9	6.5	39.94
Alaska Cedar	16	31	(N/A)	1.6	0.8	6.17
Kentucky Yellowwood	1	2	(N/A)	1.6	0.1	0.37
Green Ash	18	34	(N/A)	1.6	0.9	6.85
Honeylocust	16	31	(N/A)	1.6	0.8	6.20
Northern red oak	5	9	(N/A)	1.6	0.2	1.75
Tree of heaven	59	114	(N/A)	1.3	3.1	28.46
Other street trees	348	671	(N/A)	13.6	18.1	15.97
Citywide total	1,920	3,701	(N/A)	100.0	100.0	11.98

Appendix C5 – Annual Aesthetic / Other Benefits of Public Trees by Species

Species	Total ($)	Standard Error	% of Total Trees	% of Total $	Avg. $/tree
Sugar maple	3,500	(N/A)	19.1	15.0	59.32
Norway maple	4,669	(N/A)	13.3	20.0	113.88
Siberian elm	2,791	(N/A)	7.4	11.9	121.36
Red ash	1,054	(N/A)	5.5	4.5	62.02
Crimean Linden	583	(N/A)	5.2	2.5	36.41
Columnar Norway Maple	629	(N/A)	4.9	2.7	41.95
Silver maple	1,004	(N/A)	4.5	4.3	71.68
Littleleaf linden	387	(N/A)	3.6	1.7	35.14
Austrian pine	266	(N/A)	2.9	1.1	29.60
Autumn Blaze Maple	602	(N/A)	2.6	2.6	75.22
Amur maple	72	(N/A)	2.3	0.3	10.24
Black walnut	679	(N/A)	1.9	2.9	113.14
Japanese Yew	171	(N/A)	1.9	0.7	28.57
Scotch Elm	1,250	(N/A)	1.9	5.4	208.36
Alaska Cedar	197	(N/A)	1.6	0.8	39.37
Kentucky Yellowwood	63	(N/A)	1.6	0.3	12.55
Green Ash	335	(N/A)	1.6	1.4	66.91
Honeylocust	473	(N/A)	1.6	2.0	94.57
Northern red oak	241	(N/A)	1.6	1.0	48.25
Tree of heaven	534	(N/A)	1.3	2.3	133.53
Other street trees	3,875	(N/A)	13.6	16.6	92.25
Citywide total	23,373	(N/A)	100.0	100.0	75.64

Appendix C6 – Annual Benefits of Public Trees by Species ($/tree)

Species	Energy	CO_2	Air Quality	Stormwater	Aesthetic/Other	Total ($)	Standard Error
Sugar maple	25.97	1.73	5.64	7.04	59.32	99.70	(N/A)
Norway maple	46.51	5.39	12.62	14.71	113.88	193.10	(N/A)
Siberian elm	34.04	2.49	8.53	9.57	121.36	175.98	(N/A)
Red ash	21.14	1.10	5.01	4.91	62.02	94.18	(N/A)
Crimean Linden	49.80	2.46	11.50	13.38	36.41	113.55	(N/A)
Columnar Norway	21.66	1.48	5.04	4.15	41.95	74.29	(N/A)
Silver maple	79.82	5.85	22.31	35.39	71.68	215.05	(N/A)
Littleleaf linden	38.35	1.94	8.64	10.07	35.14	94.13	(N/A)
Austrian pine	27.01	1.43	3.41	10.52	29.60	71.99	(N/A)
Autumn Blaze	0.98	0.09	0.18	0.21	75.22	76.68	(N/A)
Amur maple	1.13	0.08	0.23	0.27	10.24	11.96	(N/A)
Black walnut	86.60	5.79	29.00	43.45	113.14	277.98	(N/A)
Japanese Yew	2.60	0.16	0.36	1.02	28.57	32.70	(N/A)
Scotch Elm	95.37	9.93	31.63	39.94	208.36	385.23	(N/A)
Alaska Cedar	15.87	0.94	1.61	6.17	39.37	63.95	(N/A)
Kentucky	2.56	0.12	0.52	0.37	12.55	16.12	(N/A)
Green Ash	29.27	1.52	6.96	6.85	66.91	111.52	(N/A)
Honeylocust	29.57	1.83	6.48	6.20	94.57	138.65	(N/A)
Northern red oak	7.36	0.44	1.32	1.75	48.25	59.13	(N/A)
Tree of heaven	63.24	4.15	20.13	28.46	133.53	249.51	(N/A)
Other street trees	43.31	3.43	11.69	15.97	92.25	166.65	(N/A)

Appendix C7 – Total Annual Benefits of Public Trees by Species ($)

Species	Energy	CO_2	Air Quality	Stormwater	Aesthetic/Other	Total ($)	Standard Error	% of Total $
Sugar maple	1,532	102	333	415	3,500	5,882	(±0)	14.0
Norway maple	1,907	221	517	603	4,669	7,917	(±0)	18.9
Siberian elm	783	57	196	220	2,791	4,048	(±0)	9.7
Red ash	359	19	85	83	1,054	1,601	(±0)	3.8
Crimean Linden	797	39	184	214	583	1,817	(±0)	4.3
Columnar Norway	325	22	76	62	629	1,114	(±0)	2.7
Silver maple	1,117	82	312	495	1,004	3,011	(±0)	7.2
Littleleaf linden	422	21	95	111	387	1,035	(±0)	2.5
Austrian pine	243	13	31	95	266	648	(±0)	1.5
Autumn Blaze Maple	8	1	1	2	602	613	(±0)	1.5
Amur maple	8	1	2	2	72	84	(±0)	0.2
Black walnut	520	35	174	261	679	1,668	(±0)	4.0
Japanese Yew	16	1	2	6	171	196	(±0)	0.5
Scotch Elm	572	60	190	240	1,250	2,311	(±0)	5.5
Alaska Cedar	79	5	8	31	197	320	(±0)	0.8
Kentucky	13	1	3	2	63	81	(±0)	0.2
Green Ash	146	8	35	34	335	558	(±0)	1.3
Honeylocust	148	9	32	31	473	693	(±0)	1.7
Northern red oak	37	2	7	9	241	296	(±0)	0.7
Tree of heaven	253	17	81	114	534	998	(±0)	2.4
Other street trees	1,819	144	491	671	3,875	6,999	(±0)	16.7
Citywide Total	11,104	858	2,854	3,701	23,373	41,890	(±0)	100.0