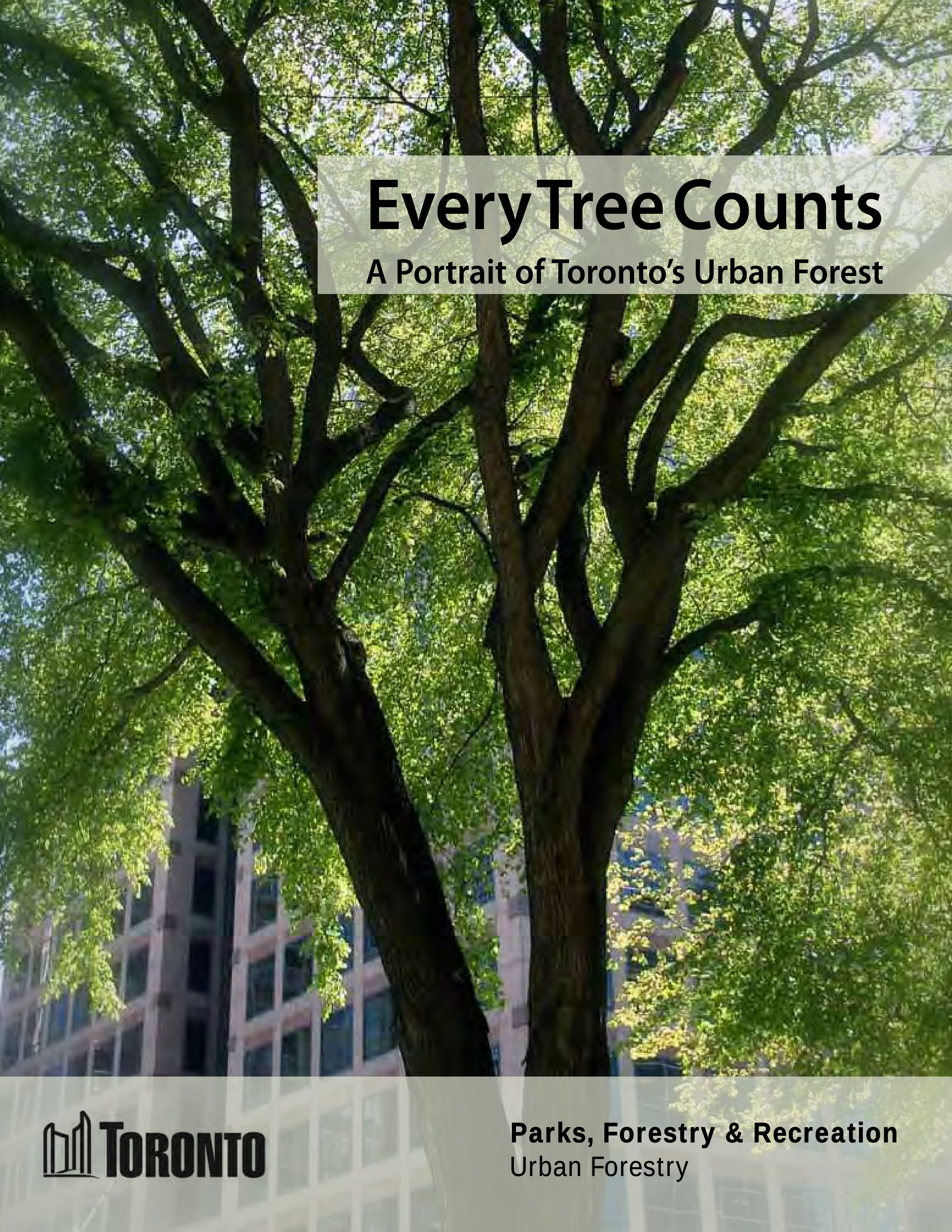
Every Tree Counts

A Portrait of Toronto's Urban Forest



TORONTO

Parks, Forestry & Recreation
Urban Forestry

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Foreword

For decades, people flying into Toronto have observed that it is a very green city. Indeed, the sight of Toronto's tree canopy from the air is impressive. More than 20 years ago, an urban forestry colleague noted that the trees in our parks should, and in many cases do, spill over into the streets like extensions of the City's parks. Across Toronto and the entire Greater Toronto Area, the urban forest plays a significant role in converting subdivisions into neighbourhoods.

Most people have an emotional connection to trees. In cities, they represent one of our remaining links to the natural world. Properly managed urban forests provide multiple services to city residents. Cleaner air and water, cooler temperatures, energy savings and higher property values are among the many benefits. With regular management, these benefits increase every year as trees continue to grow.

In 2007, Toronto City Council adopted a plan to significantly expand the City's forest cover to between 30-40%. Parks, Forestry and Recreation responded with a Forestry Service Plan aimed at managing our existing growing stock, protecting the forest and planting more trees.

Strategic management requires a detailed understanding of the state of the City's forest resource. The need for better information was a main reason to undertake this study and report on the state of Toronto's tree canopy. Emerging technologies like the i-Tree Eco model and remote sensing techniques used in this forestry study provide managers with new tools and better information to plan and execute the expansion, protection and maintenance of Toronto's urban forest.

The results of this study indicate that our forest management program is on the right track. However, we need to continue to work in coordination with other City Divisions (Toronto Water, Transportation, City Planning) to ensure that Toronto meets its forestry goals. The main challenge for planners and forest managers will be to work co-operatively to integrate the tree canopy into the changing urban landscape as the City continues to grow.

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Aerial view of increasing levels of tree canopy cover. (Credit: City of Toronto)

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View of Toronto's tree canopy (Credit: City of Toronto)

1 Executive Summary

1.1 Study Background

Toronto has approximately 20% forest cover representing 10.2 million trees.

In 2008, the USDA (United States Department of Agriculture) Forest Service Northern Research Station was contracted by Toronto Urban Forestry to help design and implement an urban forestry study for the City of Toronto. The study used the USDA Forest Service i-Tree Eco model (formerly known as Urban Forest Effects or UFORE)[1] in conjunction with aerial imagery, City datasets and City street tree data to achieve the primary study objectives. These objectives were to

1. describe the current composition, structure and distribution of Toronto's urban forest
2. quantify the ecological services and benefits provided by the urban forest
3. identify opportunities for increasing sustainable tree cover
4. define a baseline forest condition for monitoring progress toward forestry objectives.

Private property owners control a majority of the current and future tree canopy in the city.

The data resulting from this study will inform the development of strategies to expand Toronto's tree canopy and to support the health and sustainability of the urban forest.

1.2 Key Findings

For the first time, this forestry study quantifies the structure and value of Toronto's urban forest and provides baseline data to inform management decisions. The results are based on the analysis of field data collected from 407 plots in the City of Toronto as well as local weather, energy, land use and air pollution inputs. Land cover change assessment and tree canopy mapping are also important products of the study. Following are some of the key findings from the study that describe Toronto's urban forest.

1.2.1 Toronto's tree canopy

Toronto's urban forest provides the equivalent of $60 million in ecological services each year.

a. Toronto has approximately 20% forest cover representing 10.2 million trees.
b. The urban tree canopy is a vital city asset with an estimated structural value of $7 billion.
c. The 10 most common species account for 57.7% of the total trees in the population. Approximately 64% of the 116 tree species sampled are native to Ontario.
d. Of the total population, 0.6 million (6%) are City street trees, 3.5 million (34%) are trees

1 i-Tree Eco: http://www.itreetools.org

in City parks/natural areas and 6.1 million (60%) are growing on private property.

e. Private property owners in Toronto control a majority of the existing and possible tree canopy.

Urban trees contribute to cleaner air and water (Credit: City of Toronto)

1.2.2 Ecological services provided by the urban forest

a. Toronto's urban forest provides the equivalent of at least $60 million in ecological services each year. The benefits derived from the urban forest significantly exceed the annual cost of management.

b. Toronto's trees store 1.1 million metric tonnes of carbon annually or the equivalent of annual carbon emissions from 733,000 automobiles.

c. Gross carbon sequestration by trees in Toronto is estimated at 46,700 metric tons of carbon per year with an associated value of $1.3 million. Net carbon sequestration in the urban forest is 36,500 metric tons.

d. Trees affect energy consumption by shading buildings, providing evaporative cooling, and blocking winter winds. Toronto's urban forest is estimated to reduce energy use from heating and cooling of residential buildings by 41,200 MWH ($9.7 million/year).

e. Toronto's urban forest improves air quality, intercepting 1,430 metric tonnes of air pollutants annually (the equivalent value of $16.1 million/year).

f. Urban tree canopy helps to mitigate storm water runoff. Simulations that doubled the tree canopy in the Don watershed indicate a 2.5% decrease in overall flow. Simulating removal of impervious cover in the watershed reduces total flow by an average of 23.8%.

1.2.3 Land use, land cover and the changing urban forest

a. The distribution of forest cover across Toronto is uneven. Many of the City's trees are concentrated in Toronto's ravine system or valley lands.

b. Land use affects forest quantity and quality in Toronto.
   - Parks and natural areas have the highest average tree cover at 44.2%
   - Industrial areas have the lowest average forest cover at 4.1%
   - Unmanaged areas have the highest proportion of invasive species by leaf area (*Utilities & Transportation* and vacant lands with 55% and 50% compared to 2% in *Institutional* land use areas)

The distribution of forest cover across Toronto is uneven. Parks and natural areas have the highest average tree cover at 44.2%. Industrial areas have the lowest at 4.1%.

Toronto's urban forest improves air quality by intercepting 1,430 metric tonnes of air pollutants annually.

Land use affects tree cover (Credit: Bing maps)

- *Residential* and *Institutional* have larger trees on average than highly urbanized or unmanaged land use areas (*Industrial*, vacant lands).

c. Forest cover decreased slightly (-0.7%) between the years 1999-2005. Aerial photography will be used periodically to monitor changes in the tree canopy and establish long-term trends.

High Park climbing tree (Credit: City of Toronto);

1.2.4 Tree size effects

i. Urban forests have a structural value based on the tree itself and functional values based on services the tree provides. Large, healthy, long-lived trees provide the greatest structural and functional values.
ii. The average tree diameter in Toronto is 16.3cm. Only 14% of Toronto's trees are greater than 30.6cm in diameter.
iii. The most effective strategy for increasing average tree size and tree canopy is to preserve and manage existing trees in the City.
iv. The size of a tree and the amount of healthy leaf area equates directly to the benefits provided to the community.
v. A 75cm tree in Toronto intercepts ten times more air pollution, can store up to 90 times more carbon and contributes up to 100 times more leaf area to the City's tree canopy than a 15cm tree.

Forest cover decreased slightly at a rate of approximately 0.1% per year between 1999-2005. Aerial photography will be used to monitor changes in the tree canopy.

1.2.5 Forecasting future forest condition

i. Forest cover would start to decline if tree planting in Toronto stopped. Loss of tree canopy would range from 8% to16% over the next 100 years depending on tree mortality rates.
ii. Tree mortality rates have a significant impact on the amount of tree planting required to achieve the City's canopy goal. Increasing the average mortality rate from 2% to 3% would require a four-fold increase in planting effort (from 55,000 trees/year to 200,000 trees/year).
iii. From 2004-2009, an average of 84,000 trees/year were planted through City programs. Current rates of planting should be maintained to achieve a tree canopy goal of 35% in 50 years.

A 75cm tree in Toronto intercepts ten times more air pollution, can store up to 90 times more carbon and contributes up to 100 times more leaf area to the City's tree canopy than a 15cm tree.

1.2.6 Significant pest impacts

i. Emerald Ash Borer (an introduced insect pest) poses a significant threat to Toronto's tree canopy. The loss of all ash trees in Toronto would reduce overall forest cover in the city from 19.9% to about 18.3%.

Overall, the study findings support the current management direction in the Urban Forestry Service Plan which focuses on improved protection and maintenance of the existing tree canopy as well as continued tree planting. The study results will also be used to inform the development of detailed strategies to address emerging forest management issues in the context of a strategic forest management plan for the City of Toronto.

1.3 Next Steps

In recent years, there has been an increasing recognition of the value of Toronto's urban forest resource and its role in creating a sustainable, liveable City of Toronto. Funding for forest management and renewal has increased. Development policies are evolving and the green infrastructure represented by the urban forest is gradually being integrated into decision-making across all sectors of work.

Left Tree protection (Source: Urban Forestry); Right: Regular tree maintenance (Credit: Urban Forestry)

This study shows that Toronto currently supports a reasonably healthy, diverse forest despite the challenges inherent to growing trees in an urban environment. The forest provides multiple benefits to the residents of Toronto, including ecological services, recreational and health benefits as well as economic spin-offs in the real estate and commercial sectors. Active management and stewardship on public lands are improving the health and resiliency of natural areas in Toronto. Community participation in volunteer tree planting and stewardship events continues to grow.

Between 2004 and 2009 an average of 84,000 trees per year were planted through City programs.

On the other hand, a preliminary change analysis suggests that forest cover decreased slightly over the six year period between 1999-2005. There are imminent threats to the tree canopy from invasive forest insects, continuing challenges related to managing invasive plant species in the City's natural areas as well as uncertainty related to climate change effects. Urban growth objectives for the City will lead to increased pressure on green space and trees over the next several decades. All of these factors must be considered in the development of strategies to increase and maintain a sustainable urban forest.

Residential tree planting (Credit: Kanchan Maharaj for LEAF, 2009)

The study results led to the following six recommendations. Some of these will be addressed in the context of the City's urban forestry program while others will require ongoing co-operation with other City divisions and policy-makers.

1.3.1 Protecting and Maintaining the Existing Tree Canopy

1. Strengthen tree maintenance and protection programs as per Urban Forestry Service Plan, with a particular focus on maintaining and preserving large-stature trees.
2. Examine causes of tree mortality and develop strategies for minimizing loss of new and existing tree canopy.
3. Conduct regular aerial and ground monitoring to track tree canopy development and forest condition over time.

1.3.2 Opportunities for Growing Toronto's Urban Forest

4. Maintain current tree planting rates on public lands in order to achieve Toronto's 30-40% canopy objective within 50 years.
5. Use the results of the Urban Tree Canopy (UTC) assessment in conjunction with

new mapping tools to identify and prioritize locations for increasing Toronto's tree canopy.

1.3.3 Private Land Stewardship

6. Identify opportunities for increasing tree planting and stewardship on private property.

Examples of community engagement in tree planting (Credit: City of Toronto)

2 Introduction

2.1 Background

In cities, trees play a key role in creating healthy urban environments. Many citizens see trees as an important measure of the quality of their communities. In North America and internationally, there is a growing body of research that supports the importance of maintaining healthy, sustainable urban forests.

New technologies are allowing researchers to quantify the services provided by trees and confirm their value as vital green infrastructure. Unlike conventional or "grey" infrastructure, which begins to decay and depreciate the moment it is installed, the value of a properly maintained tree actually increases over its functional lifespan. By all measures of urban sustainability, trees are simply a good investment.

In 2005 the Parks, Forestry and Recreation Strategic Plan (Our Common Grounds) set an ambitious goal to increase Toronto's tree canopy from approximately 17-20% to between 30-40% over the next 50 years. The Plan also recommended a number of specific measures - including an increase in annual tree planting - to protect and enhance the urban forest.

At the time, the recommendations were made using best available information but also highlighted the need for a city-wide forest inventory to provide context for strategic management direction. Urban forests are complex, living resources that interact both positively and negatively with the surrounding environment. They produce multiple benefits and have associated management costs. In order to fully realize the benefits, community leaders, forest managers and residents of Toronto must have a sound understanding of the urban forest resource. This understanding starts at the most basic level with a forest inventory to provide baseline data for management decisions. In 2007, the General Manager of Parks, Forestry and Recreation subsequently recommended undertaking a city-wide tree canopy study, which was the main driver for this report.

2.2 Study Purpose

The main objectives of this study were to

1. describe the current composition, structure and distribution of Toronto's urban forest
2. quantify the ecological services and benefits provided by the urban forest
3. identify opportunities for increasing sustainable tree cover
4. define a baseline forest condition for monitoring progress toward forestry objectives.

For the first time, the study provides forest managers with detailed information about the City's forest resource across all land uses and ownerships. The data resulting from this study will inform the development of strategies to grow Toronto's tree canopy and ensure the health and sustainability of the urban forest.

Community benefits from the urban forest

- Energy savings through warming/cooling effects of trees
- Storm water attenuation
- Local climate modification
- Provision of wildlife habitat
- Air quality improvements
- Noise reductions
- Increased property values in treed commercial and residential areas
- Psychological and health benefits for Toronto residents

3 Forest Management Context

3.1 Toronto's Official Plan

The Greater Toronto Area is expected to grow by 2.7 million residents by 2031. Toronto is expected to absorb 20% of this increase.

Toronto's 2007 Official Plan sets the context for how the City will evolve over the next several decades. Growth is a key theme throughout the Plan, which speaks to expansion in all areas including economy, jobs, infrastructure and social development. The Greater Toronto Area (GTA) is conservatively projected to grow by 2.7 million residents by the year 2031 and Toronto is expected to absorb 20% of this expected increase[2].

The practice of urban forestry takes place in this context of high demand for limited space in an urbanizing environment. Like people, trees are living organisms that have specific environmental requirements in order to achieve optimal growth and maximum life spans. Trees can be very large. The root system of a mature tree can occupy well over 500m^2 of area and requires healthy soil to support growth. While trees often make do with less, urban forest management strives to create conditions that maximize the return on investments in trees and allows them to produce maximum benefits.

The key challenge for decision-makers and planners will be finding ways to enhance protection of the existing forest canopy and integrate new trees into the changing fabric of the city as Toronto continues to grow.

Downtown Toronto streetscape (Credit: City of Toronto)

3.2 Why Have Tree Canopy Targets?

Many North American municipalities are setting tree cover goals, recognizing the multiple social, ecological and economic benefits of urban forests and obvious links to other policy initiatives including climate change, air quality, and public health (Figure 1). It is also increasingly recognized that formal adoption of tree canopy goals - including institutionalizing these in tree by-laws, regulations and comprehensive planning efforts - is critical to realizing urban forestry objectives[3].

2 City of Toronto Official Plan. Chapter 2. http://www.toronto.ca

3 Forests for Watersheds. Url: http://www.forestsforwatersheds.org/urban-tree-canopy/

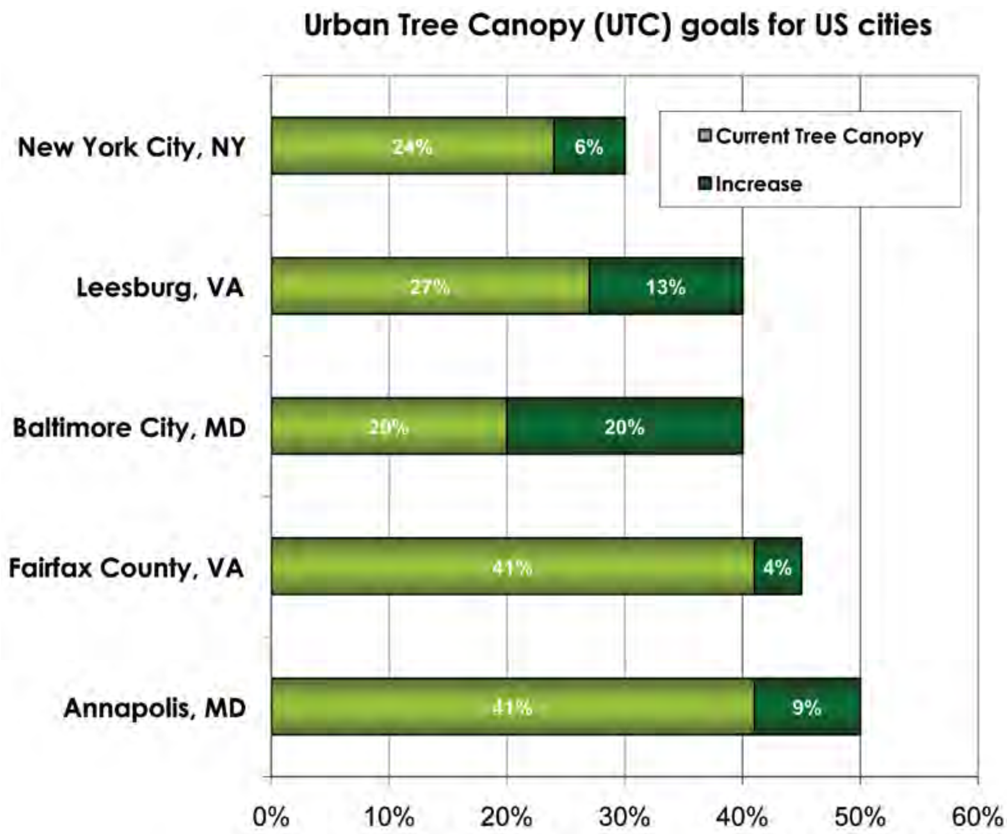


Figure 1. Urban tree canopy goals for selected North American cities. (Source: www.forestwatersheds.org)

The extent of community tree canopy cover is one of many possible indicators of urban forest sustainability[4]. Toronto's tree cover target is in part based on American Forests[5] recommendations of an average 40% canopy cover or the equivalent of approximately 50 trees per hectare. It is thought that this level of tree cover will ensure the sustainability of the urban forest and maximize the ecological, social and economic benefits derived from urban trees.

US research suggests that 40% tree cover in cities will ensure the sustainability of the urban forest and maximize community benefits from trees.

The 40% figure is based on analyses of forest condition in urban areas in different regions of the United States to determine what average cities could support. Figure 2 provides an example of what it would look like to increase tree canopy from about 20% to 40% in a residential area of Toronto.

Figure 2. Representation of 20% versus 40% tree canopy cover (Source: Bing maps).

4 Clark, J.R., N.P. Matheny, G. Cross and V. Wake. 1997. A model of urban forest sustainability. J. Arboric. 23(1):17–30.
5 http://www.americanforests.org

3.3 Managing Forests in Urban Environments: Emerging Issues

Compared to forest conditions in natural landscapes, urban trees inherently face additional stressors in their growing environment. They include environmental and physical stresses such as limited soil volumes, water shortages, salt and chemical exposure from roads and surface run-off, physical damage from lawnmowers, construction and other human activities.

The urban forest also faces emerging threats from the impacts of globalized trade, climate change, increased intensity of urban development and high intensity use of the City's green spaces. These present new challenges that will require adaptive management approaches in the coming decades. The following sections introduce some of the issues that will be explored in more detail in the context of a strategic forest management plan for the City.

3.4 Climate Change

Research by Natural Resources Canada has produced simulations of some of the expected impacts of climate change on Canada's forests[6]. While it is difficult to predict exactly what climate change will mean for urban forests, some of the trends that have been identified include:

- Warmer winter temperatures and longer growing seasons;
- Changes in the seasonality of precipitation and extreme events like droughts and heavy rainfalls;
- Expanded ranges of insects and increased over-winter survival rates;
- Increased frequency and severity of storm events.


Flooding from major storm event (Credit: City of Toronto)

Predicted effects of climate change on the urban forest

- Warmer winters and longer growing seasons
- Changes in the seasonality of precipitation and extreme weather events like drought and heavy rain
- Expanded ranges of insects and increased over-winter survival rates
- Increased frequency and severity of storm events

The level of uncertainty regarding specific climate change impacts makes planning more challenging. Forest-specific strategies for climate change adaptation have been outlined in a report entitled *Climate Change Adaptation Options for Toronto's Urban Forest*[7] that will inform Toronto's forestry climate change plan.

3.5 Introduced Insect Pests

Toronto's urban forest faces threats from multiple insect pests. Some of these have been introduced into Canada through global trade, including wood packaging from other countries[8]. Forest managers have battled and so far successfully controlled the Asian Long-Horned Beetle (ALHB) through a co-ordinated, intensive forest health care program that involved multiple agencies such as Toronto and Region Conservation Authority, Ontario Ministry of Natural Resources and Natural Resources Canada.

The City undertakes ongoing efforts to control widespread defoliation by gypsy moth through targeted aerial and ground level management interventions. Currently, the Emerald Ash Borer (EAB) poses a significant threat to the city's tree canopy and is being

6 Climate Change Impacts and Adaptations: A Canadian Perspective. Natural Resources Canada. http://adaptation.rncan.gc.ca
7 http://www.cleanairpartnership.org
8 Alien invaders: Non-indigenous Species in Urban Forests. NRCan, Canadian Forest Service. http://www.treecanada.ca

monitored closely as part of a program to control and slow widespread damage by this invasive insect pest.

The potential implications of this for the urban forest cannot be understated. With approximately 8% of Toronto's leaf area composed of ash species, the control of EAB and other invasive insect pests and disease becomes a determining factor in achieving the City's long-term tree canopy objectives. Magnifying this problem is the potential role that climate change plays in increasing the severity of pest and disease outbreaks.

Emerald Ash Borer (Credit: Canadian Food Inspection Agency)

3.6 Forest Size Class Distribution in Toronto Neighbourhoods

Street trees in any given area of a city are often even-aged for 20 to 60 years after planting, since most areas tend to be planted at the same time. Canopy cover gradually increases to a maximum just before age-related mortality begins to reduce total cover[9].

This is the prevailing situation in many older Toronto neighbourhoods, where trees planted in the early 1900s are reaching the end of their lifespan and are now starting to decline. In many cases, this is occurring without younger trees on site to compensate for the loss of mature canopy (Figure 3). Current policy now requires that every street tree removed is replaced with a new one but this was not always the case.

Trees are reaching the end of their lifespans in many of Toronto's older neighbourhoods. Timely replacement is critical to maintaining forest cover in these areas.

Figure 3. Evolution of Palmerston Boulevard tree plantings from 1908 to 2002 (Credit: City of Toronto).

Complicating the situation in many downtown neighbourhoods is an increase in the built 'footprint' of the city over time. This has reduced the number of potential planting sites that could support the type of mature, large-stature trees that are, in a sense, an artifact of a younger city.

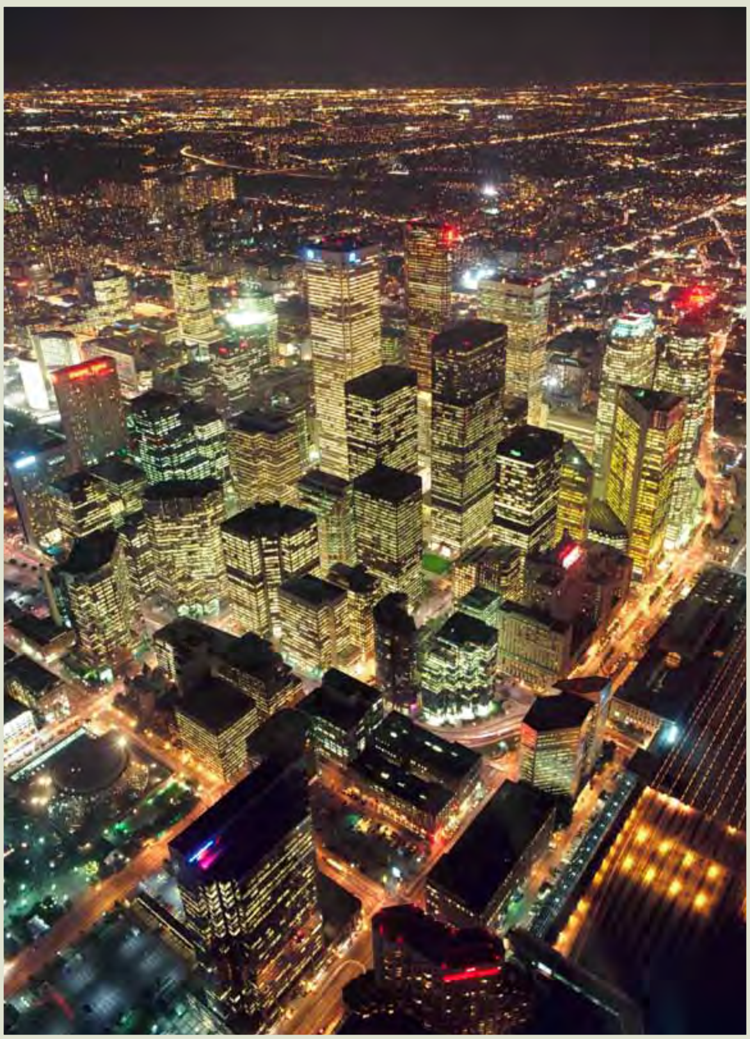
9 Maco, S.E. and E.G. McPherson. 2002. Assessing Canopy Cover Over Streets and Sidewalks in Street Tree Populations. Journal of Arboriculture 28(6): 270-276.

Understanding how land cover is changing can help decision-makers manage the dynamics between tree cover and urbanization in the city.

If trees are selectively removed and replaced over many years with similar species, canopy cover can be maintained at a sustainable level. According to a US study, the amount of canopy cover in a neighbourhood achieved by first generation street trees is in fact likely to be greater than it would be after the population has achieved a more diverse and stable age structure[10].

Managing the age class structure of the urban forest is key to maintaining a sustainable and equitable distribution of forest cover across the City. In Toronto, private land owners will have a role to play in this effort.

Residential tree removal in mature neighbourhood (Credit: R. Burkhardt)



Birdseye view of downtown Toronto (Credit: City of Toronto)

3.7 Urbanization

Most North American cities have seen a trend toward loss of natural areas and forest cover over the last several decades. During the period 1982-1997, US research shows that the amount of land devoted to urban and built-up uses grew by more than 34%[11]. This increase in developed land has come predominantly from the conversion of agricultural and forest lands. It is well documented that forests, in particular, have been the largest source of land converted to developed uses in recent decades, with resulting impacts on overall forest cover and other ecological attributes[12].

Toronto's forests have not been exempt from the impacts of urbanization. A 2008 land cover change analysis[13] of the City using LANDSAT imagery suggests that contiguous treed areas accounted for 5.8% of Toronto's total land cover in 2005, down from 6.8% in 1985.

Given the objective of doubling the City's tree canopy, this type of research can help decision-makers identify any tensions between urbanization and forest cover and develop strategies to manage them accordingly. In the context of a supportive regulatory and policy environment, sound urban forest management can help the City achieve multiple planning goals related to creating a green, liveable city.

10 ibid.
11 USDA Natural Resources Conservation Service, 2001
12 R.J. Alig et al. Landscape und Urban Planning 69 (2004) 219-234. Url: http://www.fs.fed.us/pnw/pubs/journals/pnw_2004_alig005.pdf
13 Morrison, H. 2008. Land Cover Distribution and change in Toronto, Ontario, Canada from 1985-2005. Ryerson University. http://www.ryerson.ca/graduate/programs/spatial/abstracts/morrison.html

4 Project Methodology

4.1 Overview

The i-Tree Eco model (formerly known as the Urban Forest Effects or UFORE model) developed by the USDA Forest Service was a key component of this study. To complement the information derived through i-Tree Eco, the study used spatial analysis tools combined with City mapping data as well as City street tree data to develop a detailed description of urban forest composition, structure, function and distribution. The project consisted of five main components as follows

1. study design phase and field data collection
2. data analysis using the i-Tree Eco model, including Hydro modeling
3. integration of existing City street tree data
4. manual assessment of land and forest cover change from 1999-2005
5. automated land cover mapping and Urban Tree Canopy (UTC) assessment.

Forest inventories should be updated periodically to help direct and adapt management strategies.

More information about the i-Tree Eco model and methodologies can be found at www.itreetools.org. The USDA Forest Service Northern Research Station in Syracuse, New York was the principal consultant on the study, which was completed in collaboration with City of Toronto Urban Forestry branch under the oversight of a project steering committee. The University of Vermont Spatial Analysis Laboratory completed the land cover mapping and used the resulting data to conduct a Urban Tree Canopy (UTC) assessment for the City of Toronto.

It is important to note that forests are living entities – the study data and land cover mapping represent a snapshot in time. Inventories should be updated regularly in order to help direct management activity. Scheduled updates serve two important purposes: 1) they provide trend information; and, 2) they allow managers to monitor change and adapt strategies accordingly.

4.2 Regional Collaboration: i-Tree Eco (UFORE) in the Greater Toronto Area

Toronto is part of a larger biophysical region that is bordered to the north by the Oak Ridges Moraine, on the west by the Niagara Escarpment and to the south by Lake Ontario[14]. The major watersheds found within this region connect Toronto ecologically to adjacent communities, many of which fall under the jurisdiction of the Toronto and Region Conservation Authority (TRCA).

Figure 4. Regional UFORE collaboration area (Credit: Toronto and Region Conservation Authority).

A collaboration took shape in early 2008 as a result of decisions by the cities of Mississauga, Brampton, Ajax, Pickering, Markham, Vaughan and parts of Caledon to undertake concurrent studies (Figure 4). With the TRCA in a co-ordinating role, project managers and foresters from Toronto and the participating municipalities met at a workshop to discuss opportunities for harmonizing study methodologies. A follow-up meeting was held in 2009 to compare and discuss the preliminary results.

In recognition of the diversity in governance across GTA municipalities, the collaboration represents a forum for sharing ideas, methodologies and strategies rather than a

14 Toronto Official Plan, Section 2.1 – Building a More Liveable Urban Region.

specific framework for planning and implementation. The intent was to create an opportunity for aggregating the regional data to provide information about the collective value of urban forests across the GTA.

4.3 Study Design

The first step was to identify the study area, defined as the municipal boundaries of the City of Toronto. A minimum of 200 field plots are generally recommended as input to i-Tree Eco to achieve statistically reliable results. Increasing the number of plots helps to decrease variability within the sample. In Toronto, a total of 407 plots were assigned and measured. Each plot had a radius of 11.28m and represented 400m^2 (0.04 ha). These 407 plots represent permanent sample plots that should be revisited periodically to assess change and improve understanding of forest dynamics in the City.

407 permanent sample plots will help forest managers track how Toronto's urban forest is changing over time.

The 407 plots measured in this study represent a sample of the City's tree population. As with any sample, the results provide a description of the population of interest with an associated degree of statistical error.

A second aspect of study design was to determine how to "stratify" or divide the sample plots to look at any potential effects of land use on the urban forest. A customized land use map was developed for Urban Forestry by City Planning[15]. It described a total of nine land uses and an additional category called "No Data", which captured any gaps in the data set (see Appendices 1 and 2).

The 407 plots were assigned a land use ("post-stratified") by overlaying the generalized land use map. Table 1 shows the number of plots sampled within each of the nine land uses and the total land area represented by each category. Some land uses have a higher associated sampling error because of the lower number of plots. In particular this applies to the *Utilities and Transportation* and *Open Space 2* land uses in which less than 20 plots were sampled. 20 plots represent the minimum recommended by USDA Forest Service to produce statistically robust results.

Table 1. Number of i-Tree Eco sample plots by land use.

Land Use	Total Land Area (ha)[16]	% of City's Land Area	# of Plots
Open Space 1 (Parks/TRCA lands)	6,976	10.5%	37
Open Space 2 (Commercial/Recreation/ Agriculture)	3,920	5.9%	19
Residential Singles	26,902	40.7%	181
Residential Multifamily	3,942	5.9%	23
Commercial	4,358	6.6%	30
Industrial	7,172	10.8%	44
Institutional	4,523	6.8%	25
Utilities and Transportation	2,525	3.8%	14
Other (mainly vacant land and marinas)	4,892	7.4%	31
No data	930	1.4%	3
Total	**66,140**	**100%**	**407**

15The customized land use map was developed for Urban Forestry by assigning Municipal Property Assessment Corporation (MPAC) property codes to one of the nine land use categories. The map is similar to the generalized land use maps used by City Planning, with some variations.

16As calculated by Land Information Toronto from the study's generalized land use map.

4.4 Field Data Collection and Analysis

Within each plot, data collected included

- land use
- ground and tree cover
- shrub characteristics
- individual tree attributes of species, stem diameter at breast height (d.b.h. measured at 1.37m), tree height, height to base of live crown, crown width, percentage crown canopy missing and dieback, and distance and direction to space-conditioned buildings[17].

The largest tree sampled had a diameter of 126 cm. (Credit: City of Toronto)

Figure 5 shows an example of the plot maps used by the field crews to locate the permanent sample plot centres

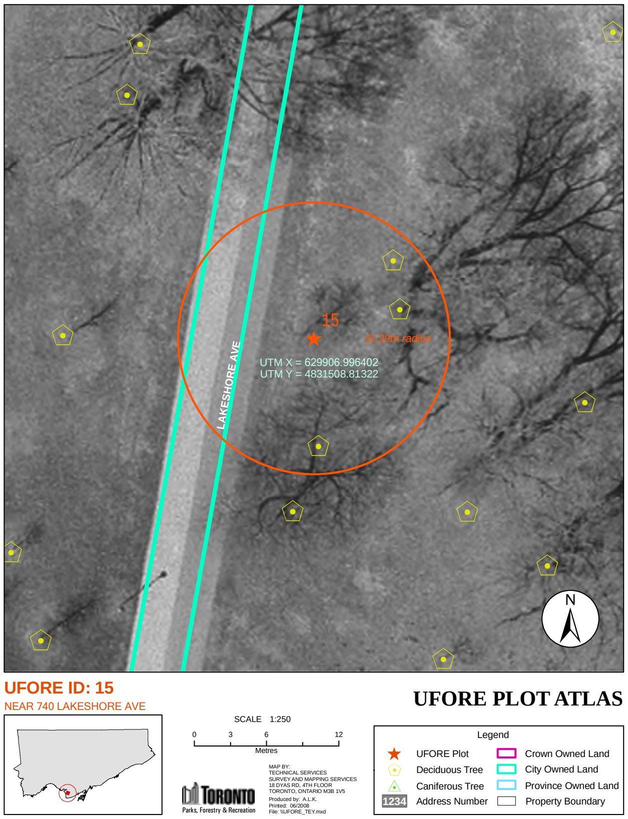


Figure 5. Sample plot map used by field crews (Credit: City of Toronto Technical Services).

Tree attributes measured in the field plots included:

- species
- diameter
- height
- crown width
- crown dieback
- percent crown missing
- distance and direction to buildings

The data was then sent to the USDA Forest Service in Syracuse, NY. Additional inputs to the model included

- hourly weather data (provided by USDA Forest Service)
- air pollution data (2007 data for Toronto Downtown and Toronto West from Ontario Ministry of Environment, PM10 data supplied by Environment Canada).

17 Detailed information on UFORE data collection protocols can be found at http://www.ufore.org/UFORE_manual.doc.

4.5 Assessment of Forest and Land Cover Change from 1999-2005

The term 'land cover' describes the physical surface of the earth.

In order to assess the effect of forest management programs on the city's tree canopy, managers need a way to track change in forest cover over time. The term "land cover" describes the physical surface of the earth. In urban areas, land cover consists mainly of a combination of vegetation types, soils, pavement, buildings, rocks/gravel and water bodies. Because forest growth is influenced by changes in the surrounding environment, monitoring land cover change provides relevant information for resource planning and management decisions. Figure 6 below shows an example of land cover change from pervious (soil and vegetation) to hard surface (building) in the High Park area.

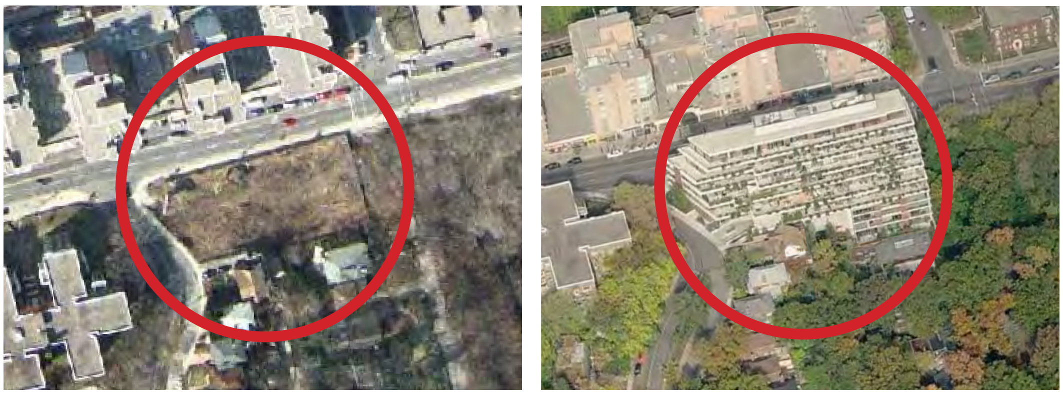


Figure 6. Example of land cover change in High Park area. Credit: 2002 (City of Toronto), 2009 (Bing maps).

The USDA Forest Service used available City of Toronto digital aerial orthophotos from 1999[18] and 2005[19] to manually estimate forest and land cover. Aerial estimates of "tree canopy" necessarily include shrub cover since most imagery does not permit accurate differentiation between trees and shrubs. Trees and shrubs together make up Toronto's urban forest resource and as such, the terms forest cover, tree cover and tree canopy are used interchangeably in this report.

Measuring land cover change provides key information to help decision-makers assess whether or not the City is meeting its planning goals.

A total of 9,998 georeferenced points were sampled on each set of aerial photographs. Because the same point on the ground was measured in 1999 and 2005, the assessment captured actual change in seven land cover categories including

1. Tree/shrub cover
2. Grass
3. Soil
4. Water
5. Building
6. Roads
7. Impervious – other

The results were then stratified or categorized by land use. The estimates produced through this sampling method have a known statistical accuracy and are a cost-effective way to use available resources to monitor tree canopy. However, they provide limited spatial information about the distribution of tree canopy in the City. This was addressed separately through the development of a land and forest cover map as described in the following section.

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18 Leaf-off black and white orthophotos provided by (former) Mapping Services, City of Toronto

19 Leaf-off colour orthophotos provided by (former) Land Information Toronto.

4.6 Land Cover Mapping and Urban Tree Canopy (UTC) Assessment

4.6.1 Land Cover Mapping

The availability of spatial data to describe grey infrastructure in cities (e.g. maps of water lines, sewers, hydro corridors) is taken for granted as a standard business practice. Adding a digital tree canopy layer as part of the base geospatial data in Toronto makes good sense since it can assist city divisions to incorporate the tree canopy in the early stages of planning.

Urban Tree Canopy (UTC) Assessment uses land cover data in conjunction with other City data sets to develop estimates of existing and possible tree cover in the City.

One of the key deliverables for the study was to develop a digital map layer of tree canopy for the entire City of Toronto. Detailed land cover for the entire City was derived from high-resolution (0.6m) QuickBird[20] satellite imagery acquired in 2007. Additional planimetric data provided by Toronto's Technical Services branch included property (parcel), road corridor and building footprint data. This planimetric data and the satellite imagery were used in combination with advanced automated processing techniques, producing land cover that was mapped with such detail that single trees were detected. The classification resulted in a map showing eight categories of land cover in the city including

1. Tree canopy
2. Water
3. Bare earth
4. Buildings
5. Pavement
6. Transportation
7. Grass/shrub
8. Agriculture.

Figure 7 shows an example of the resulting land cover map. For the first time, this map provides accurate spatial information about the distribution of tree canopy for the entire city of Toronto. This data can be used to map land and forest cover for any geographic area of interest in Toronto, such as wards, neighbourhoods and watersheds with resolution to the property level.

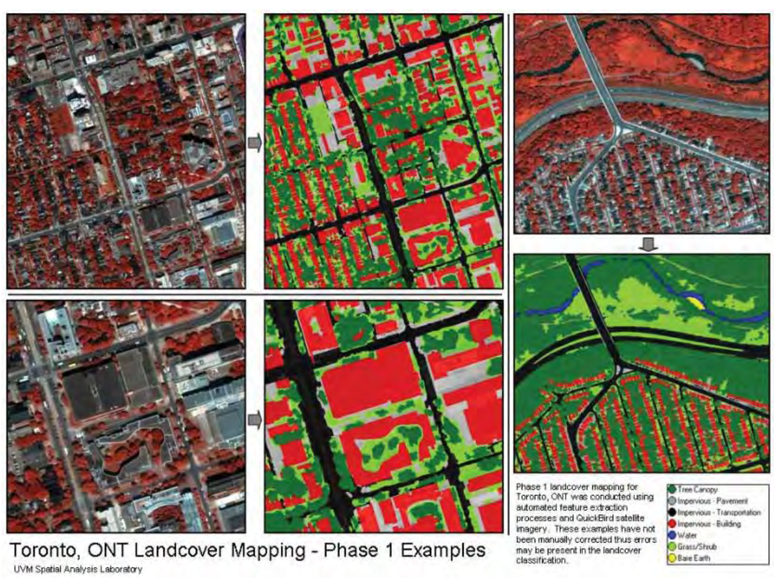


Figure 7. Classification of satellite imagery to produce a digital land cover map (Credit: University of Vermont Spatial Analysis Laboratory).

20 DigitalGlobe

4.6.2 Urban Tree Canopy (UTC) Assessment

The land cover map was used in conjunction with other city data sets to conduct what is called an Urban Tree Canopy (UTC) assessment. A UTC assessment provides information describing the amount of tree canopy currently present (Existing UTC) along with the amount of tree canopy that could be established (Possible UTC). This information can be used to estimate tree loss in a planned development or to set UTC goals at different scales.

Following the computation of the Existing and Possible UTC, the UTC metrics were summarized for each property in the city's parcel database (Figure 8). For each parcel the absolute area of Existing and Possible UTC was computed along with the percent of Existing UTC and Possible UTC (UTC area/area of the parcel).

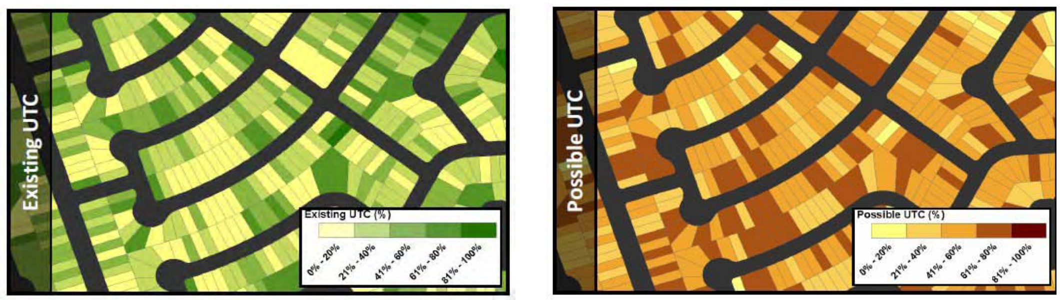


Figure 8. Parcel-based UTC metrics (Credit: Spatial Analysis Laboratory, University of Vermont).

The generalized land use map was then used to summarize UTC by land use category. For each land use category UTC metrics were computed as a percentage of all land in the city (% Land), as a percent of land area by zoning land use category (% Category) and as a percent of the area for the UTC type (% UTC Type). The full UTC report and methodology are found in Appendix 3.

A Note on Tree Canopy Assessment Methodologies

There are many different ways to assess tree canopy cover. Each approach may produce a somewhat different result depending on the source data and method used. Two different methods were used to derive tree canopy estimates for Toronto. The first approach was non-spatial, sample-based and used manual interpretation of available City leaf-off aerial photography with branching structure defining the extent of a tree's crown. The second was a spatial approach (Automated Land Cover Mapping) that used leaf-on satellite imagery and an automated (computer) classification technique to develop a digital land cover map for the City of Toronto. This map was then used to produce an estimate of tree canopy as part of the Urban Tree Canopy (UTC) assessment.

In part because it uses leaf-on source imagery, the digital map reports a higher level of tree canopy compared to the manual sampling using leaf-off photos. For reasons of cost, availability and methodology, the City's leaf-off aerial imagery was used to benchmark forest cover and will be used in future to monitor canopy development over time.

For more discussion on tree canopy assessment methodologies, see Appendix 4.

Commercial street tree in container (Credit: City of Toronto)

4.7 Toronto Street Tree Data

Street trees represent a unique population of trees within the city. Generally speaking, they grow under some of the most challenging conditions in the urban environment because they are subject to many stressors including poor soil conditions, extreme heat and water stress, pollution, road salt and mechanical damage, among others.

The Toronto Maintenance and Management System (TMMS) is a work management system used by Urban Forestry to track all management activities related to trees in City road allowances. The system permits users to develop summaries of management activities such as planting, pruning, removals and other work performed sorted by defined parameters eg. per year, by Forestry district or tree size class.

TMMS data was used in the context of this study to describe street tree species composition, size class distribution, tree conditions as well as trends in the rate of planting and tree removals over time. The intent was to use available street tree data in conjunction with the i-Tree city-wide data to enhance understanding of the variation within the urban tree population and highlight some of the recent management trends with respect to city trees.

4.8 i-Tree Hydro Application

i-Tree Hydro[21] is a stand alone application designed to simulate the effects of changes in tree and impervious cover characteristics within a watershed on stream flow and water quality. In this case, the highly urbanized Don Valley watershed in Toronto was used for the simulation. Hydro required the following inputs

- Don watershed boundaries (Toronto and Region Conservation Authority)
- land cover estimates for the Don watershed (derived through a sampling method using Google Earth 2005 aerial imagery)
- hourly precipitation data (Ontario Climate Centre – Toronto City station, climate ID: 6158355; WMO ID: 71508)
- DEM or digital elevation data (Toronto and Region Conservation Authority)
- stream flow data (Environment Canada gauge at Don River at Todmorden (02HC024) from April 1st 2007 to October 31st 2007).

The model was calibrated and run a number of times under various conditions to see how the stream flow would respond given varying tree and impervious cover in the watershed. The results were reviewed with TRCA hydrologists and Toronto Water to ensure that the findings were consistent with other hydrological studies for the City. The complete Hydro report is attached as Appendix 5.

21 Wang, Jun, Theodore A. Endreny, and David J. Nowak, 2008. Mechanistic Simulation of Tree Effects in an Urban Water Balance Model. Journal of the American Water Resources Association (JAWRA) 44(1):75-85.
DOI: 10.1111/j.1752-1688.2007.00139.x
Url: http://itreetools.org/resource_learning_center/elements/Hydro_Model_Methodology.pdf

5 Results and Discussion

5.1 The Structural and Functional Value of Toronto's Urban Forest

Urban forests have a structural value based on the tree itself, which represents the cost of having to replace an existing tree with a similar one. Urban forests also have functional values (either positive or negative) based on the functions the tree performs. Annual functional values also tend to increase with increased number and size of healthy trees.

Through proper management, urban forest values can be increased. However, the values and benefits can also decrease as the amount of healthy tree cover declines. Based on actual forestry data collected for Toronto, the i-Tree model estimates the structural and functional value of Toronto's urban forest as follows:

Toronto's urban forest is a vital city asset with an estimated replacement value of $7 billion.

Total structural values of Toronto's urban forest (CND):
Structural (replacement) value: $7 billion
Carbon storage: $31.6 million

Annual functional values of Toronto's urban forest (CND):
Carbon sequestration: $1.3 million
Pollution removal: $16.1 million
Lower energy costs and avoided carbon emissions: $10.2 million

The study shows that healthy, large trees make the most significant contribution to the sum total of benefits derived from the urban forest. This is related to their extensive crown leaf area, which expands steadily as the tree increases in size (Figure 9). Increased leaf area maximizes the services provided by trees including shading/cooling, carbon storage, energy effects, air quality improvement, mitigation of storm water runoff, noise attenuation, aesthetic benefits and habitat values.

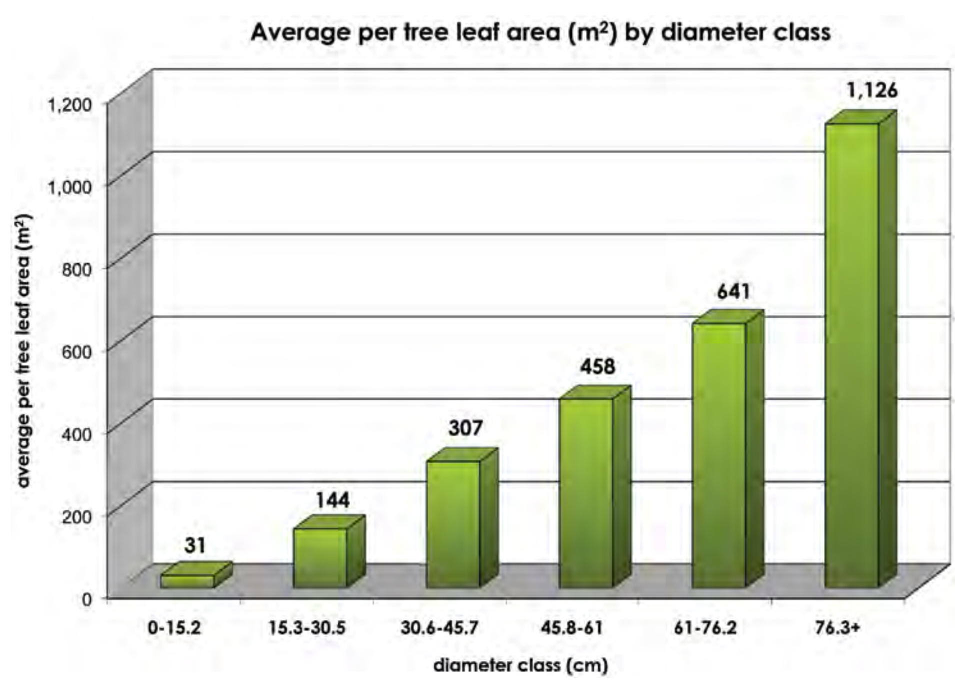


Figure 9. Average per tree leaf area (m^2) by diameter class in Toronto.

5.2 Forest and Land Cover in Toronto

An assessment of aerial imagery for the entire City of Toronto shows that forest cover represents 19.9% of the City's total land area. Beyond the tree canopy, 30.6% of Toronto's land area consists of pervious cover (grass and soil), 1.7% is water and the remaining 47.7% is comprised of impervious cover including buildings, roads and other hard surfaces (Figure 10).

At approximately 20% forest cover, Toronto is average compared to cities of similar size.

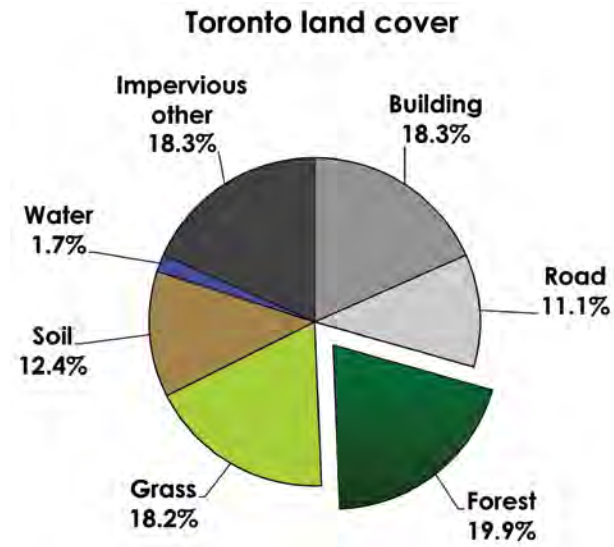


Figure 10. Forest and land cover in the City of Toronto.

5.2.1 Forest Cover Distribution

A map of the City's tree canopy shows the location and distribution of forest cover across Toronto (Figure 11). Areas of concentrated forest in ravines and river valleys are most visible at this scale of mapping. Consistent with the 2001 City of Toronto Natural Heritage Study, the map confirms that there is an uneven distribution of natural cover across the City, including contiguous forest cover.

Forest cover is concentrated in the Don, Highland Creek and Rouge River watersheds, suggesting a poor representation of tableland habitats. This reflects the historic pattern of urban growth in the City that essentially spared the ravines from extensive development. If it were not for the forest cover in these watersheds, in particular Rouge Park, average forest cover in Toronto's urban areas would be much lower[22].

Aerial view of a Toronto ravine (Credit: City of Toronto)

The issue of forest cover distribution is important for several reasons:

- It is linked to habitat availability, quality and landscape connectivity for native plant and animal species;
- It is relevant to the health and sustainability of watersheds; and
- It affects the distribution of benefits provided by the urban forest in different areas of the City.

22 City of Toronto Natural Heritage Study. 2001. Final Report. City of Toronto.

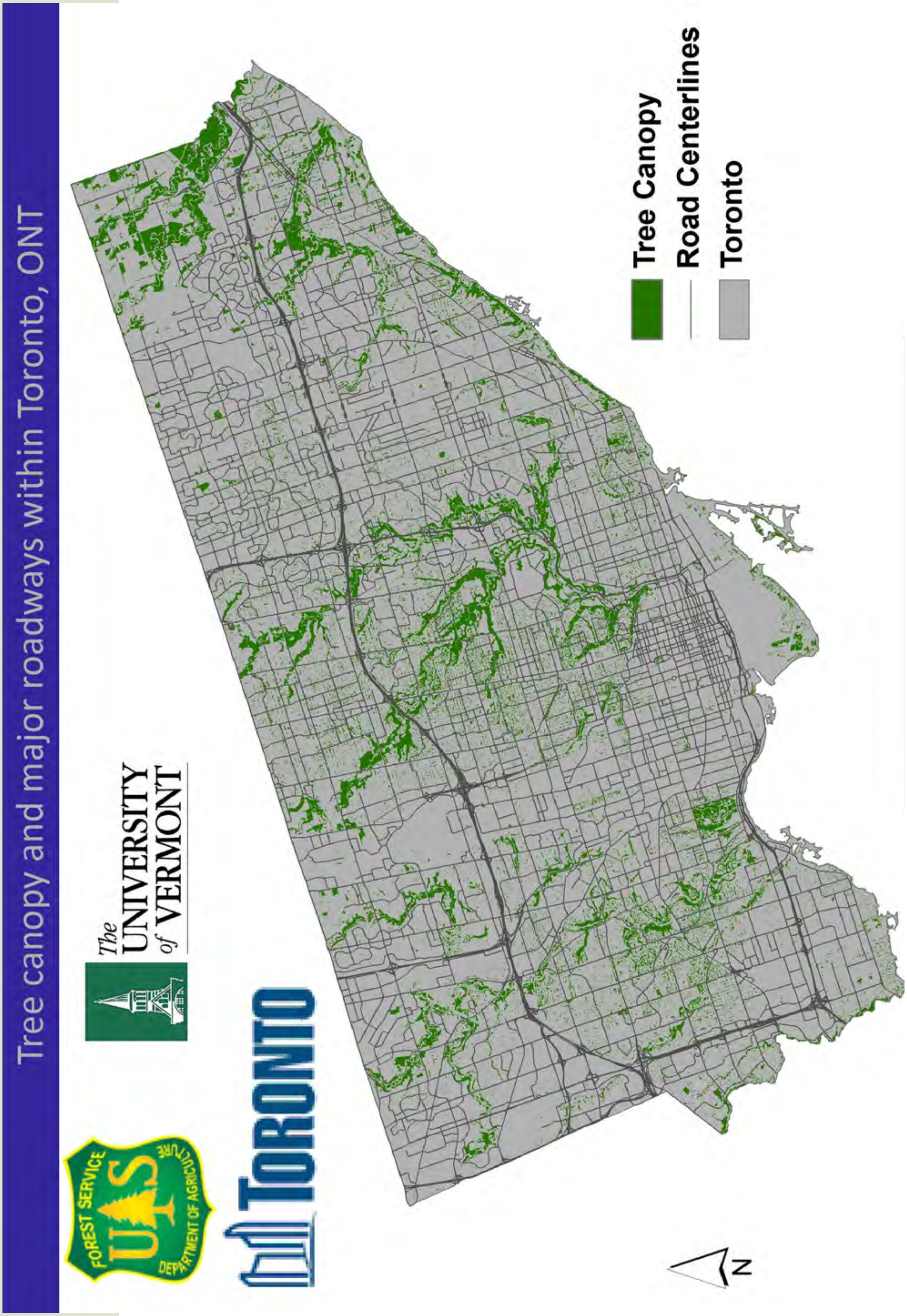


Figure 11. Map of Toronto's tree canopy (Spatial Analysis Laboratory, University of Vermont and USDA Forest Service)

5.2.2 Forest Cover in Toronto Neighbourhoods

Figure 12 shows a map of average urban tree canopy by Toronto neighbourhood (see Appendix 6 for map of Toronto neighbourhoods). The map reflects the pattern of development in the City, with areas around the main river valleys (Humber, Don and Rouge) and older sections in the downtown core having highest average tree cover. Conversely, areas in the northwest and northeast of the City representing industrial areas and newer housing developments have less tree cover on average.

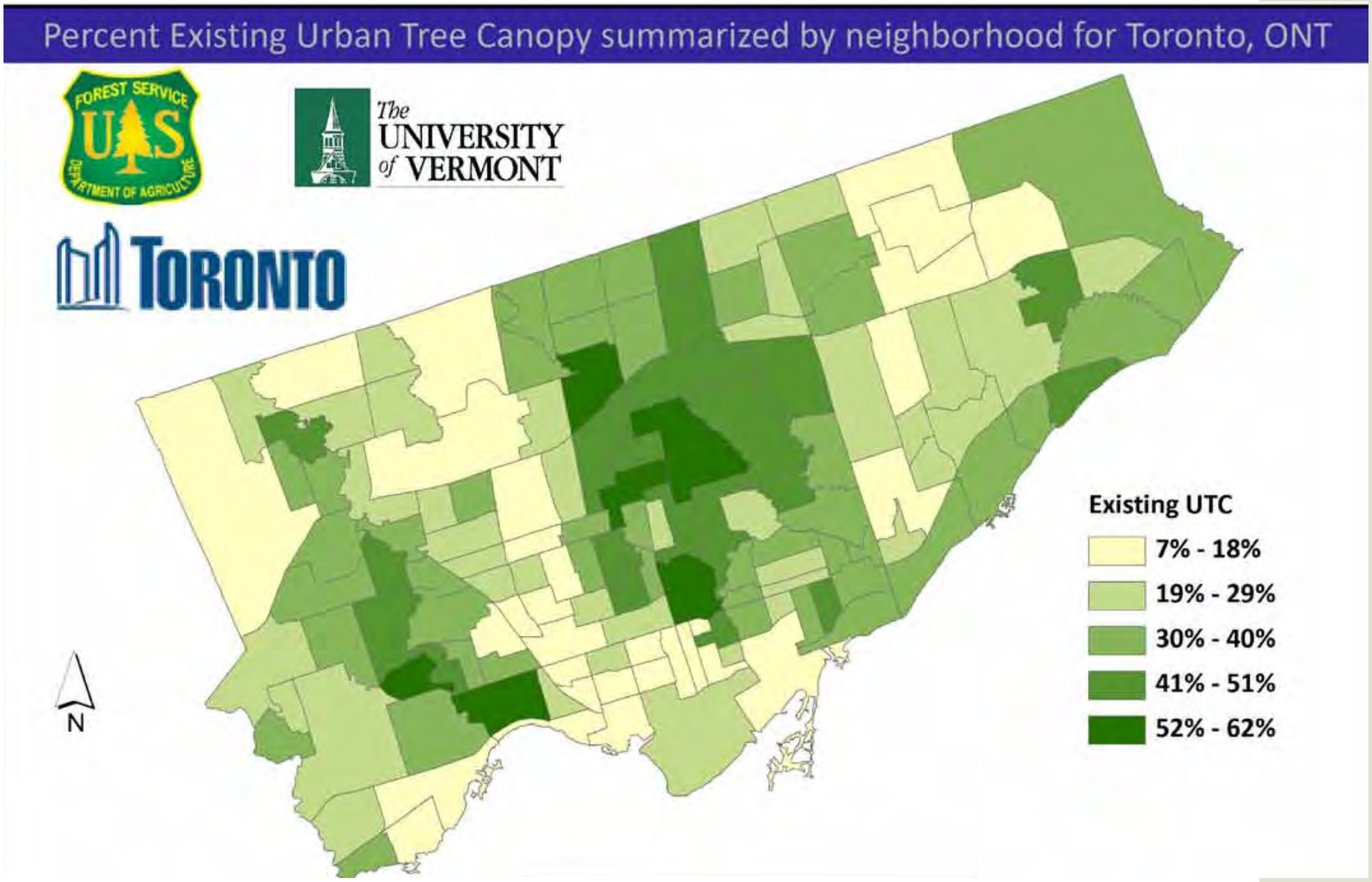


Figure 12. Average tree cover by Toronto neighbourhood (Credit: Spatial Analysis Laboratory, University of Vermont and USDA Forest Service).

Table 2 provides results of the forest cover analysis by neighbourhood for the five most and least treed neighbourhoods in the city. A complete list for all Toronto neighbourhoods can be found in Appendix 6.

Certain neighbourhoods may show higher tree cover due to the presence of large parks relative to the size of the neighbourhood. For example, Mount Pleasant Cemetery represents a significant portion of the Mount Pleasant neighbourhood and increases the average tree cover even though tree cover along streets may not be as high.

A USDA study in Rochester, New York has shown that trees can add up to 18% in value to the average sale price of a home. Another national study conducted by social scientists at the University of Washington suggests that presence of trees also positively affects consumer perception and behaviour in commercial areas.

Table 2. Percent forest cover in Toronto's five most and least treed neighbourhoods.

Neighbourhood	Average forest cover* (%)	Standard Error
MOST TREED		
Mount Pleasant East	61.9%	7.5
Bridle Path-Sunnybrooke-York Mills	55.6%	4.1
Rosedale-Moore Park	51.5%	6.1
High Park-Swansea	46.9%	5.1
Morningside	43.8%	5.5
LEAST TREED		
Humber Summit	5.5%	2.4
Steeles	5.3%	2.6
Yorkdale-Glen Park	4.9%	2.4
Milliken	3.5%	1.4
Little Portugal	2.4%	2.4

*Based on a random sample of 9,998 points across Toronto using 2005 digital leaf-off aerial photos. Each neighbourhood will reflect a different level of sampling based on the random point locations. These figures represent estimates with associated statistical error.

It is interesting to note that the neighbourhoods with the highest forest cover in Toronto also happen to be areas of high average real estate value. Appendix 7 charts the relationship between the average tree cover in Toronto neighbourhoods and average home sale values using actual home sale data from 2007-2008[23].

5.2.3 Effects of Land Use on Land Cover Distribution

Land use is a determinant of land cover. Figure 13 shows that the *Open Space 1* (parks and TRCA lands) and *Open Space 2* land uses have the highest average forest cover and least amount of impervious surfaces. Conversely, *Commercial* and *Industrial* land uses have the highest proportion of impervious surface and the lowest proportion of forest cover. This data provides useful information that forest managers can use to prioritize areas for increasing tree canopy and helps managers evaluate potential constraints.

23 Source for average home sale value: Toronto Real Estate Board, 2007-2008 stats www.realosophy.com

Open Space 1 and *Commercial* land uses. (left to right) (Credit: City of Toronto)

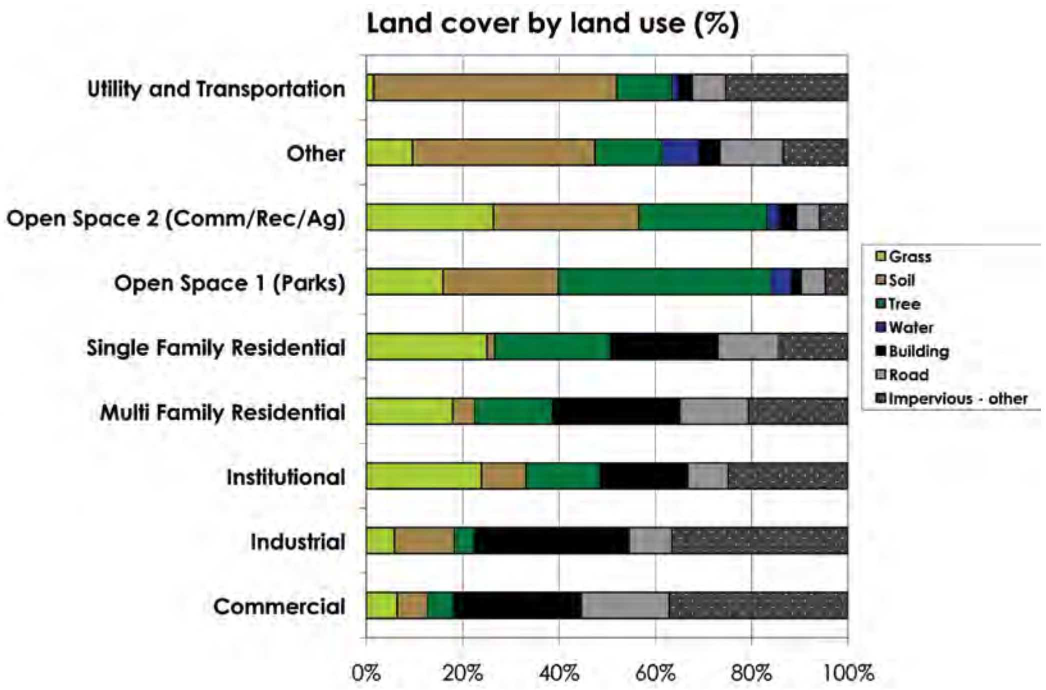


Figure 13. Land cover types by land use.

Land use is a determinant of land cover types across the city.

5.3 Forest Composition

5.3.1 Number of Trees and Ownership

The urban forest of Toronto has an estimated 10.2 million trees[24]. Figure 14 shows the number and percent of trees by land ownership, demonstrating the significant contribution of trees on private property to the city's tree canopy (60% of the city's tree population).

24 Standard Error (SE) = 954,000

Private property owners control a majority (60%) of Toronto's tree canopy.

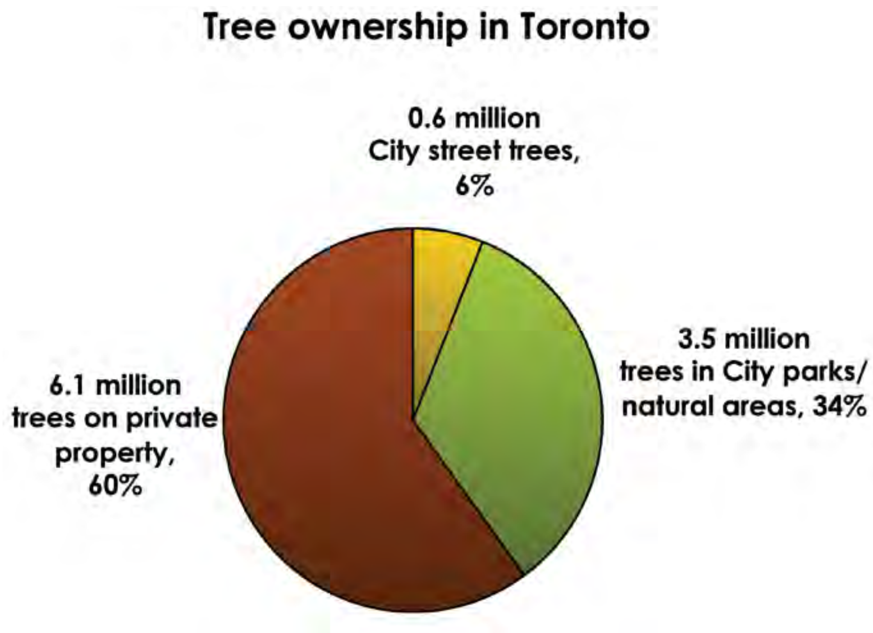


Figure 14. Tree ownership in Toronto.

Toronto has at least 116 different tree species. The top five species by leaf area are:

- Norway maple (14.9%)
- Sugar maple (11.6%)
- Manitoba maple (5.5%)
- Green ash (5%)
- White spruce (4.6%)

5.3.2 Tree Species Composition

In total, 116 species were documented in the i-Tree Eco field sample. A full list of tree species by leaf area and number of trees (as per 407 study plots) is found in Appendix 8.

There are two different ways to look at tree species composition in Toronto. The study provides measures of tree species composition expressed as both numbers of trees as well as the percentage of the tree canopy represented by the leaf area of a species in metres squared. Tree benefits are generally linked directly to the amount of healthy leaf surface area of the plant and in this case deemed a more relevant measure with respect to evaluating the contribution of tree species to the overall forest canopy.

Figure 15 shows the top ten species in Toronto by leaf area relative to the number of trees in the population. Although some species represent a high number of trees in the population, their contribution to total canopy leaf area is less significant. Eastern white cedar and white ash are examples of species found in high numbers but representing relatively less of the total tree canopy by leaf area. This is related to their smaller average crown size – eastern white cedar, for example, is found mainly in hedge form around the City and these trees rarely achieve a large stature.

Maples in a Toronto park (Credit: City of Toronto)

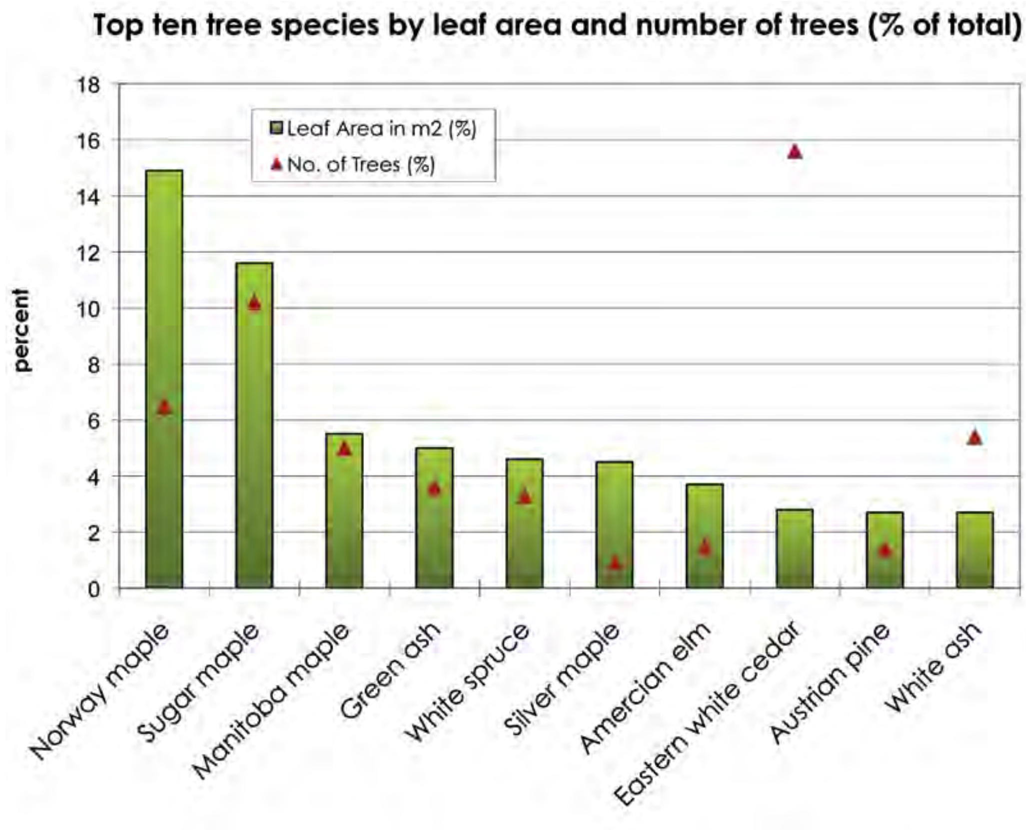


Figure 15. Top ten tree species by leaf area (m^2) and number of trees.

The top three positions in terms of total leaf area in Toronto are dominated by maples (Norway, sugar and Manitoba maple). The number one species is still Norway maple at 14.9% of Toronto's total leaf area. This is in part a legacy of Dutch Elm Disease in the middle of the last century that wiped out most of the continent's elms. In Toronto, many of these trees were replaced with Norway maple, which at the time was considered a hardy, fast-growing urban shade tree. This species has proven to be very invasive and damaging to ravines and natural areas and with some exceptions, is rarely planted on city property anymore.

One of the main strategies for sustaining a healthy urban forest is to maintain a high diversity of appropriate tree species. This makes the forest less vulnerable to large-scale impacts from any one disturbance due to pests and disease. The "*5-10-20*" rule recommends a species, genus, family ratio of no more than 5% of one species, no more than 10% of one genus, and no more than 20% of one family for the optimal planting mix in an urban forest[25].

Toronto generally meets the *5-10-20* diversity criteria with the following exceptions:

- More than 5% of the population consists of sugar maple (10.2%), Norway maple (6.5%), white ash (5.3%) and eastern white cedar (15.6%)
- Significantly more than 10% of trees represent the maple (23.8%) and cedar (17.8%) genera

In terms of leaf area, maple trees represent over one third of the city's tree canopy. This is consistent with previous US research that looked at 12 cities in eastern North America[26] and found high proportions of maple and ash species to be common.

25 Raupp, M.J., Buckelew Cumming, A. and E.C. Raupp. Street tree diversity in Eastern North America and its potential for tree loss to exotic borers. Arboriculture & Urban Forestry 2006. 32(6):297–304.
26 Ibid.

Maple is a preferred host for the Asian Long Horned Beetle (ALHB), an introduced insect pest. Toronto's recent experience fighting an ALHB infestation highlights the risks of having an imbalance in the urban forest species composition. Although the ALHB infestation is now under control, continued diversification of the urban forest is an important consideration in Toronto's urban forest management program.

5.3.3 Shrub Species Composition

The study documented over 114 shrub species in the city. The top five species by leaf area are:

- Eastern white cedar (29%)
- Common lilac (14%)
- Tartarian honeysuckle (12%)
- Staghorn sumac (11%)
- Alternate-leaved dogwood (9%)

Although shrubs do not provide the same benefits as trees, they are nevertheless an important part of the urban forest. Shrubs also serve many ecological functions – they capture pollution and help mitigate storm water runoff, they provide structural diversity (add vertical layers) to the forest environment, they can provide important food sources, cover and habitat for wildlife and help soften the urban landscape. Shrubs can also provide an alternative to greening in urban areas where it may not be possible to plant large-stature trees.

Table 3 shows the top ten shrub species by leaf area - a complete list of shrub species by leaf area can be found in Appendix 9. Three of the top ten shrub species (representing 22% of the total shrub leaf area) are considered invasive. This is relevant information for land managers since the control of invasive species is a management priority related to the goal of conserving native biodiversity in the City.

Table 3. Top ten shrub species by percent of total shrub leaf area.

Common name	Latin name	Percent (total leaf area)
Eastern white cedar	*Thuja occidentalis*	29%
Common lilac	*Syringa vulgaris*	14%
*Tartarian honeysuckle	*Lonicera tatarica*	12%
Staghorn sumac	*Rhus typhina*	11%
Alternate leaf dogwood	*Cornus alternifolia*	9%
Chinese juniper	*Juniperus chinensis*	7%
*Winged burningbush	*Euonymus alatus*	5%
*European buckthorn	*Rhamnus cathartica*	5%
Russian olive	*Elaeagnus angustifolia*	4%
Common box	*Buxus sempervirens*	4%
**Invasive species*		

5.3.4 Forest Diversity

Urban forests are a mix of native tree species that existed prior to the development of the city and exotic species that were introduced by residents or other means. As such, urban forests often have a tree diversity that is higher than surrounding native landscapes.

Land use affects forest diversity:

- Single Family Residential areas have the highest species diversity
- Commercial land use areas have the lowest species diversity

High tree diversity can minimize the overall impact or destruction by a species-specific insect or disease. On the other hand, exotic plants can also pose a biodiversity risk if they are invasive and have the potential to displace native species.

About 64% of the 116 trees that were identified are species that are native to Ontario[27]. Trees with a native origin outside of North America are mostly from Eurasia (15.7%).

The i-Tree model includes measures of biodiversity as one of its outputs. The Simpson's

27 Ontario Plant List (OPL) database, Newmaster et al. 1998 & Shrubs of Ontario, Soper & Heimburger 1982.

Diversity Index describes the number of tree species and their relative abundance in the landscape, including all native, non-native and invasive species[28]. Table 4 shows the results of this analysis, which suggests that the *Single Family Residential* land use has the highest overall tree species diversity. Ranking lowest are the *Commercial* and *Utility & Transportation* land uses.

Table 4. Simpson's Diversity Index - tree species diversity by land use.

Land Use	Simpson Index[2]	Rank
Single Family Residential	23.7782	1
Institutional	17.7273	2
Open Space 2	11.1923	3
Open Space 1	10.3559	4
Other	9.2504	5
Industrial	8.3404	6
Multi Family Residential	8.3404	7
Utility & Transportation	5.518	8
Commercial	4.4475	9

Figures 16 and 17 show the proportion of invasive tree and shrub species by land use, including Norway maple. The *Institutional* land use has the highest proportion of native tree species and lowest proportion of invasive shrubs. The land use with the lowest percentage of native tree species is *Industrial* while *Utilities and Transportation* land use areas have the most invasive trees and shrubs.

These results suggest that the presence of native species in highly urbanized land uses is less common, possibly related to the challenging growing conditions. Furthermore, unmanaged areas (eg. vacant lands, utility & transportation land use) appear to have a higher proportion of invasive species. This can likely be attributed to a lack of active stewardship in these areas.

Targeted management of invasive species in woodlands (Credit: Urban Forestry).

28 Invasive Plants of Canada: An Introduction. www.rbg.ca/cbcn/en/projects/invasives/invade1.html.
29 Simpson's Diversity Index is used to quantify habitat biodiversity for large, sampled communities. Url: www.countrysideinfo.co.uk/simpsons.htm

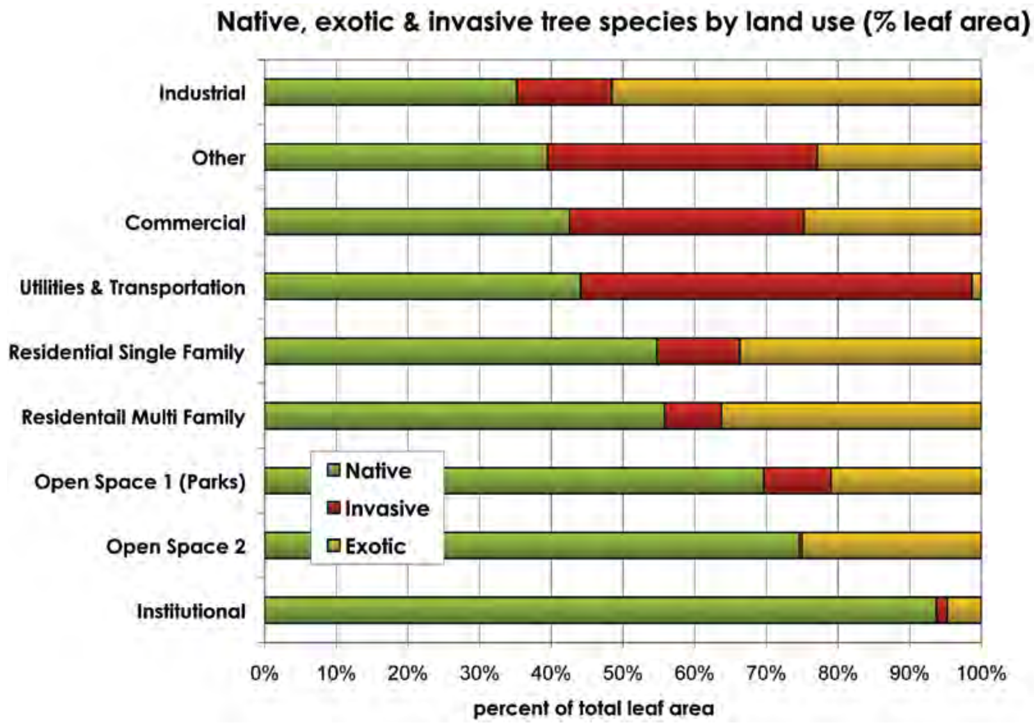


Figure 16. Percent of forest canopy comprised of native, invasive and exotic species by land use.

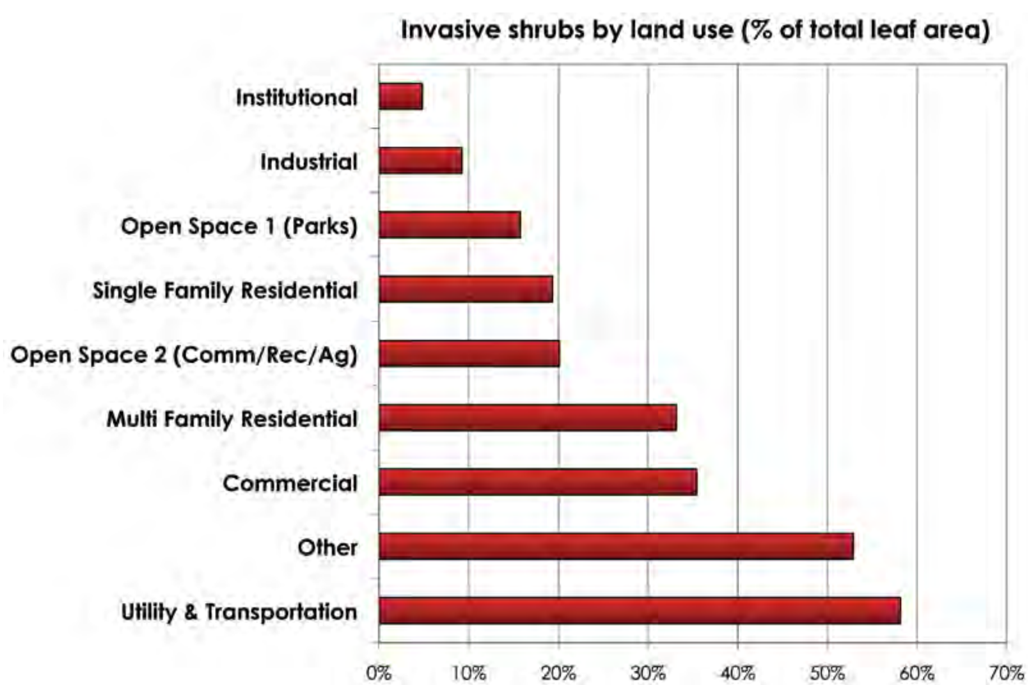


Figure 17. Proportion of invasive shrubs by land use (as % of total leaf area).

5.3.5 Forest Regeneration

More than half of Toronto's trees (54.1%) are estimated to originate from natural regeneration and the remainder are planted (45.9%). Natural regeneration refers to trees that establish spontaneously from nearby seed sources. Table 5 shows the relationship between land use and percentage of the tree population planted or naturally regenerated.

Table 5. Estimated percent of tree population planted versus naturally regenerated.

Land Use	Percent Planted	Percent Natural Regeneration
MF Residential	94.4	3.6
SF Residential	73.5	26.5
Industrial	44.9	55.1
Institutional	36.5	63.5
Commercial	31.0	69.0
Other	15.2	84.8
Open Space	14.6	85.4
Parks	11.3	88.7
Utility & Trans	3.6	96.4
Toronto	**45.9**	**54.1**

More than half (54.1%) of Toronto's trees are estimated to be the result of natural regeneration.

Natural regeneration rates are highest in areas with high densities of trees (*Open Space*, *Parks*) and areas with limited management interventions (*Other* e.g. vacant areas and *Utility & Transportation*).

Natural regeneration can have positive or negative consequences for urban forest sustainability. The establishment of desirable native species can be encouraged through passive management like fencing, monitoring and preventing management activities like mowing. On the other hand, the rapid regeneration and spread of invasive species can have negative consequences for the conservation of native biodiversity.

5.3.6 Forest Condition

i-Tree Eco uses tree crown condition to provide a measure of overall tree health. (Figure 18). There are many other possible indicators of tree health such as damage to bark or stem, evidence of decay or insect damage, structural characteristics. i-Tree Eco is not designed to conduct a detailed assessment of tree health but rather to provide managers with a basic indicator of forest condition. The rating results from an assessment of:

1. Percent crown dieback (how much deadwood there is in a tree crown)
2. Percent of crown missing (how much of the full tree crown is missing).

Because the crown is a component of net primary production in trees, crown condition does provide a useful indicator of general tree health[30]. Large, dense crowns are generally associated with potential or previous vigorous growth rates and the reverse is true for trees with small, sparse crowns. Figure 18 provides a summary of the results City-wide based on these two measures of crown condition.

30 Tree Crown Condition Indicator. USDA Forest Service. Forest Inventory and Analysis Fact Sheet Series. Url: http://fia.fs.fed.us/library/fact-sheets/p3-factsheets/Crowns.pdf

81% of Toronto's trees are in good or excellent condition based on an assessment of tree crown health indicators.

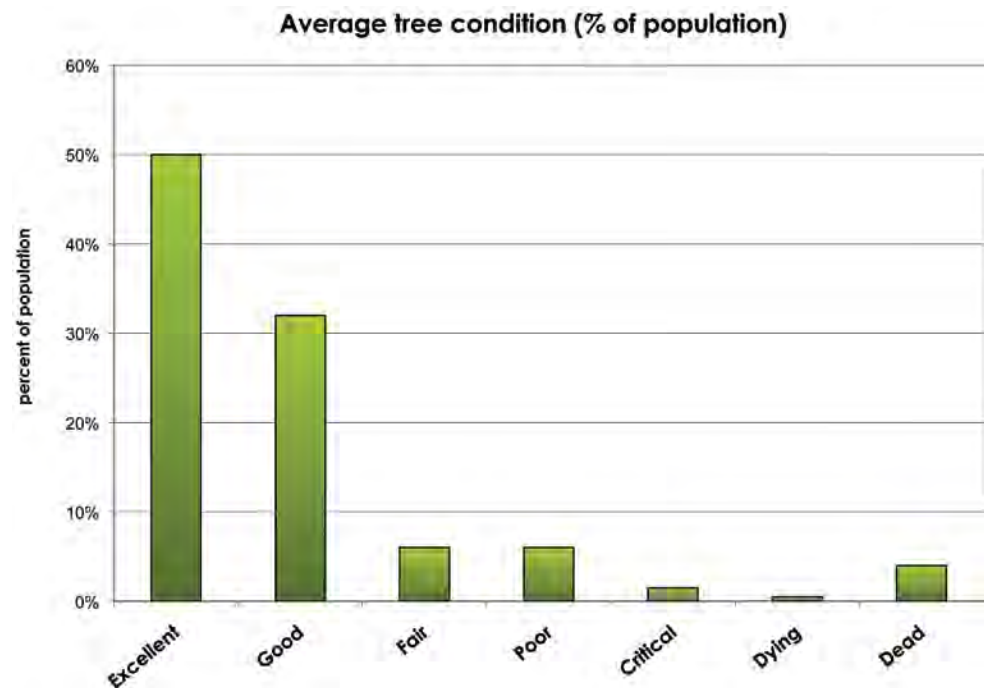


Figure 18. Tree condition (percent of population by leaf area).

Based on these criteria, 81% of Toronto's trees are rated as being in excellent or good condition. This number would likely be lower if more comprehensive tree health indicators were assessed in the field. Furthermore, crown condition ratings may be skewed in cities because many trees have deadwood pruned out periodically, which may produce higher average crown condition ratings.

Different tree species also fare differently in the urban environment. This can be related to their individual susceptibilities to insects or disease, particular sensitivity to environmental and climate factors and or even the age class structure of the species within the population. Figure 19 shows the average condition ratings for the top ten species by leaf area.

Some species fare better than others in the urban environment:

- *Norway and silver maple had the highest average condition ratings*
- *Ash, elm and sugar maple had some of the lowest average condition ratings*

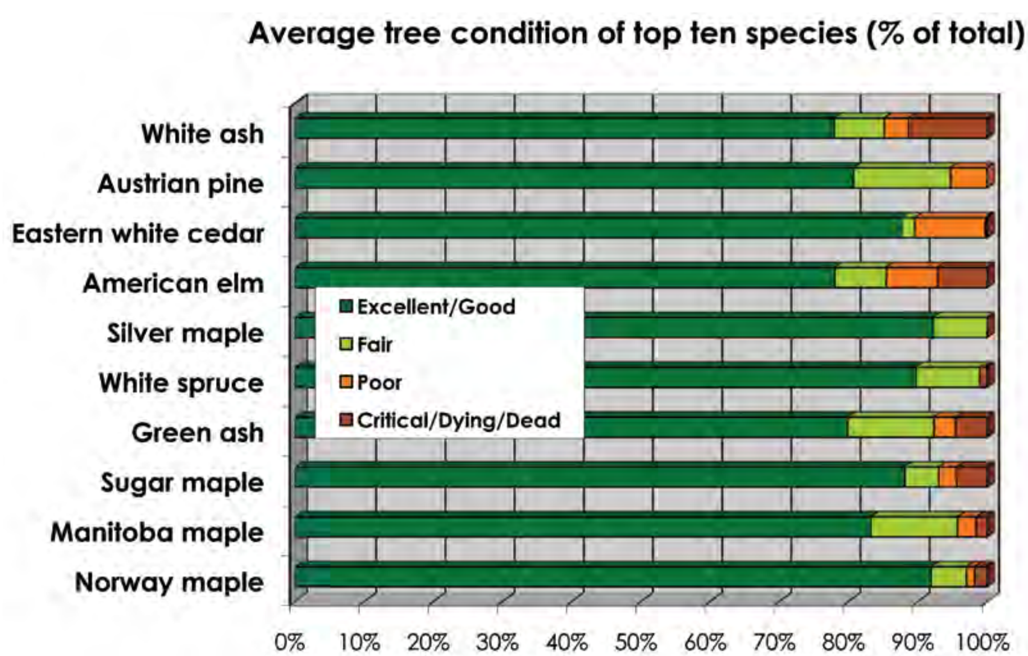


Figure 19. Average condition ratings for top ten tree species by leaf area.

Within the top ten species by leaf area

- Norway maple and silver maple have on average the highest proportion of excellent or good tree ratings
- Ash species, American elm and sugar maple show the highest number of critical, dying or dead trees in the sample.

These findings are consistent with some of the known threats to specific tree species. For example, anthracnose (*Apiognomonia errabunda*) is a common disease of ash trees in Toronto causing leaf loss in the spring. This would have been documented in the field plots as crown dieback. (According to the City's forest health experts, the impacts of Emerald Ash Borer are not yet widespread enough to be significant in a city-wide survey.)

Hosts for anthracnose include black, green, red, and white ash although green ash is relatively resistant. This is consistent with the study results, which suggest that almost twice as many white ash (14.9%) than green ash (7.7%) are in poor or critical condition.

Other contributing factors include Dutch Elm Disease, which has widespread effects on the American elm population in Toronto. Sugar maple decline has been observed in some parts of the City, likely related to this native maple species' susceptibility to pollution, road salt and other environmental stressors. On the other side of the spectrum, Norway and silver maple have higher average condition ratings that may reflect their tolerance for challenging urban growing conditions.

5.4 Forest Structure - Size Class Distribution

5.4.1 Aggregated Results for the Entire Urban Forest

Figure 20 shows the overall size class distribution of Toronto's urban forest including all trees (planted and naturally regenerated) in naturalized and urban areas. Size class distribution is a complex indicator for urban forests, since there is no "one size fits all" target distribution that can be referred to although some rules of thumb have been established as guidelines (shown in Figure 20 as 'Ideal')[31]. The concept of relative size class distribution can also be applied to refine size class targets but was not within the scope of this study.

Overall, small trees predominate in Toronto's urban forest:

- 68% of trees are less than 15.2cm in diameter
- 18% are between 15.2 and 30.6cm in diameter
- 14% are larger than 30.6cm in diameter

Furthermore, the ideal size class distribution may vary by land use. The ideal distribution in a naturalized ravine area might be quite different than that in a highly urbanized commercial area. The general management principle underlying size class distribution is to maintain a consistent proportion of young trees in the population, recognizing that there will be some level of mortality as trees grow. Managers should also strive to maintain a good distribution of mid- to large-sized trees to ensure a sustainable age class structure and produce maximum urban forest benefits over time.

31 The City of Davis, California modified from Richards (1983).

Maintaining an appropriate amount of large-stature trees is key to maximizing urban forest benefits and tree canopy cover.

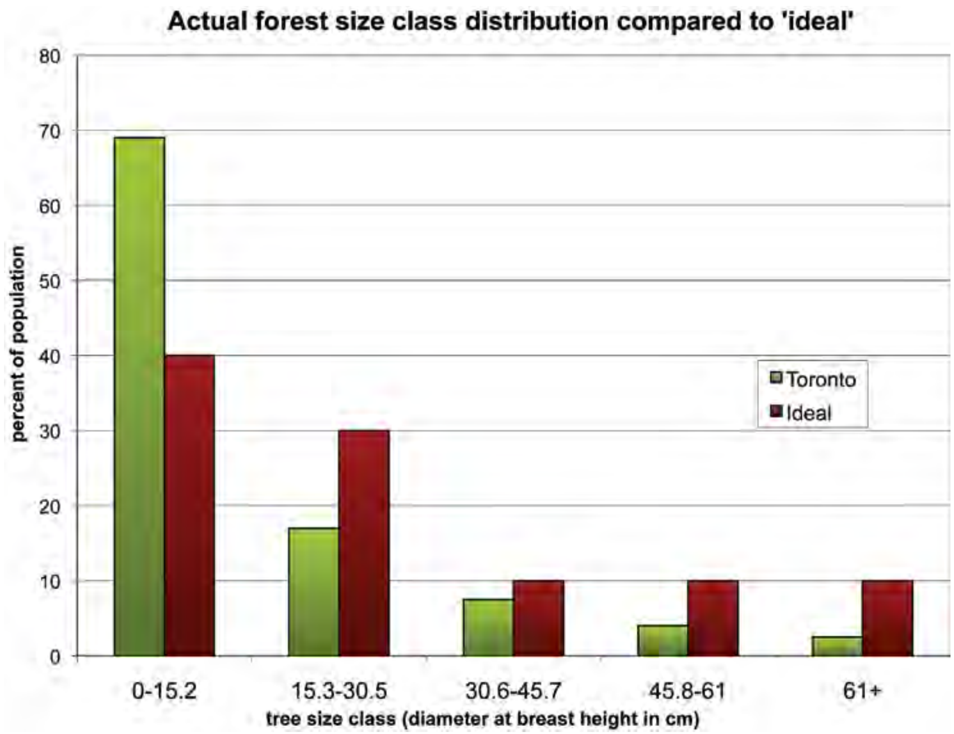


Figure 20. Percent of tree population by size class compared to suggested 'ideal'.

The results show a high proportion of Toronto's trees in the lowest size class. Approximately 68% are <15.2 cm in diameter, with consecutive size classes tapering off fairly evenly toward the larger size categories. The high number of small tree may be partly a result of the following factors:

- Including species in the sample that might normally be classified as shrubs because i-Tree Eco defines a tree as "any woody vegetation greater than 2.5cm in size". As a result, many cedar shrubs used frequently as hedges were classified as trees. This results in a lower average tree diameter for the entire population.
- The inclusion of small stature species (e.g. fruit trees) that will never achieve large diameters
- High levels of natural recruitment in some of the City's ravines and natural areas.

If cedar hedges are removed from the sample, the proportion of small trees (<15.2cm) is still high at 64% and the proportion of mid- to –large size trees is still less than ideal.

The study results suggest that while Toronto has achieved good levels of regeneration, there may be an imbalance in the age class structure related to a shortfall of larger trees. Currently, the data shows that only 14% of the entire tree population has a diameter larger than 30.6cm. Maintaining an appropriate level of tree cover in the mid- to large-sized categories is critical to maximizing urban forest benefits.

5.4.2 Size Class Distribution by Land Use

Figure 21 provides more information on the relationship between land use and tree size class distribution across the city. Although most land use areas have consistently high levels of smaller stock (<15.2cm), there is some variation by land use.

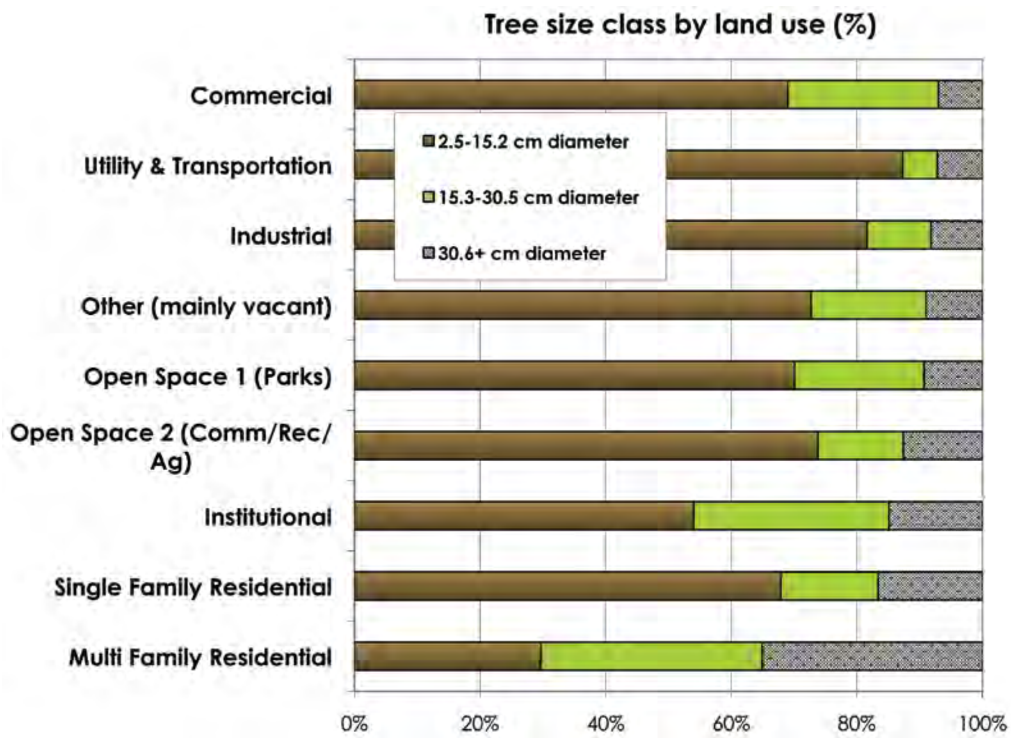


Figure 21. Tree size class distribution by land use (cm diameter at breast height).

Notable findings are as follows:

- *Multifamily Residential*, *Single Family Residential* and *Institutional* land uses have the highest proportion of trees in the larger diameter classes (> 30.5 cm diameter)
- *Multifamily Residential* has fewer small trees to replace the existing mature stock when it starts to decline, particularly in the <15.2 cm category
- *Single Family Residential* and *Open Space 2* land use areas have a relatively low proportion of mid-size trees (15.2-30.5cm) - this may result in a period of low canopy until the young trees mature
- *Utility and Transportation* and *Industrial* land use areas have the highest proportion of small trees (<15.2cm)

Land use affects tree size:

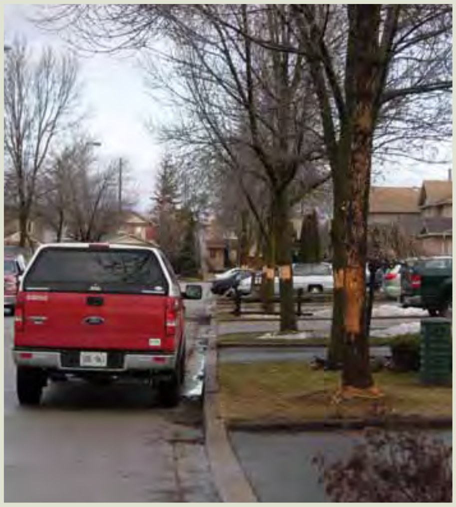
- Residential areas have the largest trees on average
- Industrial areas have the smallest trees on average

(Credit: Peter Simon)

The data highlights the importance of managing age class structure to maintain consistent and sustainable levels of tree cover through time. The current situation suggests that some land use areas will see a decline in tree cover as older trees are removed. Furthermore, there may be a lag time until smaller stock grows and begins to contribute significantly to overall tree canopy. In highly urbanized land uses areas the growing conditions make it challenging to achieve large-stature trees at all unless the appropriate soil infrastructure is put in place.

5.5 Toronto's Street Tree Population

Toronto's street trees represent a unique population represented by all trees that are established and maintained in the City's road allowances or right-of-ways (ROWs). They comprise approximately 6% of the City's total tree population. Street trees face some of the most difficult growing conditions in cities. They contend with poor quality soils, salt and chemical runoff from roadways and sidewalks, mechanical damage due to infrastructure replacement and upgrading as well as extreme heat and water stress.



Sampling for Emerald Ash Borer (Credit: City of Toronto)

Because they are a unique population, separating street trees from the City-wide results can help forest managers better understand the variability in the urban tree population and any related management implications. The data also highlights some of the recent trends in the management of City trees.

5.5.1 Species Composition and Diversity

In terms of the total number of species, Toronto has achieved a good level of diversity in the street tree population. There are at least 144 different kinds of street trees in Toronto[32] of which only 31% consists of native species (Figure 22). This is not surprising since many native species poorly tolerate the challenging growing conditions in the City's road allowances.

Toronto's street trees represent approximately 6% of the city's urban forest. 31% of street trees are considered native species as compared to 64% overall.

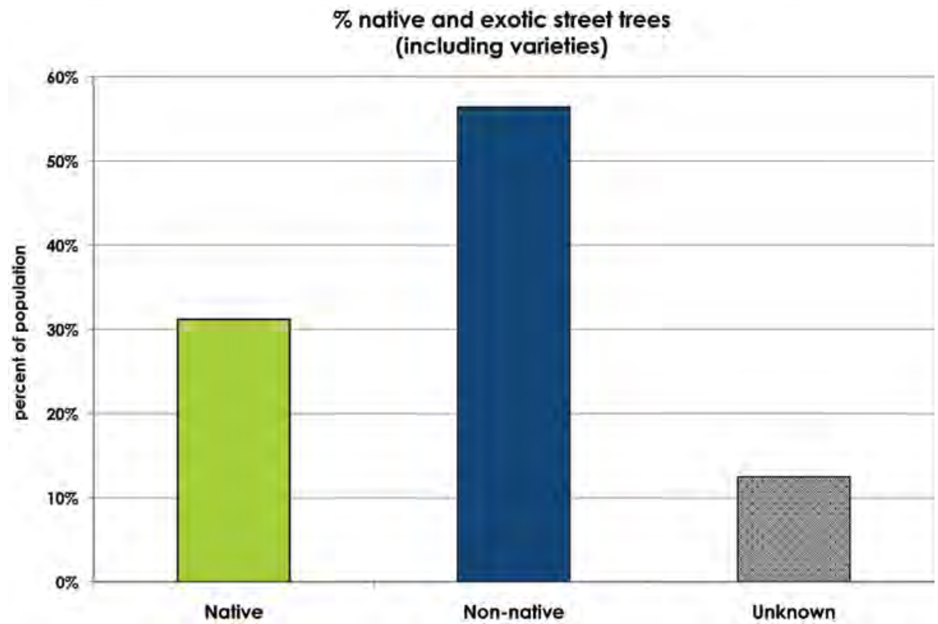


Figure 22. Percent of street trees that are native species (including varieties).

Figure 23 shows the top ten street tree species according to the number of trees in the City's TMMS database. Consistent with the city-wide data, Norway maple also dominates the streets at almost a quarter of the total population (22%).

At a species level, street trees generally meet the "*5-10-20*" diversity guidelines with the following exceptions:

- More than 5% of the population consists of Norway maple (22%) and honey locust (6%)

Maple species make up 34% of the street tree population. This is in part due to historic levels of Norway maple planting in response to Dutch elm disease.

Of more concern is the high percentage of maple (34%) as a genus in the street tree population, with more than three times the recommended percentage (10%). Because street trees represent only 6% of the total population, this is not a significant concern for the overall sustainability of the urban forest. However, the recent tree removals associated with the Asian Long Horned Beetle infestation showed that the loss of street trees can have significant impacts at the neighbourhood level. For this reason, it is important to plan for species diversity at multiple scales: not only across the entire population but also at a neighbourhood and street level.

32 Source: Toronto Maintenance and Management System (TMMS). City of Toronto, 2009.

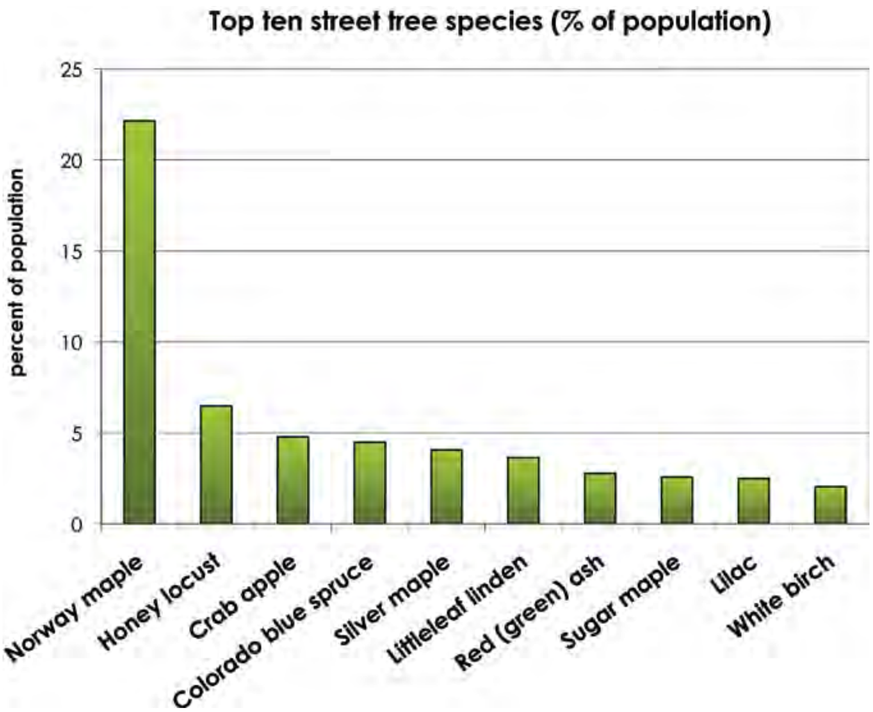


Figure 23. Top ten street tree species in Toronto as percent of population.

5.5.2 Street Tree Condition

49% of street trees are rated as being in excellent or good condition (Figure 24) as compared to 81% in the overall population. While it is expected that street trees would have poorer condition ratings than the overall population, this is also related in part to how health is reported by arborist inspectors as well as the more comprehensive criteria used to assess health of street trees.

Although the condition ratings assigned by City inspectors and i-Tree Eco are not directly comparable, the street tree data reflects the challenges common to managing street tree health in the context of the stressful growing environment.

The top five street tree species as a % of the population are:

- Norway maple (22%)
- Honey locust (6%)
- Crab apple (5%)
- Colorado blue spruce (4%)
- Silver maple (4%)

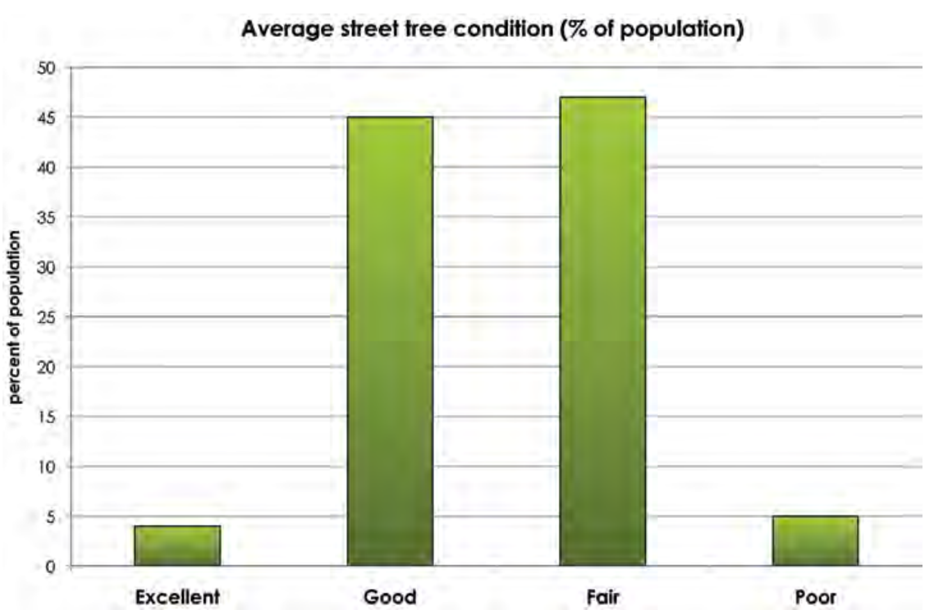


Figure 24. Average street tree condition as % of population (Source: TMMS 2009).

Street tree size class distribution:

- 47% of street trees are less than 15.2cm in diameter
- 28% are between 15.2 and 30.6cm in diameter
- 25% are greater than 30.6cm in diameter

5.5.3 Street Tree Size Class Distribution

Toronto's street tree population is relatively consistent with a suggested ideal street tree size class distribution[33] that shows the result of regular planting. (Figure 25). However, as with the City-wide results, the data indicates a shortfall of trees in the mid and large size categories to provide maximum shading and urban forest benefits along city streets. 47% of street trees are 15.2cm or less in diameter while only 25% are larger than 30.6cm as compared to the suggested 48% target.

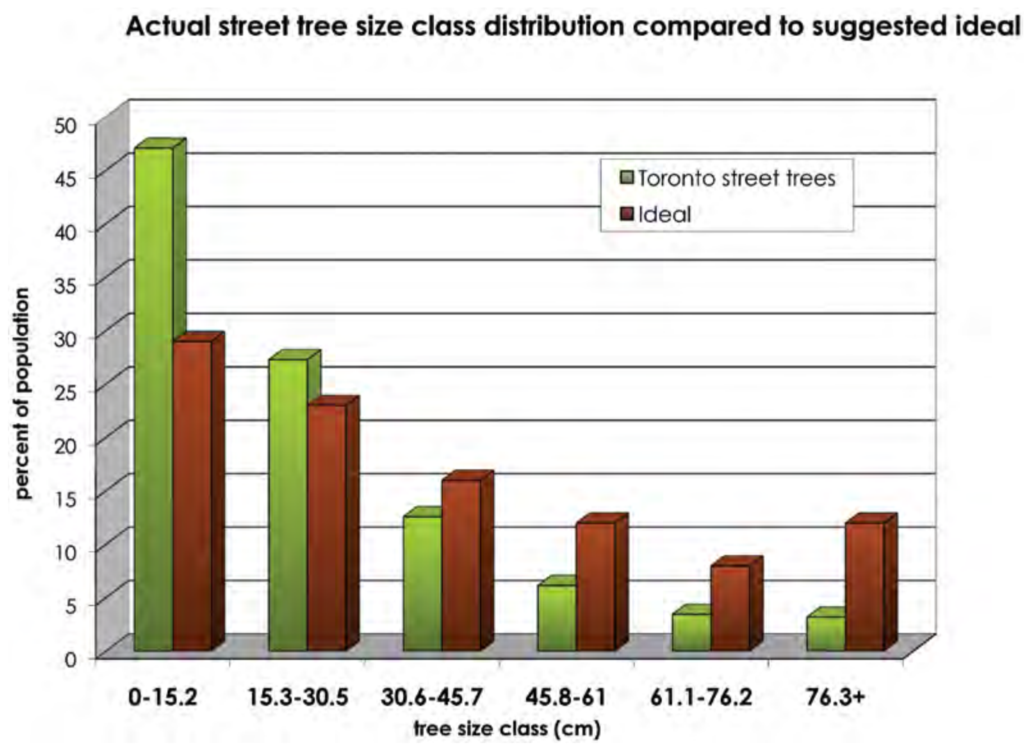


Figure 25. Street tree size class distribution compared to an idealized distribution.

5.5.4 Street Tree Planting and Removals

Maintaining a sustainable urban forest requires continuous attention to the establishment of new trees to replace the existing canopy. Figure 26 compares the rate of street tree planting to tree removals for the period 2002-2008.

(Credit: R. Burkhardt)

33 Community Forestry Program Work Team. Cornell University. Url: www.hort.cornell.edu/commfor/inventory/utilizing.html

Figure 26. Number of street trees planted versus trees removed (stemming) from 2002-2008[34].

The replacement rate of street trees was approximately equal to tree removals until around 2004[35]. Starting in 2005, tree planting began to significantly exceed tree removals as a direct result of increased funding to the City's urban forest management programs.

Starting in 2005, the rate of street tree planting increased as a direct result of increased funding to forestry programs.

5.6 Forest and Land Cover Change in Toronto from 1999-2005

Given the goal of increasing Toronto's tree canopy, a key aspect of this study was to develop a baseline estimate of forest cover from which to measure progress. A change analysis was also included in order to capture some preliminary measure of change in the tree canopy, using available City orthophotos. The results show that between 1999-2005, forest cover in Toronto decreased by 0.7% (from 20.6% to 19.9%). During this period

- new tree cover increased by 0.4% (standard error = 0.1%) but
- existing tree cover declined by 1.1% (standard error = 0.1%).

This change is statistically significant from zero (McNemars test; alpha < 0.01) and indicates a slight annual average loss of approximately 0.1% per year in tree cover over the six-year period.

Tree cover can change based on numerous factors, including annual tree mortality rates, growth rates, and annual new tree establishment rates. Past trends do not dictate future conditions as environmental and management activities (e.g., development and tree planting trends) change through time. Further monitoring is needed to track how Toronto's tree cover changes in reaction to the current management framework and to establish any conclusive trends.

From 1999-2005, forest cover decreased slightly at a rate of about 0.1% annually. During that six-year period, new tree cover increased by 0.4% while existing tree cover decreased by 1.1%.

5.6.1 Forest Cover Change by Land Use

Average forest cover is highest and most stable in the *Open Space 1* (Parks) land use at 44.2% and lowest in the *Industrial* (4.1%) and *Commercial* (5.3%) land uses. Almost every land use

34 Toronto Maintenance and Management System (TMMS), City of Toronto, November 2009.
35 There may be some data gaps during the initial implementation phase of TMMS in 2000.

Forest cover is highest and most stable in the Open Space 1 (Parks) land use at 44.2%.

The biggest change in forest cover occurred in the Single Family Residential land use.

A land cover change assessment suggests that the amount of impervious surface in the City increased over the six-year period from 1999-2005.

showed a slight decline with the exception of *Open Space 2* and *Utilities and Transportation*. As per Table 6, the most significant change in forest cover was seen in the following three land use areas:

- *Single Family Residential* (-1.3%)
- *Commercial* (-1.0%)
- *Institutional* (-0.9%)

Table 6. Change in forest cover by land use: 1999 to 2005.

Land Use	1999	2005	Change
	% cover	% cover	% cover
Single Family Residential	25.3	24	-1.3
Commercial	6.3	5.3	-1
Unknown	7.3	6.3	-1
Institutional	16.3	15.4	-0.9
Other	14.6	14	-0.6
Multi Family Residential	16.7	16.2	-0.5
Industrial	4.4	4.1	-0.3
Open Space 1 (Parks & TRCA lands)	44.3	44.2	-0.1
Utility & Transportation	10.3	11.6	1.3
Open Space 2 (Comm/Rec/Agr)	25.3	26.6	1.3

5.6.2 Land Cover Change

In addition to providing information on the City's forest canopy, land cover change analysis is useful for understanding the evolution of the City's built footprint (Table 7). As landscapes change, elected officials and planners can use this kind of information to guide them in making important land use decisions.

Patterns of land cover in urban environments are of interest to forest managers from the perspective of forest and watershed sustainability, including biodiversity conservation, at a regional and local scale. For trees in urban environments, the nature of the prevailing land cover surrounding individual or groups of trees can also factor into management decisions.

An analysis of land cover change for the period 1999 to 2005 determined that the amount of

- impervious surfaces (roads, buildings an dother) increased by 1.5%
- pervious area (soil) decreased by 1.1%
- grass increased by 0.3%.

Some of the increases in impervious surface and grass areas are probably an artifact of tree removal, in that removing tree cover will expose pre-existing paved or grassy surfaces. However, even accounting for this the data suggests that there were statistically significant changes in land cover over this six-year period[36].

36 Differences were significant at the 0.05 confidence level (pers. comm.., D. Nowak. USDA Forest Service).

Table 7. Land cover change in Toronto: 1999 to 2005.

Cover Type	1999		2005	
	% cover	SE	% cover	SE
Grass	17.9	0.4	18.2	0.4
Tree	20.6	0.4	19.9	0.4
Building	17.7	0.4	18.3	0.4
Road	10.8	0.3	11.1	0.3
Impervious - other	17.7	0.4	18.3	0.4
Water	1.7	0.1	1.7	0.1
Soil	13.5	0.3	12.4	0.3
SE = standard error				

Table 8 shows the change in impervious surface by land use, with impervious representing roads, buildings and an "other" category. The results show the highest increase in the *Commercial* and *Industrial* land uses. Another category showing more change than most is the *Multifamily Residential* land use. Appendix 10 provides a summary of land and forest cover change by generalized land use.

Table 8. Change in impervious surface by land use: 1999-2005.

Land Use	1999	2005	Change
	% cover	% cover	% cover
Commercial	77.6	81.6	+4.0
Industrial	74.9	77.4	+2.5
Multi Family Residential	58.8	61.2	+2.4
Utility and Transportation	33.5	35.3	+1.8
Institutional	49.6	51.4	+1.8
Single Family Residential	47.6	49.2	+1.6
No data	30.7	31.7	+1.0
Other	30.5	31	+0.5
Open Space 1 (Parks and TRCA lands)	11.2	11.7	+0.5
Open Space 2 (Comm/Rec/Agr)	14.6	14.3	-0.3

Quantifying and monitoring land cover change provides useful information about the physical context for decision-making regarding land use in Toronto. From a forestry perspective, the data highlights the importance of maintaining quality growing environments in a changing urban landscape.

5.7 i-Tree Hydro: Measuring Urban Forest Effects in the Don Watershed

The i-Tree Hydro model was used to simulate the effects of tree and land cover on urban hydrology in the Don watershed[37] (Figure 27). Urban trees can reduce the amount of runoff and pollutant loading in receiving waters in three main ways[38]

1. leaves and branch surfaces intercept and store rainfall, thereby reducing runoff volumes and delaying the onset of peak flows

Forest Cover Effects in the Don Watershed

- Doubling the tree canopy in the Don watershed would reduce stream flow by approximately 2.5%
- Converting green space in the Don watershed to impervious surface (47.8 to 60%) would increase overall flow by 30%
- Preserving green space and increasing tree cover would maximize urban forest benefits as part of an integrated storm water management plan

37 Total area = 460 km2

38 New York, New York. Municipal Forest Resource Analysis. 2007. USDA Forest Service. Pacific Southwest Research Station.

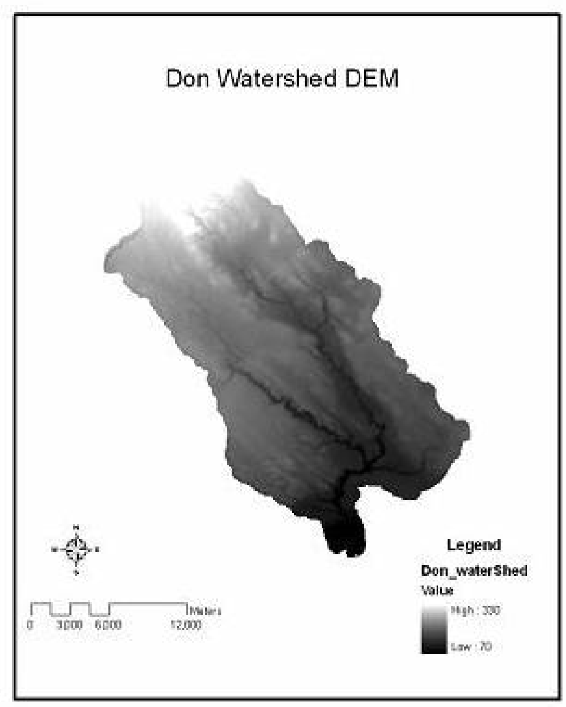


Figure 27. Don watershed Digital Elevation Model (Credit: Toronto and Region Conservation Authority)

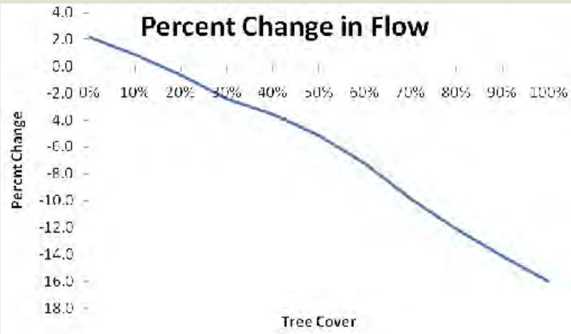


Figure 28. Percent change in stream flow given varying percent tree cover in Don watershed.

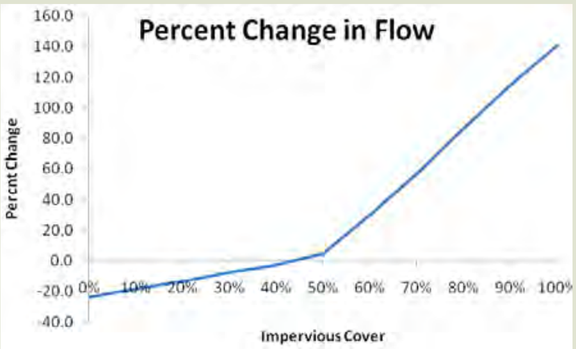


Figure 29. Percent change in stream flow given varying percent impervious cover in Don watershed

2. root growth and decomposition increase the capacity and rate of soil infiltration by rainfall and reduce overland flow
3. tree canopies reduce soil erosion and surface transport by diminishing the impact of raindrops on barren surfaces.

Land cover in the Don Watershed was estimated as follows:

- impervious cover = 47.8%
- tree cover = 15.7%
- grass and shrub cover = 27%
- bare soil = 9%

After calibration, the model was run a number of times under various conditions to see how stream flow would respond to varying levels of tree and impervious cover in the watershed.

5.7.1 Forest Cover Effects

The results show that doubling the tree canopy to approximately 30% would reduce overall flow by 2.5% over the seven month simulation period. Increasing tree cover reduces base flow, as well as flow regenerated from both pervious and impervious areas. Conversely, the model suggests that loss of all tree cover would increase total flow during the seven month simulation period by an average of 2.1% (Figure 28).

5.7.2 Impervious Cover Effects

The extent of hard surface in a watershed has a more significant impact on flow rates than the amount of tree cover. i-Tree Hydro showed that the conversion of green space or forest in the Don watershed to hard surface from 47.8% to 60% would increase total flow another 30% over the seven month simulation period. Conversely, reducing current impervious cover would reduce total flow during the seven month simulation period by an average of 23.8% (Figure 29).

Essentially, impervious cover has a 12 fold impact relative to tree cover. From a storm water management perspective, optimal results would be achieved by minimizing loss of pervious green space or vegetated areas. Furthermore, these effects can be maximized by expanding forest cover, in particular over large, impervious areas.

These findings are consistent with other hydrological studies for Toronto. Studies by Toronto Water have similarly shown the effect of increasing levels of impervious cover on the storm runoff coefficient (as cited in the City's Wet Weather Flow Management Guidelines)[39].

39 Toronto Water. The Rationale for Water Balance Management. www.toronto.ca/water/protecting_quality/wwfmmp_guidelines

5.8 Simulating Future Forest Growth and Regeneration Requirements

Urban tree cover changes through time based on many factors, including tree mortality rates, growth rates, and rates of new tree establishment. The i-Tree GrowOut program uses the output from i-Tree Eco to project future tree population totals, canopy cover, and carbon storage based on user inputs of estimated mortality rates. Populations can be projected over a 100-year period. The program also can be used to determine annual tree planting/establishment rates needed to sustain a specific tree canopy cover[40]. For these simulations, an average tree diameter growth rate of 0.6 cm/yr was used along with varying average annual mortality rates of 4, 5 and 6%. Two scenarios were modeled:

1. Change in tree cover with no tree planting, and
2. Rate of annual planting required to reach a 35% overall canopy goal in 50 years.

Under a scenario of no further tree planting, canopy cover would drop to between 4% and 11% after 100 years depending on tree mortality rates.

Multiple runs for each simulation were conducted using three different mortality rates since actual average mortality rate for trees in Toronto is unknown. The model also takes into account the percentage of natural regeneration (54%) versus percentage of trees planted in the City (46%).

5.8.1 Forecasting Tree Canopy Development Under a "No Planting" Scenario

Under a scenario of no further tree planting, the GrowOut program shows that tree cover will drop to between 4% and 11% after 100 years depending upon mortality rates even with natural regeneration of 162,000 trees per year (Figure 30).

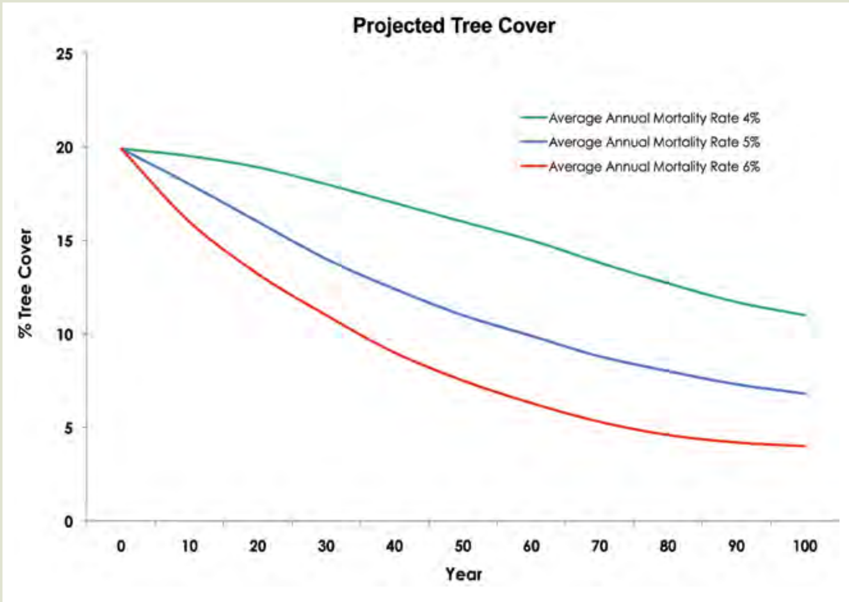


Figure 30. Projected tree cover in 100 years based on various mortality rates.

5.8.2 Estimating Tree Planting Requirements

In order to estimate the number of trees that need to be planted to reach a tree cover goal of 35% in 50 years, the estimated number of trees needing to be established was multiplied by the proportion of trees planted in Toronto (Table 9).

Increasing tree cover from 19.9% to 35% in 50 years (a 75% relative increase in canopy cover) will take many new trees and the annual planting rate will vary depending upon mortality. Urban actions (development, mowing) often preclude tree cover in Toronto with decreased mowing and impervious surfaces tending to lead to more natural regeneration. The annual planting rate to reach this goal assumes that the current rate of 54% natural regeneration remains the same.

Goal: 35% tree cover in 50 years

- Assuming 2% tree mortality, the City would have to plant an estimated 55,000 trees per year to achieve 35% forest cover in 50 years
- At 3% mortality, the required rate of tree planting increases to 200,000 tree per year
- Between 2004-2009, the City and its partners planted an average of 84,000 trees per year

40 www.itreetools.org

Table 9. Estimate of annual tree establishment required (planted and natural regeneration) to reach canopy cover goal based on "Grow Out" model.

Average mortality rate	Annual planting to reach cover goal	Total annual tree establishment needed (planting and natural regeneration)
2%	55,000	120,000
3%	200,000	440,000
4%	365,000	800,000
5%	570,000	1,250,000
6%	800,000	1,750,000

This planting estimate is an elementary approximation of tree planting to help guide urban forest management in Toronto. Further monitoring of Toronto's urban forest using the i-Tree Eco permanent sample plots will provide better data related to mortality, planting and establishment rates to help guide urban forest management in future.

The average mortality rate will significantly influence the total number of trees that must be established each year to achieve the canopy goal. For example, between 2% and 3% mortality the number of trees that would have to be planted annually increases from 55,000 to 200,000. As such, management activities that reduce tree mortality will have a significant effect on the number of trees that need to be established annually to reach a desired tree cover.

The actual rate of planting on all City property steadily increased between 2004-2009 (Figure 31), averaging approximately 84,000 trees/year over that six-year period. These figures do not include additional tree planting that is undertaken on private property in Toronto. Assuming a mortality rate of between 2-3%, these estimates suggest that the City must maintain current planting levels in order to meet its tree canopy goal.

Figure 31. Total number of trees planted on City property from 2004-2009 (all stock types)[41].

41 Available Urban Forestry statistics, January 2010.

5.9 Urban Tree Canopy (UTC) Assessment – Identifying Opportunities for Tree Canopy Improvements

A key product of this study was a digital forest and land cover map for the entire City of Toronto. For the first time, forest managers have detailed information about the spatial distribution of the urban forest across the City. The map represents another layer of foundation data that can be added to the City's integrated geospatial environment and used by all City Divisions for planning. It also permits area-based analyses of forest and land cover by defined geographic boundaries, such as watersheds, wards and neighbourhoods. Figure 32 provides an example of the digital land cover data.

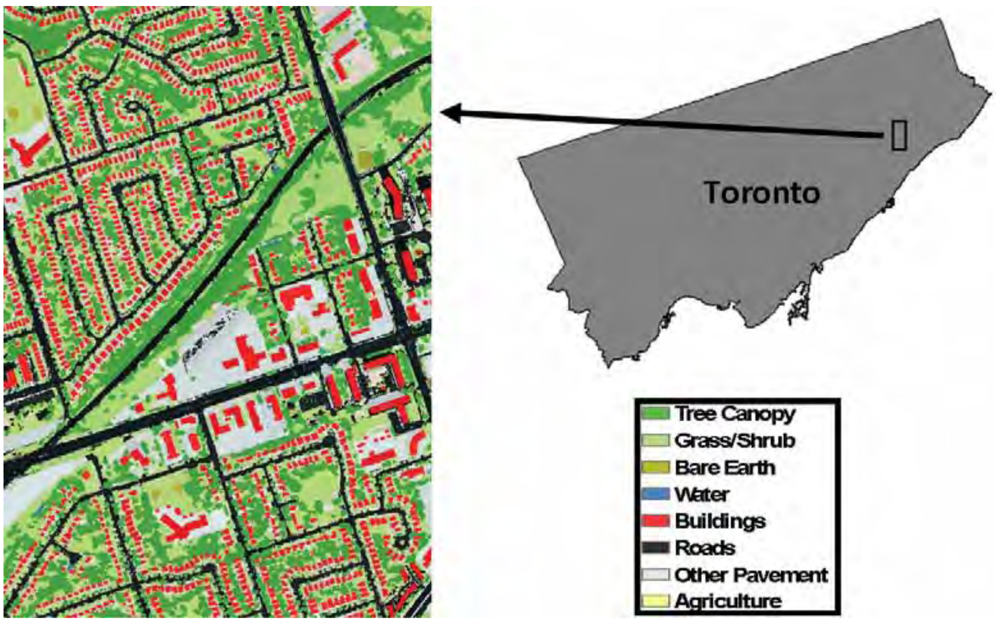


Figure 32. Area sample of digital land cover map for Toronto (Spatial Analysis Laboratory, University of Vermont).

Urban Tree Canopy (UTC) assessment uses this land cover data in conjunction with other City map layers such as parcel (property), corridor (roads) and building footprint data to produce the following tree canopy statistics:

- Existing urban tree canopy
- Possible urban tree canopy (vegetation)
- Possible urban tree canopy (impervious)

The category of impervious 'possible urban tree canopy' describes open areas consisting of impervious or paved surfaces that could potentially support additional tree canopy. An example of how this applies is the City's new "*Guidelines for Greening Surface Parking Lots*". The guidelines require that a minimum number of trees per units of parking space be incorporated in the development or redevelopment or parking lots. Industrial areas provide another example of a land use with extensive impervious cover that could potentially support additional tree canopy.

For the purposes of this report, the Urban Tree Canopy (UTC) assessment was mainly used to identify areas of opportunity for establishing additional tree canopy in the City of Toronto, defined as "*Possible UTC*". It can also be used to estimate the amount of tree loss in a planned development or set UTC improvement goals for an individual property.

Figure 33. Example of possible UTC "vegetation" (Credit: Urban Forestry)

Figure 34. Example of possible UTC "impervious" (Credit: Urban Forestry)

The land cover map and UTC report will be used to prioritize areas of opportunity for tree canopy improvements.

Although the UTC report also provided estimates of existing tree canopy, this information was not used to describe Toronto's forest cover because it was determined that the land cover map may overestimate vegetative cover for the City, including tree and shrub cover. Furthermore, it was decided that the automated classification method for mapping forest and land cover is not practical to use on a regular basis to monitor tree canopy for reasons of cost and replicability, as discussed in Appendix 4.

According to the UTC assessment, an additional 41% (263 km^2) of the city could theoretically support additional tree canopy (Table 10). Of this total area,

- 23% (150 km^2) were vegetated *Possible UTC*
- 18% (113 km^2) of the city were impervious *Possible UTC*

From a cost standpoint, the greatest areas of immediate opportunity to increase tree cover would be in the vegetation (pervious) category of *Possible UTC*. The results show that a significant proportion of *Possible UTC* (vegetation) is located in the *Single Family Residential* land use. *Open Space 1* (representing Parks and TRCA lands) are second after neighbourhoods, with 3% *Possible UTC* (vegetation). Rights of Way or road allowances follow, representing another 3% of *Possible UTC* (vegetation) across the City.

Toronto's tree canopy

Approximately 41% of Toronto's land area consists of open areas (both pervious and impervious) that could potentially support additional tree canopy:

- 23% (150km^2) is vegetated or pervious land area
- 18% (113km^2) is consists of hard or impervious land area unoccupied by trees

Table 10. Possible urban tree canopy (UTC) by land use.

Land Use	Possible UTC (Vegetation) *as % of City's land area*	Possible UTC (Impervious) *as % of City's land area*	Total Possible UTC *as % of City's land area*
Single Family Residential	9%	4%	13%
Multifamily Residential	1%	2%	3%
Commercial	1%	3%	4%
Industrial	2%	4%	6%
Institutional	2%	2%	4%
Utilities & Transportation	1%	1%	2%
Other (mainly vacant)	2%	1%	3%
Open Space 1 (Parks & TRCA lands)	3%	0%	3%
Open Space 2 (Comm/ Rec/Agr)	2%	1%	3%
Total	23%	18%	41%
Rights of Way	3%	0%	3%

Note: Rights-of-way (ROW) and land use categories are overlapping layers thus the total percentages reflect the sum of all land use and ROWs, not the City.

13% of Toronto's "possible" urban tree canopy is located in the Single Family Residential land use.

Opportunities for increasing tree cover over impervious surfaces are also high in the Single Family Residential land use at 4%, followed by industrial areas at another 4% of the City's land area. Commercial districts are another area of opportunity, representing 3% Possible UTC (impervious) in total. Figure 35 shows an example of a one of the techniques being used in the City to improve growing conditions for trees in Commercial areas. This system uses "Silvacell" technology to provide structural reinforcement for sidewalks and roads while providing increased soil volumes for root growth underground.

UTC assessment looks only at physical land cover and does not account for land use constraints that may preclude the establishment of additional forest cover. For example, sports fields in parks are counted as "Possible UTC" but are not actually available for tree planting since they have an assigned social use. The UTC assessment is intended to provide foundation data as a starting point to be followed by more detailed operational planning. The full UTC report is found in Appendix 3.

Figure 35. Silvacells being used to increase soil volumes for tree planting in a commercial area (Credit: Urban Forestry).

5.10 Forest Values and Services

5.10.1 Air Pollution Removal by Urban Trees

The urban forest intercepts 1,430 metric tones of air pollution annually, representing an equivalent value of $16.1 million per year in ecological services.

The urban forest improves air quality in five main ways by

- absorbing gaseous pollutants (ozone [O_3], nitrogen dioxide [NO_2]) through leaf surfaces
- intercepting particulate matter (e.g., dust, ash, dirt, pollen, smoke)
- reducing emissions from power generation by reducing energy consumption from heating and cooling in sheltered/shaded buildings
- releasing oxygen through photosynthesis
- transpiring water and shading surfaces, resulting in lower local air temperatures, thereby reducing O_3 levels.

Although trees do emit volatile organic compounds (VOCs) that can contribute to ozone formation, integrative studies have revealed that an increase in tree cover actually leads to reduced ozone formation[42]. In the City of Toronto, it is estimated that trees and shrubs remove 1,430 metric tonnes of air pollution (CO, NO_2, O_3, PM_{10}, SO_2) per year with an associated value of $16.1 million CND[43] (Figure 36). Shrubs also play an important role in improving air quality, contributing the equivalent of about 25% of the air quality benefits of trees in Toronto.

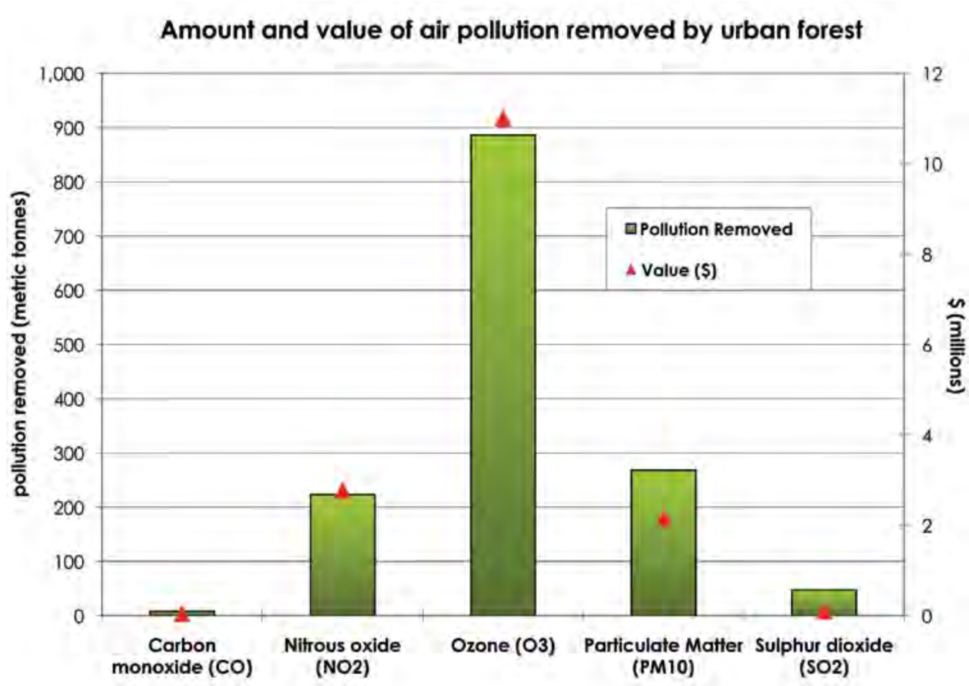


Figure 36. Amount and value of air pollution removed by urban forest.

The pollution removed by trees was compared to industrial facility emissions from Toronto for 2006 (Table 11). Total pollution removed by trees (excluding ozone which is not emitted by facilities) is 19.7% percent of the total facilities emissions based emissions data from Environment Canada's National Pollution Release Inventory. The greatest percent reduction compared to facility emission was for particulate matter less than 10 microns (PM_{10}), showing a 53.7% reduction.

42 Nowak D.J.; Dwyer, J.F. 2000. Understanding the benefits and costs of urban forest ecosystems. In: Kuser, John E., ed. Handbook of urban and community forestry in the northeast. New York: Kluwer Academics/Plenum: 11-22.

43 Based on estimated national median externality costs associated with pollutants

Table 11. Pollution removal by urban forest relative to Toronto industrial facilities emissions.

Pollutant	Urban Forest Removal (metric tonnes)	Facility Emissions (metric tonnes)	Urban Forest Effect (%)
CO	8.8	894	1.0
NO_x	262	1,576	16.6
O_3	1,040	n/a	n/a
PM_{10}	314	585	53.7
SO_2	55	195	28.0
Total (w/o O_3)	**1,680**	**3,250**	**19.7**

Large trees (>75cm diameter) intercept up to ten times more air pollution than small trees (<15cm diameter).

The size of a tree plays an important role in its ability to intercept pollutants. Large trees in Toronto (75cm+) intercept up to ten times more air pollution than small trees (<15 cm). Figure 37 shows the relationship between tree size class and the relative contribution to pollution removal.

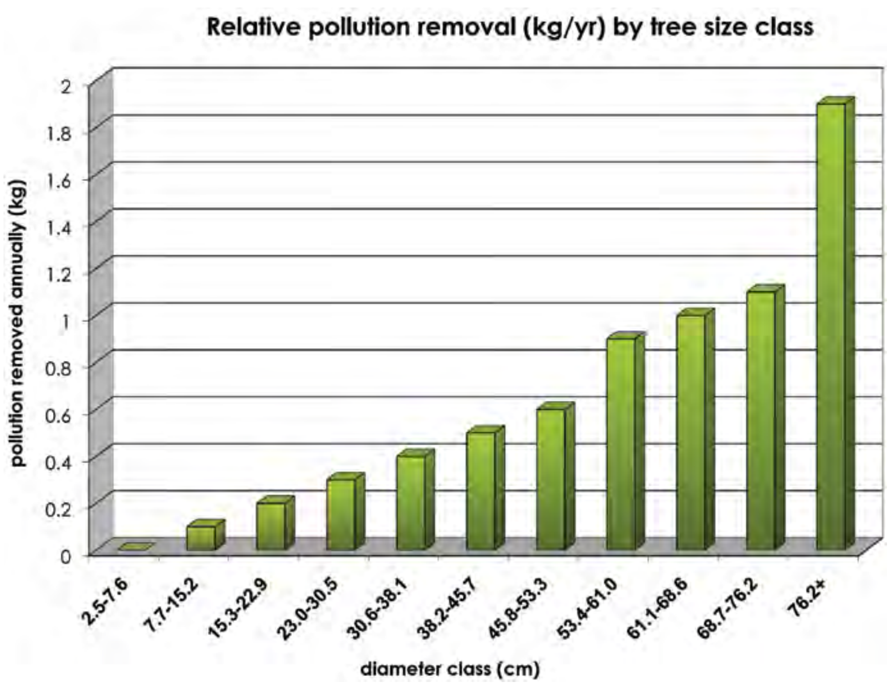


Figure 37. Annual pollution removal (kg) by tree size class.

A large tree with a diameter of 75cm can intercept up to ten times more air pollution than a small tree with a diameter of 15cm.

Different species of trees also vary in their ability to absorb or intercept air pollution. This may be a relevant consideration at a site level when choosing species composition for new tree plantings. However, the value of certain species for air pollution removal must also be balanced with site suitability and species diversity objectives in planning. Appendix 11 includes a list that ranks species according to their value for improving air quality.

5.10.2 Carbon Storage and Sequestration

Urban trees can help mitigate climate change by sequestering atmospheric carbon (from carbon dioxide) in tissue and by reducing energy use in buildings, and consequently reducing carbon dioxide emissions from fossil-fuel based power plants. The amount of carbon sequestered annually is increased with healthier trees while stored carbon is maximized in larger diameter trees.

Gross carbon sequestration by trees in Toronto is about 46,700 metric tonnes of carbon per year with an associated value of $1.3 million CND. Net carbon sequestration in

Carbon storage by Toronto's urban forest is equivalent to:

- Amount of carbon (C) emitted in the city in 29 days or
- Annual carbon emissions from 733,000 automobiles or
- Annual C emissions from 367,900 single family houses.

Toronto's urban forest stores 1.1 million metric tonnes of carbon.

the urban forest is about 36,500 metric tonnes. Net carbon sequestration can be negative if emission of carbon from decomposition is greater than the amount sequestered by healthy trees.

Trees also store carbon once they have captured it, which is of interest for mitigating climate change effects from CO_2 emissions. The longer carbon is stored in trees the less is released into the atmosphere. Trees in Toronto are estimated to store 1.1 million metric tonnes of carbon ($31.6 million CND).

Tree Canada has developed a Forest and Urban Tree Carbon Project Protocol in an effort to standardize the eligibility of measurement of carbon offset projects.

Figure 38 shows the relationship between the amount of carbon sequestered and stored relative to the size of Toronto's trees. The results show that younger (rapidly growing) trees have higher rates of carbon sequestration while larger (older) trees store proportionately more carbon. Ideally, management strives to maintain a sustainable balance between actively growing younger stock and healthy, mature trees to optimize urban forest benefits.

Large trees store more carbon (Credit: R. Burkhardt)

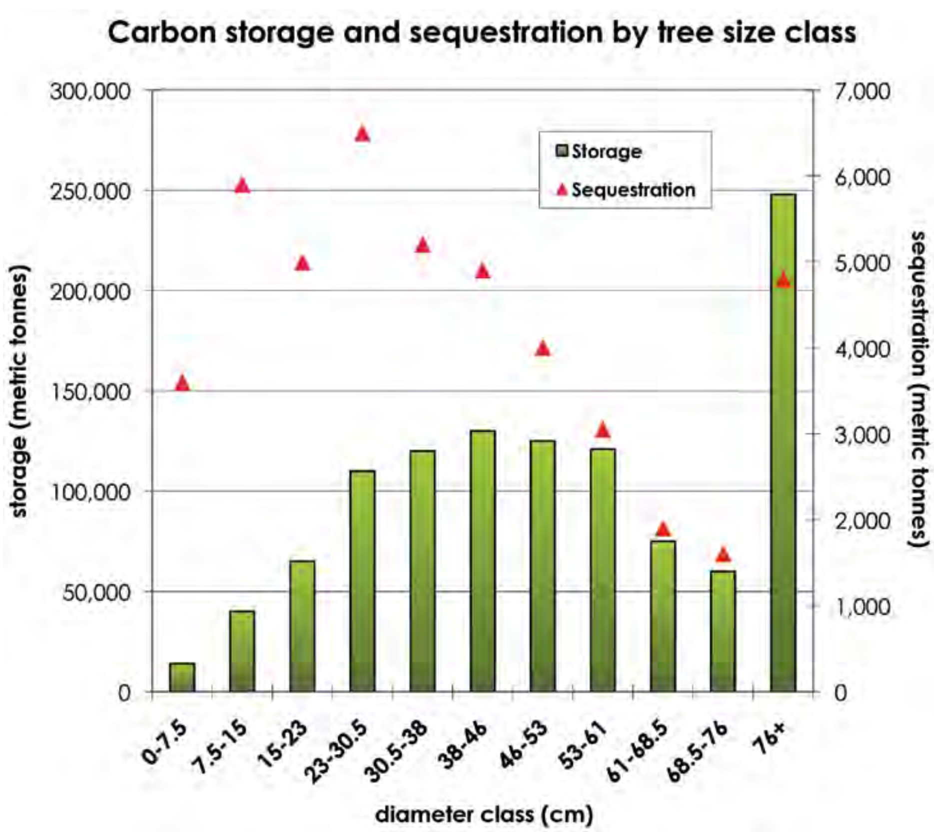


Figure 38. Carbon sequestration and storage by diameter class (cm).

While the i-Tree model provides aggregate data on carbon storage and sequestration of the entire urban forest, it cannot be used to capture the carbon value of individual urban planting sites for the purpose of "carbon offset projects". This is an area of increasing interest as governments and the private sector begin to quantify green house gas emissions (GHGs) and find ways to mitigate these. Tree Canada has developed a protocol to calculate the specific carbon value of their tree planting projects[44]. The potential role of the urban forest as related to carbon credits is being examined by the Toronto Environment office in co-operation with Urban Forestry.

5.10.3 Trees and Energy Use in Buildings

Trees modify climate and conserve energy in three principal ways[45]

1. shading reduces the amount of radiant energy absorbed and stored by built surfaces
2. transpiration converts moisture to water vapour and thus cools the air by using solar energy that would otherwise result in heating of the air
3. wind-speed reduction reduces the movement of outside air into interior spaces and heat loss where thermal conductivity is relatively high (e.g., glass windows).

These effects are maximized with the proper situation of trees on a site. Improperly situated trees can either increase or decrease building energy use in the winter months, depending on the location of trees around the building. Estimates of tree effects on energy use are based on field measurements of tree distance and direction to space-conditioned residential buildings.[46]

Based on average energy costs in 2008[47], trees in Toronto are estimated to reduce energy costs from residential buildings by $9.7 million annually. Trees also provide an additional $483,000 CND in value per year by reducing the amount of carbon released by fossil-fuel based power plants, representing a reduction of 17,000 metric tonnes of carbon emissions (Table 12). These values could be increased through more strategic tree planting to maximize the potential energy effects of trees

Table 12. Annual energy savings resulting from trees near space-conditioned buildings.

Unit	Heating	Cooling	Total Energy Savings (Heating & Cooling)	Total $ Savings (Heating & Cooling)
Million British Thermal Units (and equivalent $value)	749,000 MBTU ($6.5 million)	n/a	749,000 MBTU	$6,502,000
Megawatt-hour (and equivalent $ value)	6,400 MWH ($0.5 million)	34,800 ($2.7 million)	41,200 MWH	$3,208,000
Metric tonnes of carbon avoided (and equivalent $ value)	12,500 metric tonnes ($12,500)	4,500 ($127,200)	17,000 metric tonnes	$483,600

Tree Energy Facts

- The net cooling effect of a young, healthy tree is equivalent to ten room-sized air conditioners operating 20 hours a day (USDA Forest Service)
- Trees properly situated around buildings can reduce air conditioning needs by 30% and can save 25% of energy used in heating (USDA Forest Service, Heisler 1986)

Toronto's trees are estimated to reduce energy costs by $9.7 million annually.

44 www.treecanada.ca
45 Simpson, J.R. 1998. Urban forest impacts on regional space conditioning energy use: Sacramento County case study. Journal of Arboriculture. 24(4): 201–214.
46 McPherson, E.G.; Simpson, J.R. 1999. Carbon dioxide reduction through urban forestry: guidelines for professional and volunteer tree planters. Gen. Tech. Rep. PSW-171. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 237 p.
47 Based on 2008 electricity costs (7.79 cents/kWh) from Canada Energy.

5.10.4 Potential Insect and Disease Impacts

Various insects and diseases can infest urban forests, potentially killing trees and reducing the health, value and sustainability of the urban forest. Furthermore, global travel and trade have led to the spread of invasive pests that have no natural control mechanisms in Canada.

Four exotic pests that have been identified in Toronto were analyzed for their potential impact: Asian long horned beetle (ALHB), gypsy moth (GM), emerald ash borer (EAB), and Dutch Elm Disease (DED).

- The Asian long-horned beetle (ALHB) is an insect that bores into and kills a wide range of hardwood species. This beetle was discovered in 1996 in Brooklyn, NY and has subsequently spread. It was first reported in Toronto and Vaughan in 2003. This beetle represents a potential loss to the Toronto urban forest of $4.0 billion in structural value (42.9% of the population).
- The gypsy moth (GM) is a defoliator that feeds on many species causing widespread defoliation and tree death if outbreak conditions last several years. This pest could potentially result in damage to or a loss of $1.5 billion in structural value (16.2% of the population).
- American elm, one of the most important street trees in the 20th century, has been devastated by the Dutch elm disease (DED). Since first reported in the 1930s, it has killed over 50 percent of the native elm population in the United States. Although some elm species have shown varying degrees of resistance, Toronto could lose 1.6% of its trees to this disease ($279 million in structural value).
- The most immediate and significant threat to Toronto's trees is the Emerald Ash Borer (EAB). Since being discovered in Detroit in 2002, EAB has killed millions of ash trees in the United States. EAB has the potential to affect 8.4% of Toronto's trees ($570 million in structural value). Loss of ash trees in Toronto would reduce tree and shrub cover in the city from 19.9% to about 18.3%.

Impacts from insects and disease will create additional challenges for Toronto to meet its canopy goals.

Figure 39 summarizes the population and structural value of Toronto's urban forest at risk from these four examples of pests and disease. The significance of the potential loss not only locally but also nationally underscores the importance of maintaining rigorous forest health care programs. Toronto is working with many other partners including NRCan, Ontario Ministry of Natural Resources and Toronto and Region Conservation Authority to monitor and mitigate these forest threats.

Left: Emerald ash borer larva (Credit: City of Toronto)
Right: Emerald ash borer head (Credit: Canadian Food Inspection Agency)

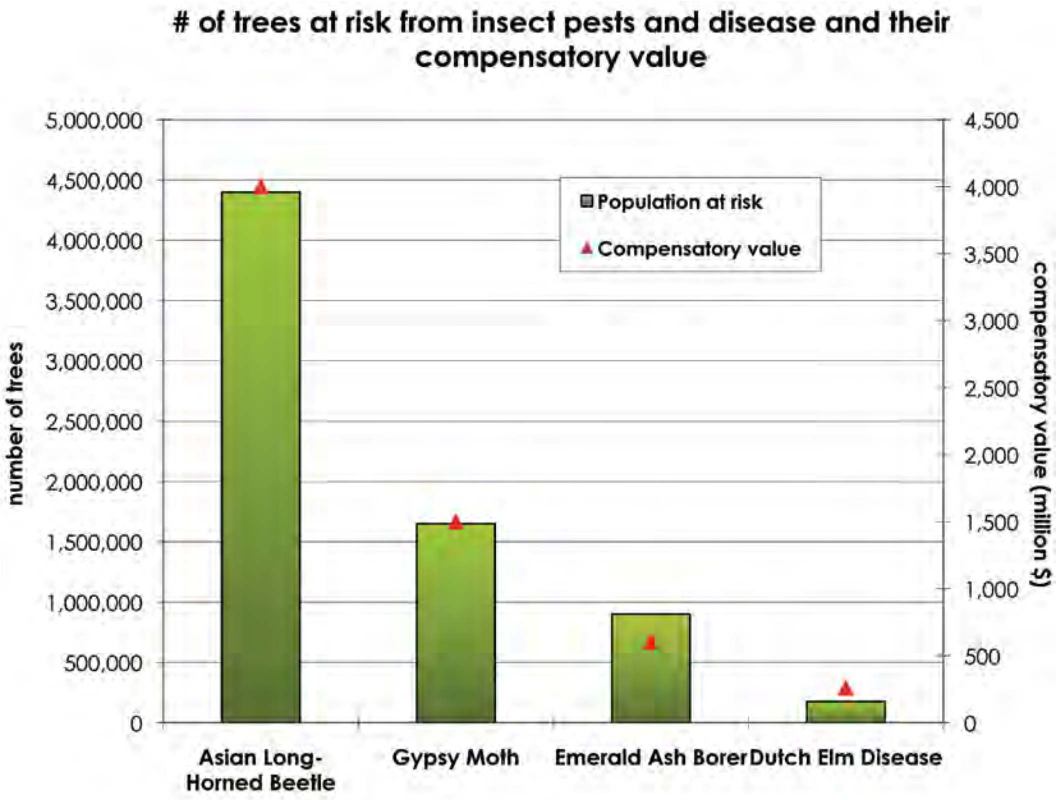


Figure 39. Number and compensatory value of trees at risk from insect pests and disease in Toronto.

The loss of ash trees from Emerald Ash Borer would reduce average tree cover in Toronto from 19.9% to 18.3%.

Injecting TreeAzin into ash trees to prevent EAB damage (Credit: City of Toronto)

Glen Stewart ravine (Credit: R. Burkhardt)

6. Conclusions and Next Steps

6.1 Toronto's Urban Forest is a Vital City Asset

Overall, the study results suggest that Toronto has a relatively healthy and regenerating urban forest despite the challenges inherent to growing trees in a highly urbanized environment. The data also suggests that active stewardship is working to improve the health and diversity of publicly-owned forests. In recent years, the rate of tree planting on public property has increased significantly and positively reflects the support of citizens and decision-makers for growing Toronto's urban forest.

Toronto's urban forest is a vital city asset

- The urban forest has a structural value of $7 billion
- It provides the equivalent of over $60 million in ecological services each year
- It offers multiple social and economic benefits to all citizens of Toronto

The structural value of Toronto's urban forest represents a staggering $7 billion. Furthermore, the environmental and social services provided by the urban forest greatly exceed the annual investment in its management. The urban forest provides over $60 million annually in ecological services, including climate change and air pollution mitigation and energy conservation benefits, plus additional storm water management services that were not quantified in this report. Urban forest benefits derived increase significantly with the increased leaf area of a tree. A 75cm tree in Toronto intercepts ten times more air pollution than a 15cm tree, can store 90 times more carbon and contributes up to 100 times more leaf area to the City's tree canopy. This highlights the importance of growing, maintaining and preserving large-stature trees, leading to the following recommendation:

1. **Strengthen tree maintenance and protection programs as per Urban Forestry Service Plan, with a particular focus on maintaining and preserving large-stature trees.**

6.2 The Tree Canopy is Changing

Renewed investment in Toronto's urban forest has occurred in the context of a growing international recognition of the importance of trees as "green infrastructure" in increasingly urbanized environments. In addition to investments in urban forestry programs, city-wide policy initiatives like the *Toronto Green Standard and Guidelines for Greening Surface Parking Lots* are being integrated into the city's planning framework in ongoing efforts to realize the goal of growing the urban forest.

Having quantitative information to describe the value of the urban forest is extremely useful information for land managers. Historic undervaluation of forests and trees in economic decision-making has made them more vulnerable to development and conversion to other uses. This has led to a widespread decline in green space and tree cover across most North American municipalities, including Toronto.

An analysis of forest cover change between1999-2005 showed that the rate of canopy gain from planting was less than the rate of loss of existing tree canopy, leading to a slight decrease in forest cover of approximately 0.1% per year. Forests are dynamic, and this analysis captures a limited measure of change over a short period of time. Nonetheless, the finding requires further investigation and monitoring and leads to the following recommendations:

The city is changing and so is the urban forest. Regular monitoring is needed to support Toronto's urban forestry objectives.

2. Examine causes of tree mortality and develop strategies for minimizing loss of new and existing tree canopy.

3. Conduct regular aerial and ground monitoring to track tree canopy development and forest condition over time.

6.3 Forest Regeneration Is Critical

It is estimated that approximately 54% of new trees in Toronto are established through natural regeneration and the remaining 46% are planted. Simulations using the i-Tree Eco "GrowOut" model showed that despite high levels of natural regeneration, forest cover would decline between 9-16% over 100 years if tree planting were discontinued. The actual rate of loss would depend on the average tree mortality rate across the City.

A second simulation looked at the question of how many trees need to be planted annually to achieve 35% forest cover in 50 years. At 2% mortality, it is estimated that the City must plant 55,000 trees per year to achieve this canopy goal. At 3% mortality, there is a four-fold increase to 200,000 trees per year to achieve the same goal.

From 2004-2009, the City planted an average of 84,000 trees a year. The study results suggest the current tree planting rates should be maintained to achieve a 35% canopy target by 2060. This leads to the following recommendation:

4. Maintain current tree planting rates on public lands in order to achieve Toronto's 30-40% canopy objective within 50 years.

Left: Tree planting in Don Valley (Credit: City of Toronto); Right: Urban Forestry Garrison Tree Nursery (Credit: R.Burkhardt)

Protection and maintenance of existing trees are a critical part of maintaining forest health and expanding the City's tree canopy. Current rates of tree planting should also continue to achieve 35% forest cover by 2060.

6.4 Opportunities for Increasing Toronto's Tree Canopy

A key product of the study was the development of a digital land and forest cover map for the entire City of Toronto. For the first time, this allows forest managers to map the spatial distribution of the tree canopy and perform area-based analysis of forest and land cover for defined geographic areas. This map also provides a valuable communication tool for decision-makers and residents who can use tree canopy maps to drive community interest in trees at a ward or neighbourhood level.

An Urban Tree Canopy (UTC) assessment used the City land cover data to provide quantitative information to identify key areas of opportunity for "Possible UTC" or tree canopy improvements. This analysis looked at both the amount of physically available pervious as well as impervious areas that could represent Possible UTC.

The data shows that the most Possible UTC is located on private property in neighbourhoods and equals approximately 13% of the City's total land area. Industrial areas were identified as having high potential for tree canopy gains in the impervious category (4% of City's land area) in addition to some pervious areas (2%). Other areas of opportunity are located in City parks and road allowances (representing 6% of the City's total land area). From a cost perspective, increasing tree cover in pervious areas with existing soils is significantly less costly than increasing tree cover over impervious surfaces.

Tree canopy gains will be most easily achieved on City property. However, the analysis does not consider how tree planting in parks is limited by other recreational land uses (sports fields, dog off-leash areas, playgrounds). Furthermore, achieving optimal tree growth in road allowances is challenging due to the difficult growing conditions and has associated management costs. The availability of this spatial data for planning leads to the following recommendation:

5. Use the results of Urban Tree Canopy (UTC) assessment in conjunction with new mapping tools to identify and prioritize locations for increasing Toronto's tree canopy.

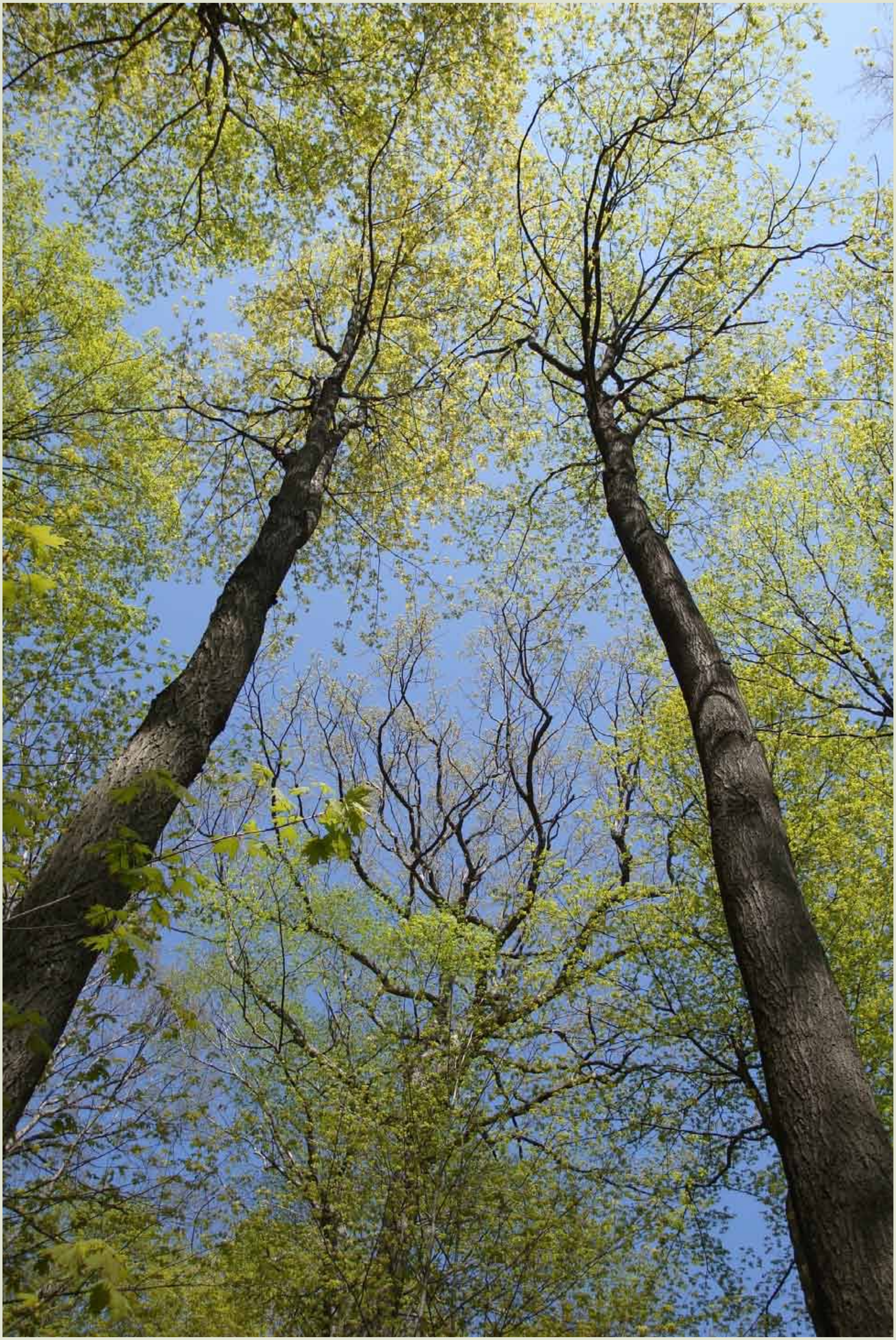
Private property owners and residents must be actively engaged in forest stewardship and tree planting efforts as part of a strategy to achieve the City's tree canopy goals.

By ownership type, it is Toronto's residents and other private land owners that control the largest percentage of the city's tree canopy. At the same time, the study data suggests that the Single Family Residential land use saw the highest degree of forest cover change relative to other land uses between 1999 and 2005. It follows that programs to engage residents and property owners in tree stewardship and incentives to plant trees are critical if Toronto is going to sustain its tree canopy in the long term.

6. Identify opportunities for increasing tree planting and stewardship on private property.

These recommendations and other issues highlighted by the study will be explored in more detail in the context of a strategic forest management plan. This report on Toronto's tree canopy also provides valuable foundation data that will help enrich the dialogue between decision-makers, planners, forest managers and the City's residents regarding the future of Toronto's urban forest.

Credit: R. Burkhardt



Appendices

Appendix 1: Generalized Land Use Map Codes

Base data: Ontario MPAC property classifications (Municipal Property Assessment Corporation)

Table 1. Generalized Land Use (GLU)Codes for Forestry Map

GLU Codes Breakdown:	
1	Residential – Single Family
3	Residential – Multi Family
4	Commercial
5	Industrial
6	Institutional
7	Utilities & Transportation
23	Other (mainly vacant and marinas)
91	Open Space 1 (Parks/TRCA lands)
100	Open Space 2 (Agriculture/Commercial/Recreational)

GLU Code	MPAC Code	Description of Property (as per Ontario Municipal Property Assessment Corporation classifications)
RESIDENTIAL - SINGLE FAMILY		
1	301	Single family detached (not on water)
1	302	More than one structure used for residential purposes with at least one of the structures occupied permanently
1	303	Residence with a commercial unit
1	304	Residence with a commercial/ industrial use building
1	305	Link home – are homes linked together at the footing or foundation by a wall above or below grade.
1	307	Community lifestyle (not a mobile home park) – Typically, a gated community. The site is typically under single ownership. Typically, people own the structure.
1	309	Freehold Townhouse/Row house – more than two units in a row with separate ownership
1	311	Semi-detached residential – two residential homes sharing a common center wall with separate ownership.
1	313	Single family detached on water – year round residence
1	314	Clergy Residence
1	322	Semi-detached residence with both units under one ownership – two residential homes sharing a common center wall.
1	332	Typically a Duplex – residential structure with two self-contained units.
1	333	Residential property with three self-contained units
1	334	Residential property with four self-contained units
1	335	Residential property with five self-contained units
1	336	Residential property with six self-contained units

GLU Code	MPAC Code	Description of Property (as per Ontario Municipal Property Assessment Corporation classifications)
1	360	Rooming or boarding house – rental by room/bedroom , tenant(s) share a kitchen, bathroom and living quarters.
1	361	Bachelorette, typically a converted house with 7 or more self-contained units
1	363	House-keeping cottages - no American plan – typically a mini resort where you rent a cabin. No package plan available. All activities, meals, etc. are extra.
1	364	House-keeping cottages - less than 50% American plan – typically a mini resort where you rent a cabin and package plans are available. Activities, meals, etc. maybe included.
1	365	Group Home as defined in Claus 240(1) of the Municipal Act, 2001 – a residence licensed or funded under a federal or provincial statute for the accommodation of three to ten persons, exclusive of staff, living under supervision in a single housekeeping un
RESIDENTIAL – MULTI FAMILY		
3	127	Townhouse block - freehold units
3	350	Row housing, with three to six units under single ownership
3	352	Row housing, with seven or more units under single ownership
3	115	Property in process of redevelopment utilizing existing structure(s)
3	125	Residential development land
3	340	Multi-residential, with 7 or more self-contained units (excludes row-housing)
3	369	Vacant land condominium (residential - improved) – condo plan registered against the land.
COMMERCIAL		
4	400	Small Office building (generally single tenant or owner occupied under 7,500 s.f.)
4	401	Large office building (generally multi - tenanted, over 7,500 s.f.)
4	402	Small Medical/dental building (generally single tenant or owner occupied under 7,500 s.f.)
4	403	Large medical/dental building (generally multi - tenanted over 7,500 s.f.)
4	405	Office use converted from house
4	406	Retail use converted from house
4	407	Retail lumber yard
4	408	Freestanding Beer Store or LCBO - not associated with power or shopping centre
4	409	Retail - one storey, generally over 10,000 s.f.
4	410	Retail - one storey, generally under 10,000 s.f.
4	411	Restaurant - conventional
4	412	Restaurant - fast food
4	413	Restaurant - conventional, national chain
4	414	Restaurant - fast food, national chain
4	415	Cinema/movie house/drive-in
4	416	Concert hall/live theatre
4	417	Entertainment complex - with a large cinema as anchor tenant
4	419	Automotive service centre, highway - 400 series highways
4	420	Automotive fuel station with or without service facilities
4	421	Specialty automotive shop/auto repair/ collision service/car or truck wash
4	422	Auto dealership

GLU Code	MPAC Code	Description of Property (as per Ontario Municipal Property Assessment Corporation classifications)
4	423	Auto dealership - independent dealer or used vehicles
4	425	Neighbourhood shopping centre - with more than two stores attached, under one ownership, with anchor - generally less than 150,000 s.f.
4	426	Small box shopping centre less than 100,000 s.f. minimum 3 box stores with one anchor (large grocery or discount store)
4	427	Big box shopping/power centre greater than 100,000 s.f. with 2 or more main anchors such as discount or grocery stores with a collection of box or strip stores and in a commercial concentration concept
4	428	Regional shopping centre
4	429	Community shopping centre
4	430	Neighbourhood shopping centre - with more than 2 stores attached, under one ownership, without anchor - generally less than 150,000 s.f.
4	431	Department store
4	432	Banks and similar financial institutions, including credit unions - typically single tenanted, generally less than 7,500 s.f.
4	433	Banks and similar financial institutions, including credit unions - typically multi tenanted, generally greater than 7,500 s.f.
4	434	Freestanding supermarket
4	435	Large retail building centre, generally greater than 30,000 s.f.
4	436	Freestanding large retail store, national chain - generally greater than 30,000 s.f.
4	438	Neighbourhood shopping centre with offices above
4	440	Hotel
4	441	Tavern/public house/small hotel
4	444	Full service hotel
4	445	Limited service hotel
4	446	Apartment hotel
4	447	Condominium Hotel Unit
4	450	Motel
4	451	Seasonal motel
4	460	Resort hotel
4	461	Resort lodge
4	462	Country inns & small inns
4	463	Fishing/hunting lodges/resorts
4	465	Child and community oriented camp/resort
4	470	Multi-type complex - defined as a large multi-use complex consisting of retail/office and other uses (multi res/condominium/hotel)
4	471	Retail or office with residential unit(s) above or behind - less than 10,000 s.f. gross building area (GBA), street or onsite parking, with 6 or less apartments, older downtown core
4	472	Retail or office with residential unit(s) above or behind - greater than 10,000 s.f. GBA, street or onsite parking, with 7 or more apartments, older downtown core
4	473	Retail with more than one non-retail use
4	475	Commercial condominium
4	476	Commercial condominium (live/work)
4	477	Retail with office(s) - less than 10,000 s.f., GBA with offices above

GLU Code	MPAC Code	Description of Property (as per Ontario Municipal Property Assessment Corporation classifications)
4	478	Retail with office(s) - greater than 10,000 s.f., GBA with offices above
4	480	Surface parking lot - excludes parking facilities that are used in conjunction with another property
4	481	Parking garage - excludes parking facilities that are used in conjunction with another property
4	482	Surface parking lot - used in conjunction with another property
4	483	Parking garage - used in conjunction with another property
4	499	Unspecified commercial property
4	704	Crematorium
4	705	Funeral Home
4	711	Bowling alley
4	713	Casino
INDUSTRIAL		
5	155	Land associated with power dam
5	500	Mines - active
5	501	Mines - inactive, including properties where closure plans invoked
5	502	Mine tailings site associated with an active mine
5	503	Mine tailings site not associated with an active mine
5	504	Oil/gas wells
5	505	Sawmill/lumber mill
5	506	Forest products - including value added plywood/veneer plants
5	510	Heavy manufacturing (non-automotive)
5	511	Pulp and paper mill
5	512	Cement/asphalt manufacturing plant
5	513	Steel mill
5	514	Automotive assembly plant
5	515	Shipyard/dry-dock
5	516	Automotive parts production plant
5	517	Specialty steel production (mini-mills)
5	518	Smelter/ore processing
5	519	Foundry
5	520	Standard industrial properties not specifically identified by other industrial Property Codes
5	521	Distillery/brewery
5	522	Grain elevators - Great Lakes waterway
5	523	Grain handling - Primary elevators (including feed mills)
5	525	Process elevators - flour mills, oilseed crushing, malt houses
5	527	Abattoir/slaughter house/rendering plants
5	528	Food processing plant
5	529	Freezer plant/cold storage
5	530	Warehousing
5	531	Mini-warehousing

GLU Code	MPAC Code	Description of Property (as per Ontario Municipal Property Assessment Corporation classifications)
5	532	Dry Cleaning Plant
5	535	Research and development facilities
5	540	Other industrial (all other types not specifically defined)
5	541	Printing plant
5	544	Truck terminal
5	545	Major distribution centre
5	550	Petro-chemical plant
5	551	Oil refinery
5	552	Tank farm
5	553	Bulk oil/fuel distribution terminal
5	575	Industrial condominium
5	580	Industrial mall
5	590	Water treatment/filtration/water towers/pumping station
5	591	Sewage treatment/waste pumping/waste disposal
5	592	Dump/transfer station/incineration plant/landfill
5	593	Gravel pit, quarry, sand pit
5	594	Peat moss operation
5	595	Heat or steam plant
5	596	Recycling facility
INSTITUTIONAL		
6	601	Post secondary education - university, community college, etc
6	602	Multiple occupancy educational institutional residence located on or off campus
6	605	School (elementary or secondary, including private)
6	608	Day Care
6	610	Other educational institution (e.g. schools for the blind, deaf, special education, training)
6	611	Other institutional residence
6	621	Hospital, private or public
6	623	Continuum of care seniors facility
6	624	Retirement/nursing home (combined)
6	625	Nursing home
6	626	Old age/retirement home
6	627	Other health care facility
6	630	Federal penitentiary or correctional facility
6	631	Provincial correctional facility
6	632	Other correctional facility
6	700	Place of worship - with a clergy residence
6	701	Place of Worship - without a clergy residence
6	730	Museum and/or art gallery
6	731	Library and/or literary institutions
6	733	Convention, conference, congress centre

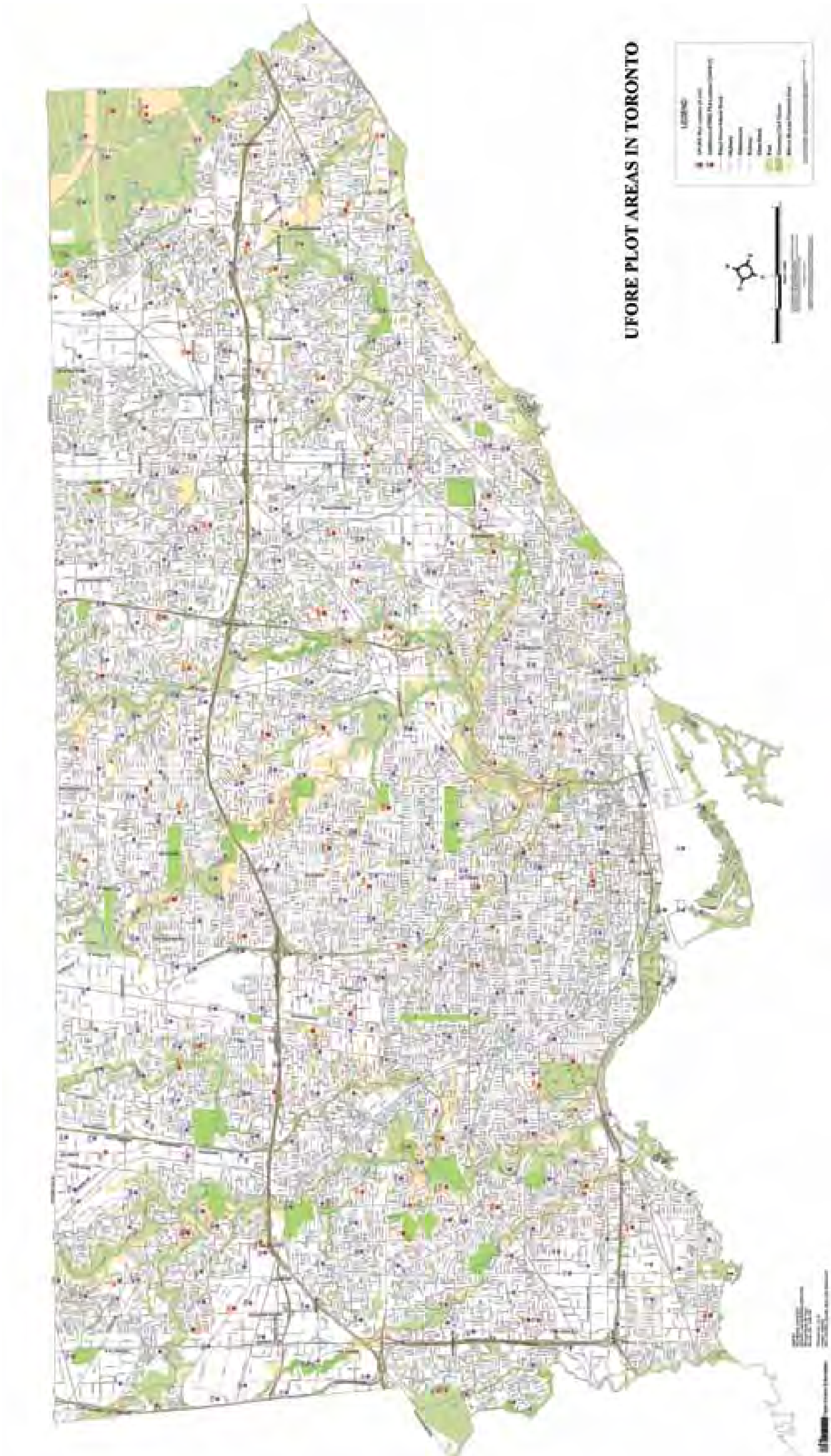
GLU Code	MPAC Code	Description of Property (as per Ontario Municipal Property Assessment Corporation classifications)
6	734	Banquet hall
6	735	Assembly hall, community hall
6	736	Clubs - private, fraternal
6	750	Scientific, pharmaceutical, medical research facility (structures predominantly other than office)
6	760	Military base or camp (CFB)
6	761	Armoury
6	762	Military education facility
6	805	Post office or depot
6	806	Postal mechanical sorting facility
6	810	Fire Hall
6	812	Ambulance Station
6	815	Police Station
6	822	Government - agricultural research facility - predominantly non farm property (office building, laboratories)
UTILITIES AND TRANSPORTATON		
7	495	Communication towers - with or without secondary communication structures
7	496	Communication buildings
7	498	Railway buildings and lands
7	555	O.P.G. Hydraulic Generating Station
7	556	O.P.G. Nuclear Generating Station
7	557	O.P.G. Fossil Generating Station
7	558	Hydro One Transformer Station
7	559	MEU Generating Station
7	560	MEU Transformer Station
7	561	Hydro One Right-of-Way
7	562	Private Hydro Rights-of-Way
7	563	Private Hydraulic Generating Station
7	564	Private Nuclear Generating Station
7	565	Private Generating Station (Fossil Fuels and Cogen)
7	566	Private Transformer Station
7	567	Wind Turbine
7	588	Pipelines - transmission, distribution, field & gathering and all other types including distribution connections
7	589	Compressor station - structures and turbines used in connection with transportation and distribution of gas
7	597	Railway right-of-way
7	598	Railway buildings and lands described as assessable in the Assessment Act
7	599	GO transit station/rail yard
7	737	Federal airport
7	738	Provincial airport
7	739	Local government airport

GLU Code	MPAC Code	Description of Property (as per Ontario Municipal Property Assessment Corporation classifications)
7	740	Airport leasehold
7	741	Airport Authority
7	742	Public transportation - easements and rights
7	743	International bridge/tunnel
7	744	Private airport/hangar
7	745	Recreational airport
7	746	Subway station
7	748	Transit garage
7	749	Public transportation - other
7	755	Lighthouses
7	824	Government - wharves and harbours
7	826	Government - special educational facility
7	828	Government - canals and locks
7	830	Government - navigational facilities
7	832	Government - historic site or monument
7	840	Port authority - port activities
7	842	Port authority - other activities
OTHER (MAINLY VACANT AND MARINAS)		
23	100	Vacant residential land not on water
23	101	Second tier vacant lot – refers to location not being directly on the water but one row back from the water
23	104	Vacant exempt land (other than parkland or Conservation Authority lands)
23	105	Vacant commercial land
23	106	Vacant industrial land
23	110	Vacant residential/recreational land on water
23	111	Island under single ownership
23	112	Multi-residential vacant land
23	113	Condominium development land - residential (vacant lot)
23	114	Condominium development land - non residential (vacant lot)
23	120	Water lot (entirely under water)
23	130	Non-buildable land (walkways, buffer/berm, storm water management pond,etc)
23	140	Common land
23	150	Mining lands - patented
23	151	Mining lands - unpatented
23	169	Vacant land condominium (residential)-defined land that's described by a condominium plan
23	240	Managed forest property, vacant land not on water
23	241	Managed forest property, vacant land on water
23	306	Boathouse with residence above
23	368	Residential Dockominium – owners receive a deed and title to the boat slip. Ownership is in fee simple title and includes submerged land and air rights associated with the slip. Similar to condominium properties, all common elements are detailed in the

GLU Code	MPAC Code	Description of Property (as per Ontario Municipal Property Assessment Corporation classifications)
23	391	Seasonal/recreational dwelling - first tier on water
23	392	Seasonal/recreational dwelling - second tier to water
23	395	Seasonal/recreational dwelling - not located on water
23	487	Billboard
23	492	Marina - located on waterfront - defined as a commercial facility for the maintenance, storage, service and/or sale of watercraft
23	493	Marina - not located on waterfront - defined as a commercial facility for the maintenance, storage, service and/or sale of watercraft
OPEN SPACE 1 (PARKS AND TRCA LANDS)		
91	102	Conservation Authority lands
91	103	Municipal park
91	107	Provincial park
91	108	Federal park
91	134	Land designated and zoned for open space
OPEN SPACE 2 (AGRICULTURAL/COMMERCIAL/RECREATION)		
100	109	Large land holdings, greater than 1000 acres
100	382	Mobile home park – more than one mobile home on a parcel of land, which is a mobile park operation.
100	486	Campground
100	489	Driving range/golf centre - stand alone, not part of a regulation golf course
100	490	Golf Course
100	491	Ski Resort
100	702	Cemetery
100	703	Cemetery with non-internment services
100	710	Recreational sport club - non commercial (excludes golf clubs and ski resorts)
100	715	Race track, auto
100	716	Racetrack - horse, with slot facility
100	717	Racetrack - horse, without slot facility
100	718	Exhibition/fair grounds
100	720	Commercial sport complex
100	721	Non-commercial sports complex
100	722	Professional sports complex
100	725	Amusement park
100	726	Amusement park - large/regional
100	200	Farm property without any buildings/structures
100	201	Farm with residence - with or without secondary structures; no farm outbuildings
100	210	Farm without residence - with secondary structures; with farm outbuildings
100	211	Farm with residence - with or without secondary structures; with farm outbuildings
100	220	Farm without residence - with commercial/industrial operation
100	221	Farm with residence - with commercial/industrial operation
100	222	Farm with a winery

GLU Code	MPAC Code	Description of Property (as per Ontario Municipal Property Assessment Corporation classifications)
100	223	Grain/seed and feed operation
100	224	Tobacco farm
100	225	Ginseng farm
100	226	Exotic farms i.e emu, ostrich, pheasant, bison, elk, deer
100	227	Nut Orchard
100	228	Farm with gravel pit
100	229	Farm with campground/mobile home park
100	230	Intensive farm operation - without residence
100	231	Intensive farm operation - with residence
100	232	Large scale greenhouse operation
100	233	Large scale swine operation
100	234	Large scale poultry operation
100	235	Government - agriculture research facility - predominately farm property
100	236	Farm with oil/gas well(s)
100	242	Managed forest property, seasonal residence not on water
100	243	Managed forest property, seasonal residence on water
100	244	Managed forest property, residence not on water
100	245	Managed forest property, residence on water
100	260	Vacant residential/commercial/ industrial land owned by a non-farmer with a portion being farmed
100	261	Land owned by a non-farmer improved with a non-farm residence with a portion being farmed
100	262	Land owned by a farmer improved with a non-farm residence with a portion being farmed

Appendix 2: i-Tree Eco (UFORE) Plot Location Map



Appendix 3: Urban Tree Canopy (UTC) Assessment Report

Prepared by: Spatial Analysis Laboratory, University of Vermont

A Report on the City of Toronto's Existing and Possible Urban Tree Canopy

Why is Tree Canopy Important?

Urban tree canopy (UTC) is the layer of leaves, branches, and stems of trees that cover the ground when viewed from above. Urban tree canopy provides many benefits to communities including improving water quality, saving energy, lowering city temperatures, reducing air pollution, enhancing property values, providing wildlife habitat, facilitating social and educational opportunities, and providing aesthetic benefits. Establishing a UTC goal is crucial for those communities seeking to improve their green infrastructure. A UTC assessment that provides the amount of tree canopy currently present (Existing UTC) along with the amount of tree canopy that could be established (Possible UTC) is the first step in the UTC goal setting process.

How Much Tree Canopy Does Toronto Have?

An analysis of Toronto's urban tree canopy based on land cover derived from high resolution satellite imagery (Figure 1) found that more than 180km^2 of the City were covered by tree canopy (termed Existing UTC) representing 28% of all land in the city[1]. An additional 42% (263 km^2) of the city could theoretically be improved (Possible UTC) to support tree canopy (Figure 2). Of the areas for Possible UTC, 18% (113 km^2) of the city were Impervious Possible UTC and another 24% (150 km^2) were Vegetated Possible UTC. Vegetated Possible UTC or grass and shrub areas are much easier for establishing new tree canopy while establishing tree canopy on Impervious Possible UTC will have a greater impact on water quality.

[1] Canopy assessment results may vary depending on the source data and methodology used. A separate study reported that Toronto has approximately 20% tree cover, based on extensive point sampling of 2005 aerial, leaf-off photography. By comparison, 2008 UFORE field data produced an estimate of 24%.

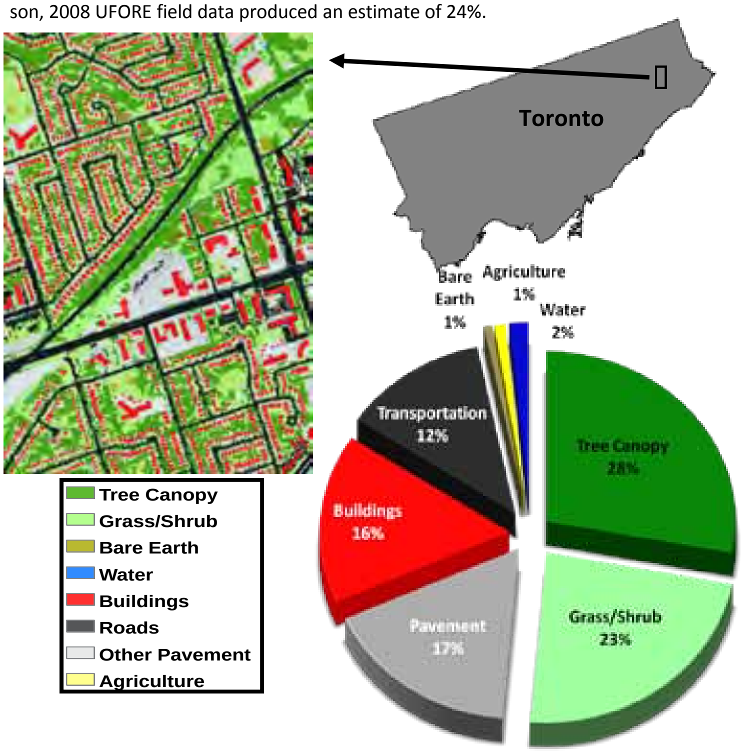


Figure 1: Land cover classes were derived from high resolution satellite imagery for the entire City of Toronto.

Project Background

The analysis of Toronto's urban tree canopy (UTC) was carried out in collaboration with the City of Toronto. The analysis was performed by the Spatial Analysis Laboratory (SAL) of the University of Vermont's Rubenstein School of the Environment and Natural Resources in consultation with the USDA Forest Service's Northern Research Station.

The goal of the project was to apply the USDA Forest Service's UTC assessment protocols to the City of Toronto. This analysis was conducted based on year 2007 data.

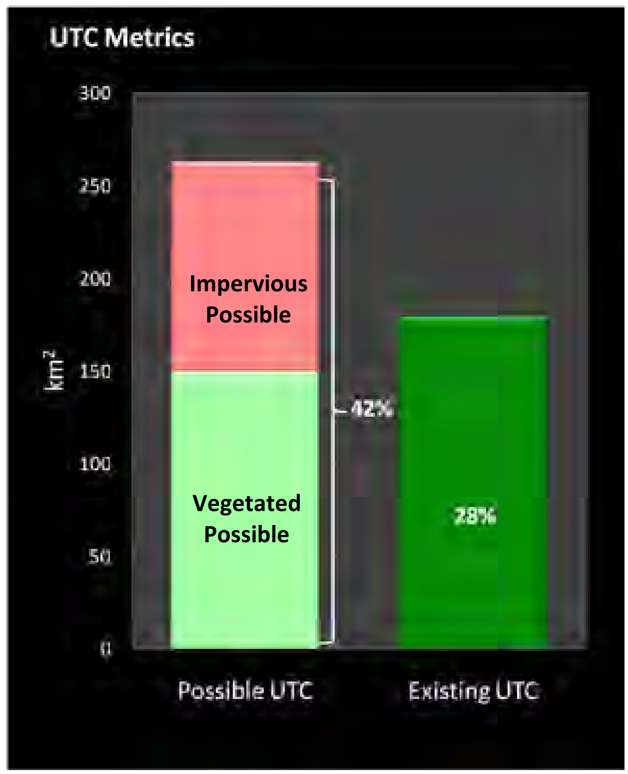


Figure 2: UTC metrics for Toronto based on % of land area covered by each UTC type.

Key Terms

UTC: Urban tree canopy (UTC) is the layer of leaves, branches, and stems of trees that cover the ground when viewed from above.

Land Cover: Physical features on the earth mapped from aerial or satellite imagery, such as trees, grass, water, and impervious surfaces.

UTC Metrics: UTC summaries (see below) based on various geographies such as parcels or neighborhoods.

Existing UTC: The amount of urban tree canopy present when viewed from above using aerial or satellite imagery.

Impervious Possible UTC: Asphalt or concrete surfaces, excluding roads and buildings, that are theoretically available for the establishment of tree canopy.

Vegetated Possible UTC: Grass or shrub area that is theoretically available for the establishment of tree canopy.

Mapping Toronto's Trees

Detailed land cover for the entire City was derived from high-resolution (0.6m) QuickBird (DigitalGlobe) satellite imagery acquired in 2007. The planimetric data (Figure 3a) and imagery (Figure 3b) were used in combination with advanced automated processing techniques, producing land cover that was mapped with such detail that single trees were detected (Figure 3c).

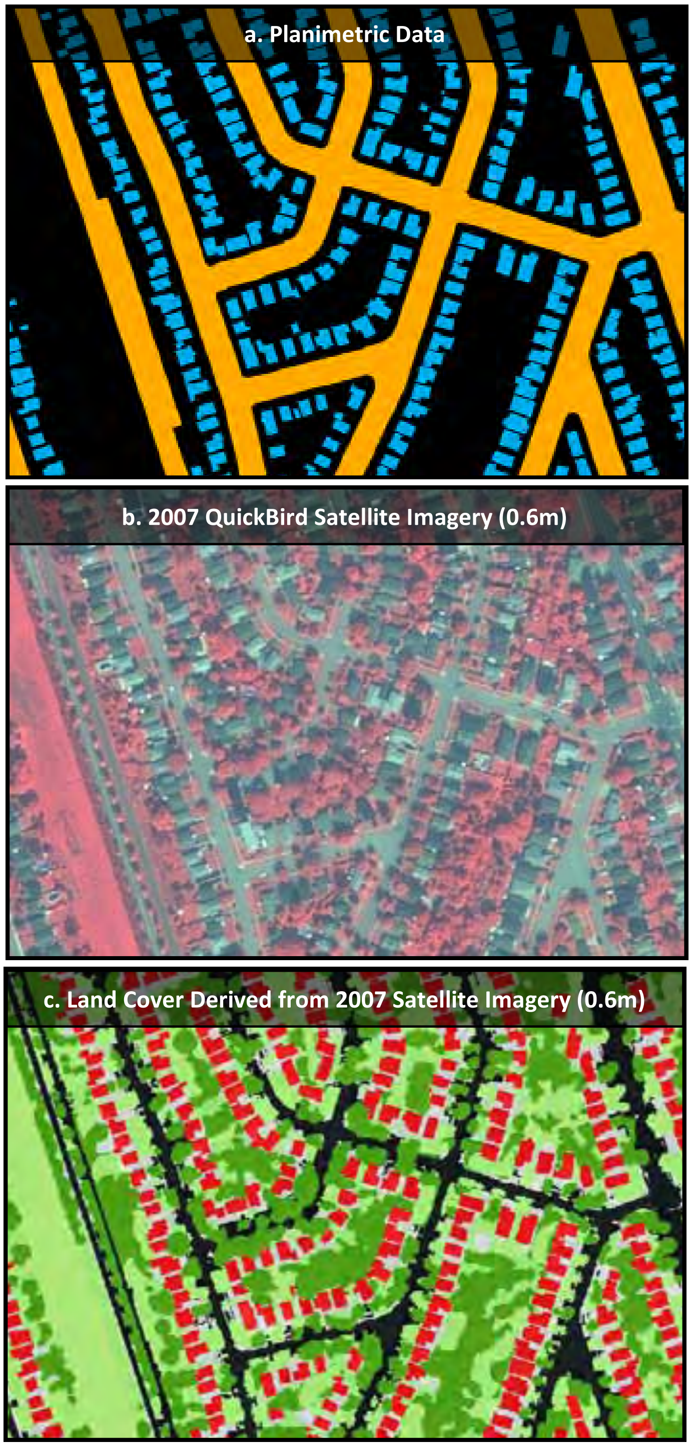


Figure 3. Land cover was derived from planimetric data (e.g. buildings and rights-of-ways) and high resolution satellite imagery using advanced automated processing techniques.

Parcel & Land Use Summary

Following the computation of the Existing and Possible UTC the UTC metrics were summarized for each property in the city's parcel database (Figure 4). For each parcel the absolute area of Existing and Possible UTC was computed along with the percent of Existing UTC and Possible UTC (UTC area / area of the parcel).

A City-wide land use layer was used to summarize UTC by land use category (Figure 5). For each land use category UTC metrics were computed as a percentage of all land in the city (% Land), as a percent of land area by zoning land use category (% Category) and as a percent of the area for the UTC type (% UTC Type). For example, land designated as "Residential Singles" has the most Existing UTC in km^2 (15% by % Land), but in terms of the percent of the land use type occupied by possible UTC vegetation, land designated for "Utilities and Transportation" (39% by % Category) has the most (Table 1).

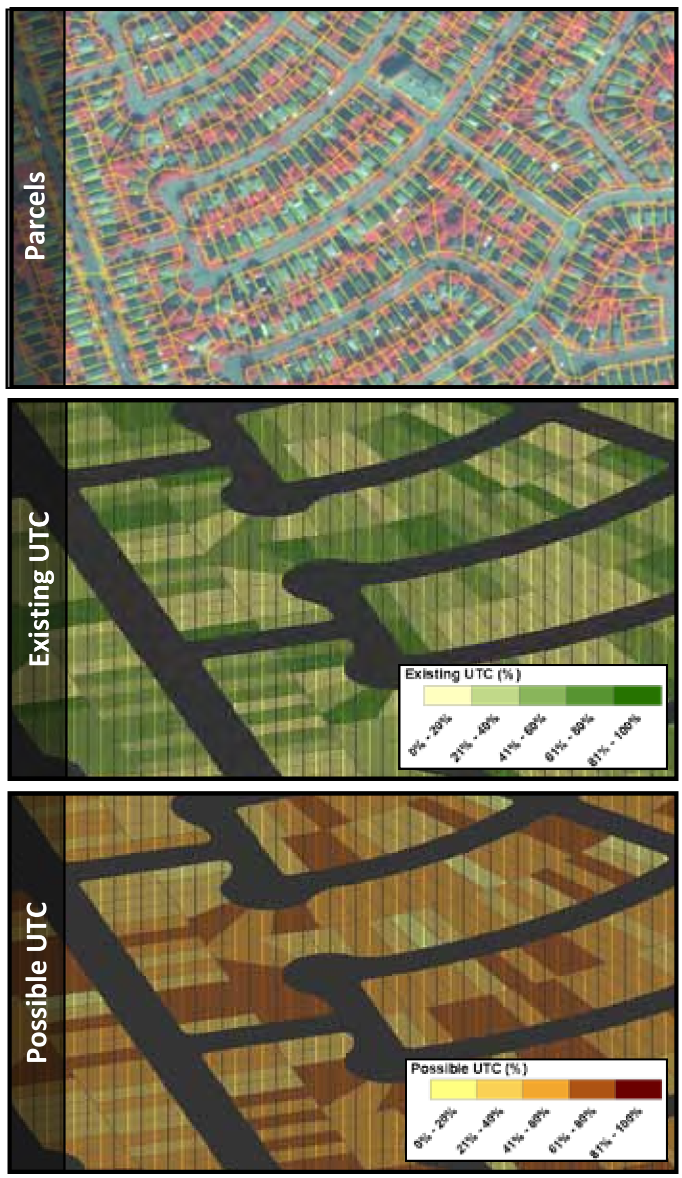


Figure 4: Parcel-based UTC metrics. UTC metrics are generated at the parcel level, allowing each property to be evaluated with respect to its Existing UTC and Possible UTC.

Figure 5: UTC metrics summarized by land use. Note: Rights-of-way (ROW) and land use categories are overlapping layers thus the total percentages reflect the sum of all land use and ROW (33%) not the City.

Land Use	Existing UTC			Possible UTC Vegetation			Possible UTC Impervious		
	% Land	% Category	% UTC Type	% Land	% Category	% UTC Type	% Land	% Category	% UTC Type
Residential Singles	15%	35%	52%	9%	21%	37%	4%	9%	22%
Residential Multifamily	1%	24%	5%	1%	18%	5%	2%	24%	9%
Commercial	0%	6%	1%	1%	10%	3%	3%	39%	15%
Industrial	1%	6%	2%	2%	16%	8%	4%	38%	24%
Institutional	1%	18%	5%	2%	34%	10%	2%	24%	9%
Utilities & Transportation	1%	16%	2%	1%	39%	6%	1%	32%	7%
Other (mainly vacant and marinas)	2%	25%	6%	2%	33%	9%	1%	22%	8%
Open Space 1 (Parks/TRCA lands)	5%	59%	19%	3%	30%	12%	0%	5%	3%
Open Space 2 (Commercial/Recreation/Agricu	2%	34%	7%	2%	36%	9%	1%	10%	3%
Rights-of-Way	5%	23%	17%	3%	15%	13%	0%	0%	0%
No Data	0%	18%	1%	0%	37%	2%	0%	19%	1%

% Land = Area of UTC type for specified land use / Area of all land

The % Land Area value of 15% indicates that 15% of Toronto's land area is tree canopy in areas where the land use is "Residential Singles."

% Category = Area of UTC type for specified land use / Area of all land for specified land use

The % Land Use value of 35% indicates that 35% of "Residential Singles" land is covered by tree canopy.

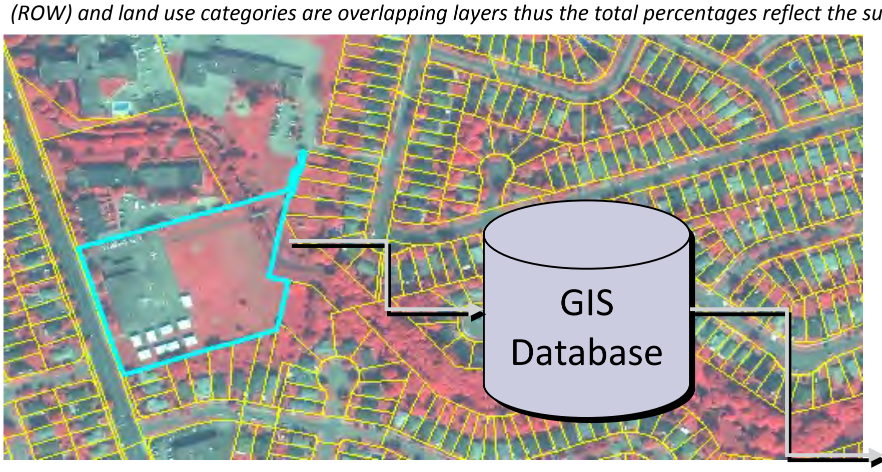
% UTC Type = Area of UTC type for specified land use / Area of all UTC type

The % UTC Type value of 52% indicates that 52% of all Existing UTC lies in areas of "Residential Singles" land use.

Table 1: UTC metrics by type, summarized by land use. For each land use category UTC metrics were computed as a percent of land in the city (% Land), as a percent of land area by land use category (% Category) and as a percent of the area for the UTC type (% UTC Type). Rights-of-way (ROW) and land use categories are overlapping layers thus the total percentages reflect the sum of all land use and ROW (33%) not the City.

Decision Support

The parcel-based UTC metrics were integrated into the city's existing GIS database. Decision makers can use GIS to find out specific UTC metrics for a parcel or set of parcels (Figure 6). This information can be used to estimate the amount of tree loss in a planned development or set UTC improvement goals for an individual property.



Attribute	Value
Parcel ID	410091
Land Use	Institutional
Legal Square Meters	20651.8
Existing UTC Area	1239.1
Existing UTC	6%
Possible UTC Area	17347.5
Possible UTC	84%
Possible UTC - Vegetation	61%
Possible UTC - Impervious	23%

Figure 6: GIS-based analysis of the parcel-based UTC metrics for decision support. In this example GIS is used to select an individual parcel. The attributes for that parcel, including the parcel-based UTC metrics, are displayed in tabular form providing instant access to relevant information.

Watersheds

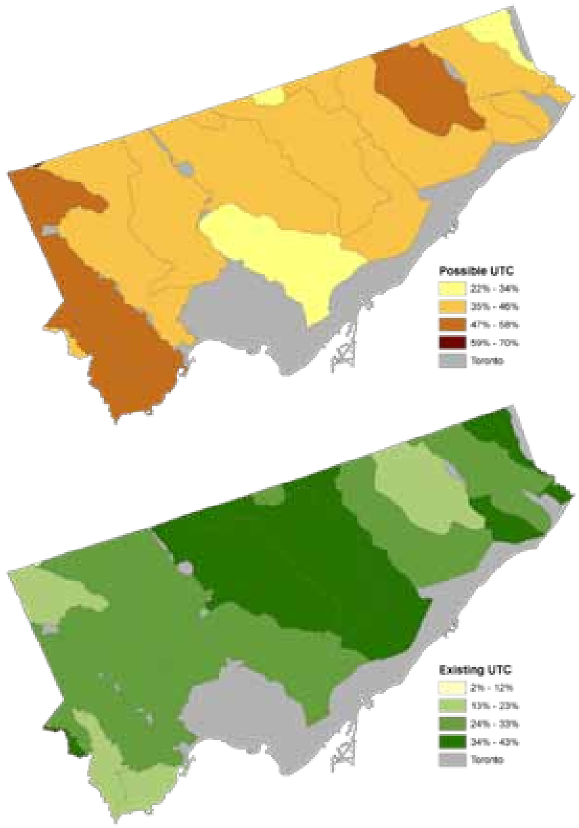


Figure 8: UTC metrics for Toronto were summarized by Toronto and Region Conservation Authority (TRCA) watersheds.

Neighborhoods

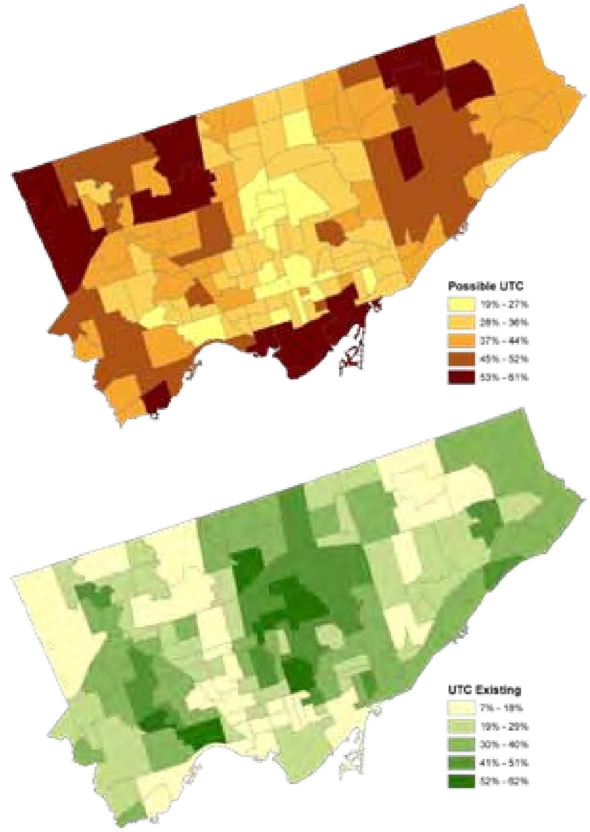


Figure 9: UTC metrics for Toronto were summarized by neighborhoods.

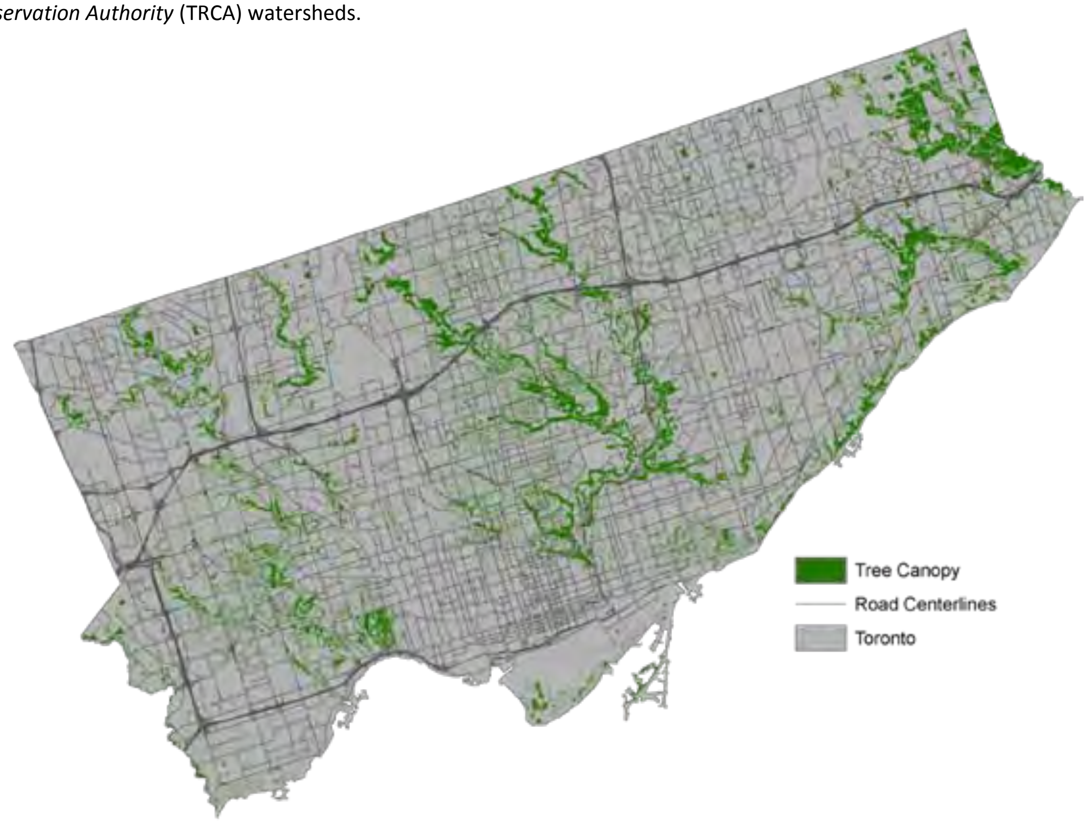


Figure 10: The distribution of major roads (e.g. collector, major and minor arteries, and expressways) and tree canopy within Toronto.

Conclusions

- Toronto's urban tree canopy is a vital city asset; reducing stormwater runoff, improving air quality, reducing the city's carbon footprint, enhancing quality of life, contributing to savings on energy bills, and serving as habitat for wildlife.
- Occupying 28% of the city's land area, Toronto has average tree canopy compared to other cities of similar size (Figure 11).
- Toronto should continue efforts toward its UTC goal. This goal should not be limited to increasing the city's overall tree canopy, it should focus on increasing tree canopy in those parcels or blocks that have the least Existing UTC and highest Possible UTC. This targeted effort can be performed using the UTC parcel database that was produced as part of this assessment.
- With Existing UTC and Possible UTC summarized at the parcel level and integrated with the City's GIS database, individual parcels and subdivisions can be examined and targeted for UTC improvement.
- Of particular focus for UTC improvement should be parcels within the city that have large contiguous impervious surfaces. These parcels contribute high amounts of runoff, degrading water quality. The establishment of tree canopy on these parcels will help to reduce runoff during periods of peak overland flow.
- By ownership type, it is Toronto's residents that control the largest percentage of the city's tree canopy. Programs that educate residents on tree stewardship and incentives provided to residents that plant trees are crucial if Toronto is going to sustain its tree canopy in the long term.
- Increases in UTC will be most easily achieved on vacant land and governmental land. These land uses have a relatively high percentage of Possible UTC and these are lands where the City can most readily implement policy.
- Parcels where the land use is "commercial" have a disproportionately low amount of their land covered by tree canopy (0%). Incentive or regulatory measures should be employed to encourage property owners to increase tree canopy on these parcels.
- Existing tree canopy is relatively low in transportation rights-of-ways (5%). Thus a "street trees" initiative should be employed to increase tree canopy in these areas.
- Neighborhood- and watershed-level summaries could be used for targeting tree planting and preservation efforts within different regions of the City.

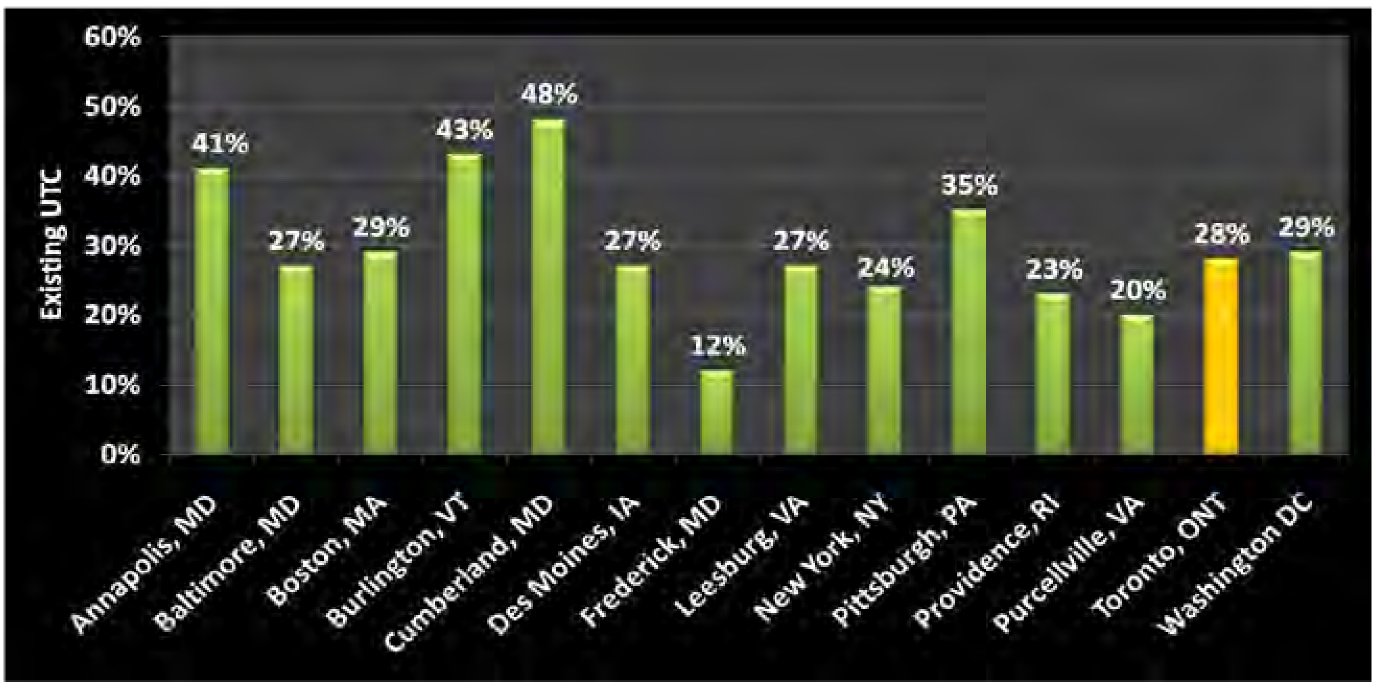


Figure 11: Comparison of Existing UTC with other selected cities that have completed UTC assessments.

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Additional Information

The study was conducted with funding from the City of Toronto and USDA Forest Service. More information on the UTC assessment project can be found at the following web site: **http://nrs.fs.fed.us/urban/utc/**

Appendix 4: Methodologies for Estimating Forest Cover

Estimating Forest Cover in Toronto

Forest cover is one of many possible indicators for measuring urban forestry program success. In light of the objective to increase Toronto's tree canopy, this study included an assessment of current forest cover in the City, comparing three different methods. These included:

- Ocular estimates of canopy cover by field crews during data collection (2008)
- 9,998 random point sample of leaf-off aerial orthophotos (imagery available in required orthorecitifed format included 1999 and 2005)
- Forest cover estimate derived through automated land cover classification using leaf-on satellite imagery (2007 Quickbird, 0.6 metre resolution)

It is important to note that every approach for estimating canopy may produce a somewhat different result, depending on the methodology and the nature/resolution of the data (leaf-on versus leaf-off, aerial photos versus satellite imagery, 20cm versus 60cm resolution, etc). This does not mean that any one estimate is necessarily incorrect, but rather that it must be interpreted in context with consideration for the expected statistical accuracy. In this case, three different methods were applied and the merits and limitations of each were assessed for the purpose of future monitoring.

Table 1 summarizes all of the known estimates of tree canopy for Toronto since 2001 and illustrates the possible variability of the results. The baseline forest cover established in this study using a sample-based method of aerial orthophoto interpretation (19.9%) is highlighted in grey.

Table 1. Methodologies and results for tree canopy assessment in Toronto.

Method	Result (% tree canopy)
USDA Forest Service - automated classification of leaf-on 2007 satellite imagery	28%
City of Toronto 2008 i-Tree Eco (UFORE) study, ocular estimates of canopy cover in 407 plots by field crews	24%
USDA Forest Service - 9,998 point sample, manual interpretation of 2005 leaf-off aerial photos	19.9%
USDA Forest Service - 9,998 point sample, manual interpretation of 1999 leaf-off aerial photos	20.6%
City of Toronto Urban Forestry –small sample size, digitized manually from 2002 aerial photos with area estimates by land use	17.5%
University of Toronto 2000 UFORE study, ocular estimates of canopy cover in 211 plots by field crews	20.5%

One of the objectives of this study was to use a statistically rigorous and easily replicable methodology to develop a baseline measure of forest cover from which to monitor future change. It was concluded that regular sampling of readily available leaf-off aerial photography is a statistically reliable and cost-effective way to assess change, recognizing that this data and method produce a more conservative estimate of forest cover than would be obtained using leaf-on imagery.

Appendix 5: i-Tree Eco (UFORE) Hydro Report Don Watershed Analysis

Prepared by: USDA Forest Service Northern Research Station

Don Watershed Analysis: i-Tree Eco (UFORE) Hydro Report

Abstract. An urban forest hydrologic model was used to simulate the effects of tree and impervious cover on the flow in the Don watershed during April through October 2007. Based on model estimates, the loss of existing tree cover (15.7%) would increase total stream flow by 2.1%, while loss of existing impervious cover (47.8%) would reduce stream flow by 23.8%. Increasing tree cover will reduce stream flow, but the dominant cover type influencing stream flow is impervious surfaces. Overall, impervious cover had a 12 fold impact relative to tree cover. Increasing impervious cover by 1% averaged a 2.2% increase in stream flow, while increasing tree cover by 1% averaged only a 0.2% decrease in stream flow.

Introduction

The Don watershed (460 km^2) in the Toronto area (Figure 1) was analyzed using the UFORE-Hydro model (Wang et al., 2008). UFORE-Hydro is a semi-distributed, physical-based model created to simulate and study tree effects on urban hydrology. The model simulates the stream flow hydrograph using hourly precipitation data, digital elevation data and cover parameters. The model flow is calibrated against actual stream flow values.

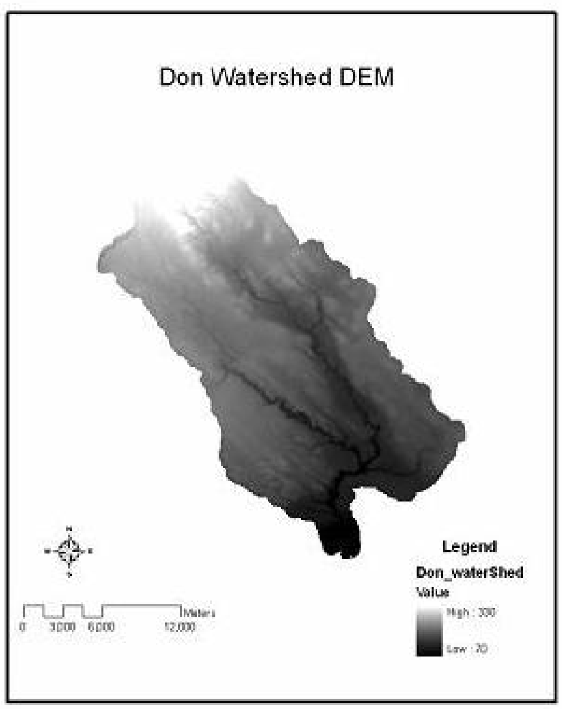


Figure 2. Relative elevation in Don watershed

The precipitation data were collected from a weather station at Toronto City (climate ID: 6158355; WMO ID: 71508). The digital elevation model data were obtained from the

Toronto Regional Conservation Authority. Tree and impervious cover parameters were derived from photo-interpretation of Google Earth imagery (images dates circa 2005) using 500 randomly located points:

- Impervious cover = 47.8%
- Tree cover = 15.7%
- Grass and shrub cover = 27%
- Bare soil = 9%

In addition, field data from Toronto were used to estimate the tree canopy leaf area index (5.1) and percent of impervious cover connected to the stream was estimated at 40%. The model was calibrated using hourly stream flow data collected at the gauge at Don River at Tormorden (02HC024) from April 1st 2007 to October 31st 2007. Model calibration indicated a reasonably good fit to the measured flow data. The calibration coefficients of the model were (1.0 = perfect fit):

- Peak flow weighted = 0.39
- Base flow weighted = 0.31
- Balance flow (peak and base) = 0.52

After calibration, the model was run a number of times under various conditions to see how the stream flow would respond given varying tree and impervious cover in the watershed. For tree cover simulations (Figure 2), impervious cover was held constant (47.8%) with tree cover varying between 0 and 100%. Increasing tree cover was assumed to fill bare soil spaces first, then grass and shrub covered areas, and then finally impervious covered land. At 100% tree cover, all impervious land is cover by trees. This assumption is unreasonable as all buildings, road and parking lots would be cover by trees, but the results illustrate the potential impact. Reductions in tree cover were assumed to be filled with grass and shrub cover.

For impervious cover simulations (Figure 3), tree cover was held constant (15.7%) with impervious cover varying between 0 and 100%. Increasing impervious cover was assumed to fill bare soil spaces first, then grass and shrub covered areas, and then finally under tree canopies. The assumption of 100% impervious cover is unreasonable, but the results illustrate the potential impact. In addition, as impervious increased from the current conditions, so did the percent of the impervious cover connected to the stream such that at 100% impervious cover, all (100%) impervious cover is connected to the stream. Reductions in impervious cover were assumed to be filled with grass and shrub cover.

Results

<u>Tree Cover Effects</u>: Loss of current tree cover would increase total flow during the simulation period by an average of 2.1% (943,000 m^3) (Figure 2). Doubling of canopy cover would reduce overall flow by another 2.5% (1.1 million m^3) during this 7 month period. Increasing tree cover reduces flow base flow, as well as flow regenerated from both pervious and impervious areas.

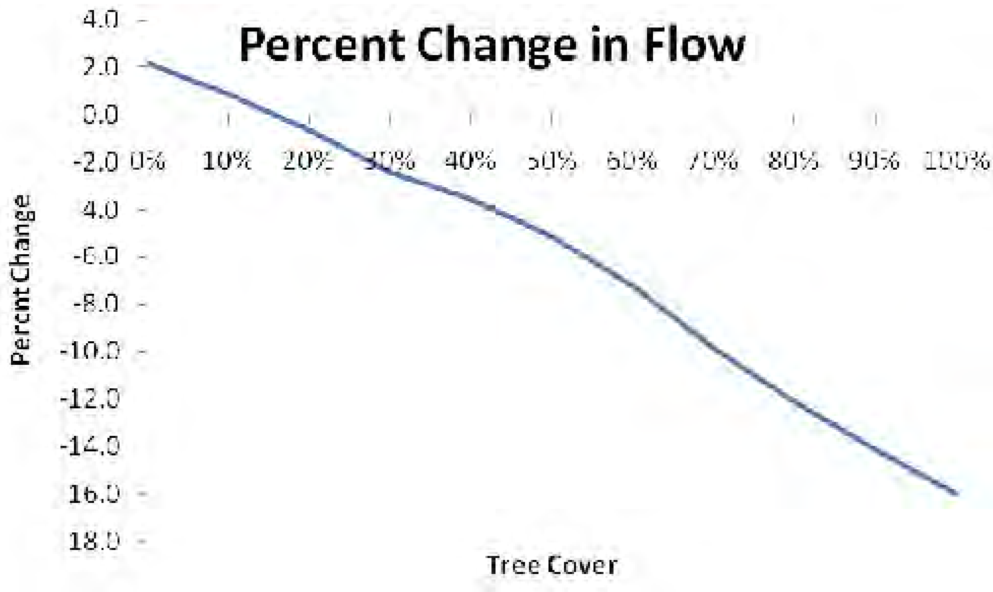


Figure 3. Percent change in stream flow given varying percent tree cover in Don watershed.

Impervious Cover Effects: Removal of current impervious cover would reduce total flow during the simulation period by an average of 23.8% (10.5 million m^3) (Figure 3). Increasing impervious cover from 47.8% to 60% of the watershed would increase total flow another 30% (13.3 million m^3) during this 7 month period. Increasing impervious cover reduces base flow while significantly increasing flow from impervious surfaces (Figure 4).

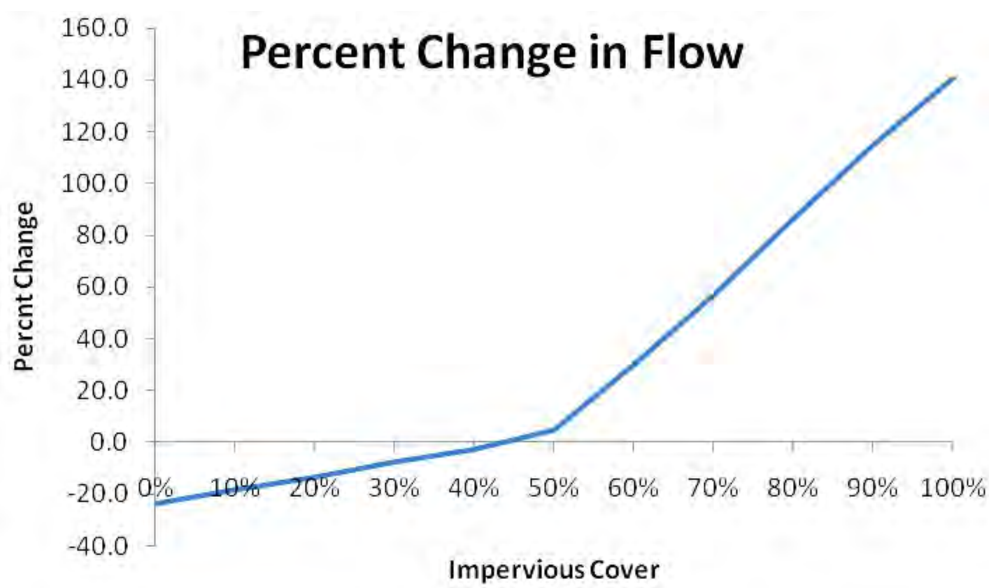


Figure 4. Percent change in stream flow given varying percent impervious cover in Don watershed.

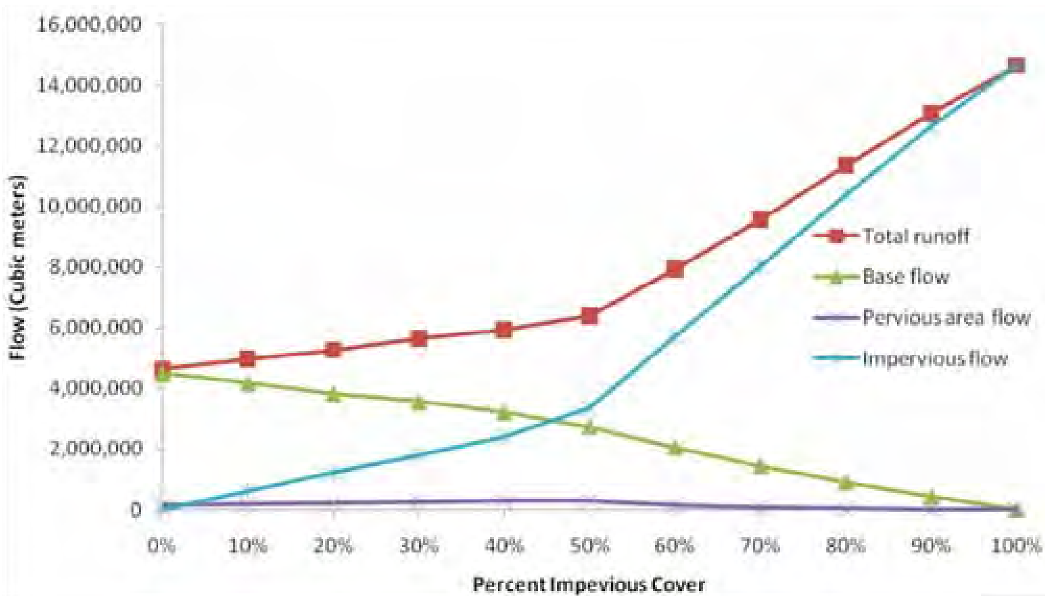


Figure 5. Partitioning of total stream flow components given varying percent impervious cover in Don watershed.

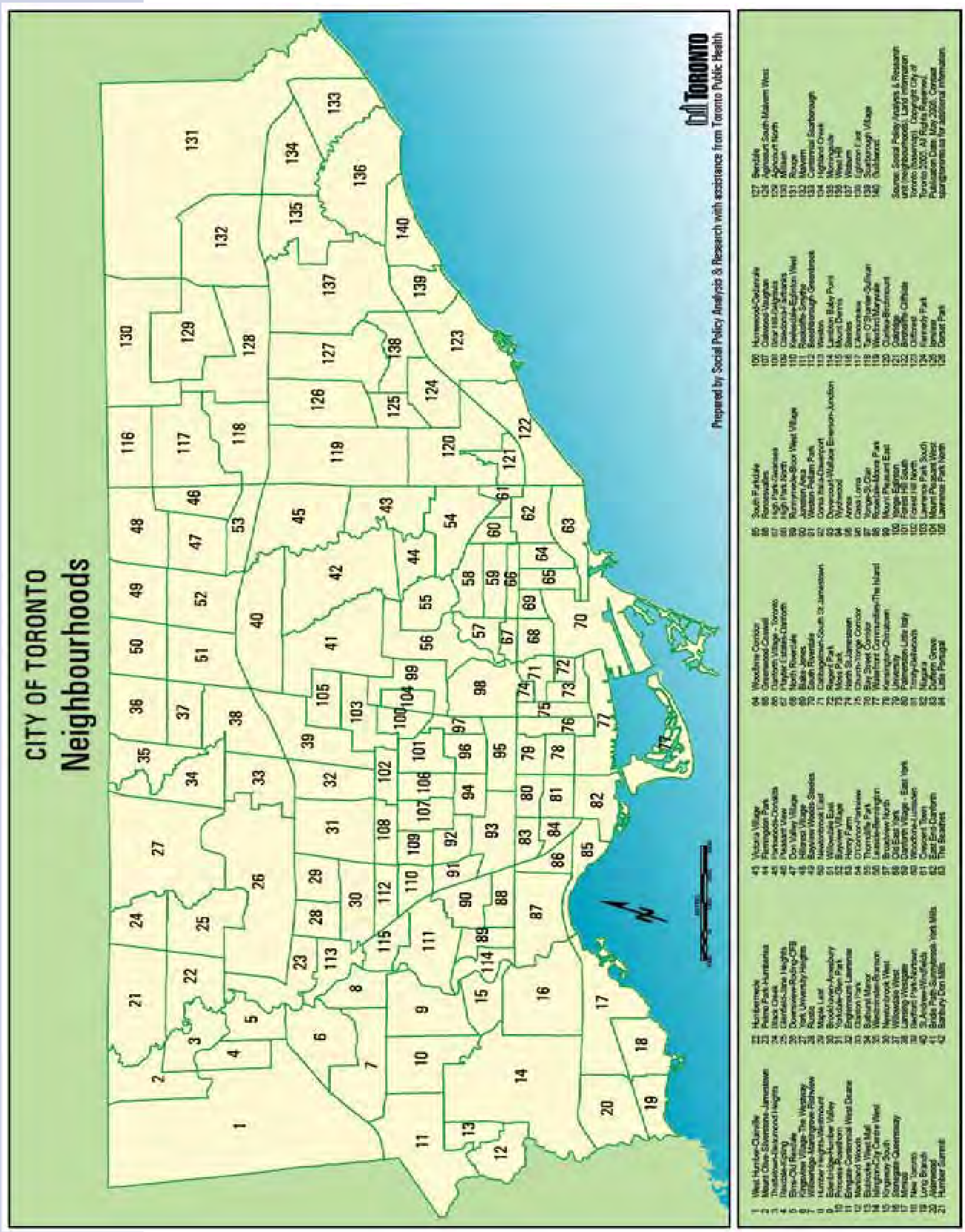
Increasing tree cover will reduce stream flow, but the dominant cover type influencing stream flow is impervious surfaces. Overall impervious cover had a 12 fold impact relative tree cover. Increasing impervious cover by 1% averaged a 2.2% increase in stream flow, while increasing tree cover by 1% averaged only a 0.2% decrease in stream flow.

During the simulation period the total rainfall recorded at the Toronto City was 315.1 mm. Since that amount is assumed to have fallen over the entire 460 sq. km watershed, a total of 144.9 million cubic meters of rain fell on the watershed during the simulation time. The total flow in Don watershed throughout the simulation time was 43.9 million cubic meters. The total flow is the made up of surface runoff and baseflow (water that travels underground to the stream). Baseflow and flow from impervious areas are the biggest contributors to stream flow with 47.5% and 47.3% of total flow generated from base and impervious surfaces respectively. Flow from pervious areas was only estimated to generate 5.2% of total flow. Trees intercepted a little more than 17% of the precipitation that fell in their canopy areas, but since their crowns only cover about 16% of the watershed, they only intercepted about 2.7% of the total rainfall. Trees intercepted 24.9 million cubic meters of precipitation, and short vegetation, including shrubs, intercepted 8.4 million cubic meters. About 47% of total precipitation is estimated to re-enter the atmosphere through evaporation or evapotranspiration.

References

Wang, J., T.A. Endreny, and D.J. Nowak. 2008. Mechanistic simulation of urban tree effects in an urban water balance model. Journal of American Water Resource Association. 44(1):75-85.

Appendix 6: Average Tree Cover in Toronto Neighbourhoods



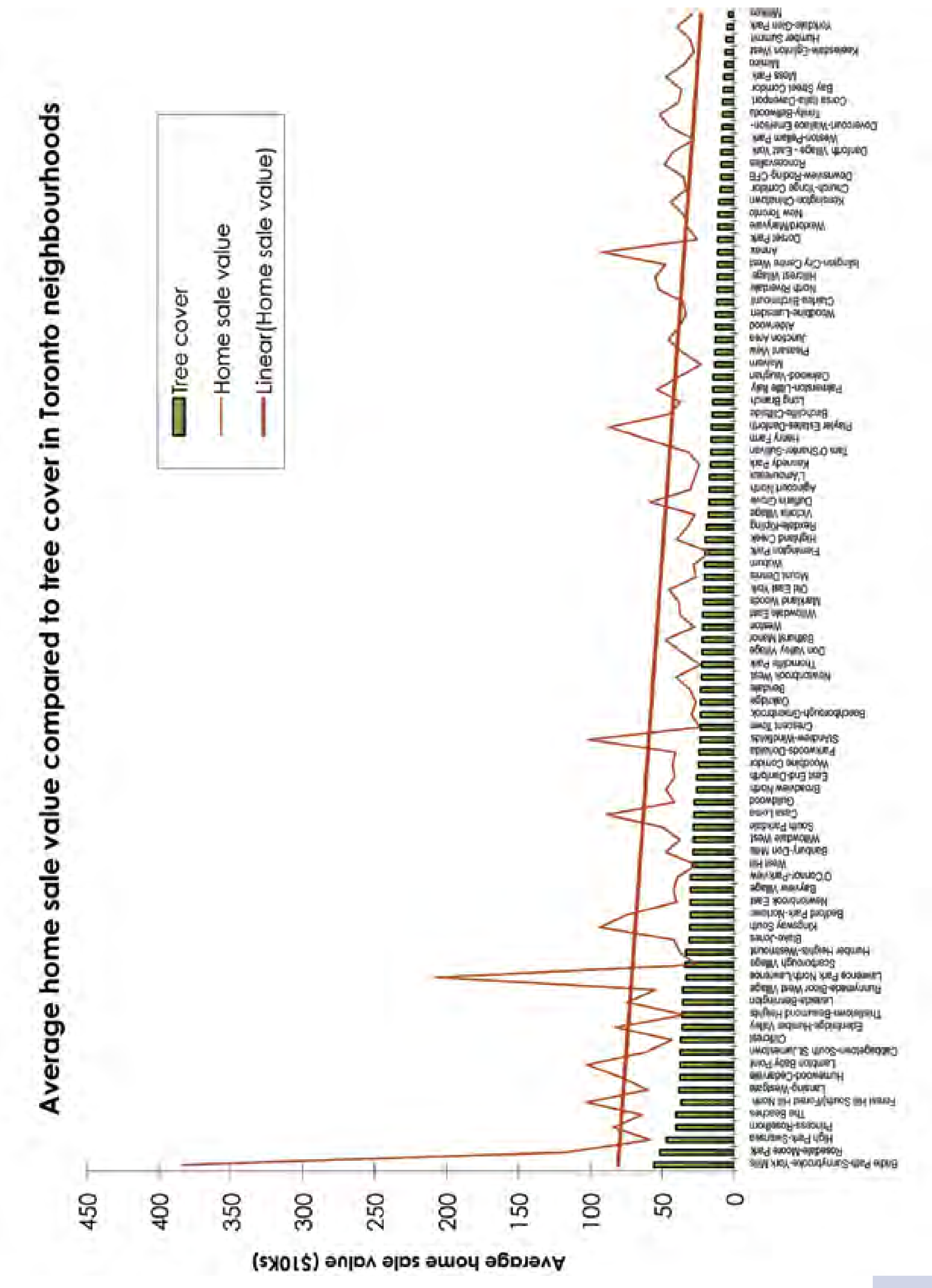
Neighbourhood Name & Number	Average tree cover (%)	Standard Error	n (sample size)
Agincourt North (129)	16.7	3.6	108
Agincourt South-Malvern West (128)	13.9	3.1	122
Alderwood (20)	12.9	3.6	85
Annex (95)	11.1	5.2	36
Banbury-Don Mills (42)	28.5	3.7	151
Bathurst Manor (34)	22.1	5	68
Bay Street Corridor (76)	7.3	3.5	55
Bayview Village (52)	30.1	5.4	73
Bayview Woods-Steeles (49)	31.3	5.8	64
Bedford Park-Nortown (39)	30.2	4.5	106
Beechborough-Greenbrook (112)	23.1	5.8	52
Bendale (127)	23.1	3.9	117
Birchcliffe-Cliffside (122)	14.9	3.8	87
Black Creek (24)	13.2	4.1	68
Blake-Jones (69)	31	7.1	42
Briar Hill-Belgravia (108)	13.9	5.8	36
Bridle Path-Sunnybrooke-York Mills (41)	55.6	4.1	144
Broadview North (57)	25.7	7.4	35
Brookhaven-Amesbury (30)	16.4	4.5	67
Cabbagetown-South StJamestown (71)	37.3	6.8	51
Caledonia-Fairbanks (109)	16	5.2	50
Casa Loma (96)	27.7	6.5	47
Centennial Scarborough (133)	24.1	4.6	87
Church-Yonge Corridor (75)	9.3	4.4	43
Clairlea-Birchmount (120)	12	3.2	100
Clanton Park (33)	12.5	3.9	72
Cliffcrest (123)	37.1	5.1	89
Corsa Italia-Davenport (92)	7.7	3.7	52
Crescent Town (61)	23.1	6.7	39
Danforth Village - East York (59)	8.8	4.9	34
Danforth Village - Toronto (66)	14.3	5.4	42
Don Valley Village (47)	22.1	4.5	86
Dorset Park (126)	11.1	3.3	90
Dovercourt-Wallace Emerson-Junction (93)	8.1	3.5	62
Downsview-Roding-CFB (26)	9	2	210
Dufferin Grove (83)	17.1	5.9	41
East End-Danforth (62)	25.7	7.4	35
Edenbridge-Humber Valley (9)	36	5.2	86
Eglinton East (138)	14.9	4.4	67
Elms-Old Rexdale (5)	16.7	6.2	36
Englemount-Lawrence (32)	16.3	5.3	49

Neighbourhood Name & Number	Average tree cover (%)	Standard Error	n (sample size)
Eringate-Centennial-West Deane (11)	12.1	2.8	132
Etobicoke West Mall (13)	10.4	4.4	48
Flemington Park (44)	20	6.3	40
Forest Hill North (102)	34.1	7.1	44
Forest Hill South (101)	39	7.6	41
Glenfield-Jane Heights (25)	15.7	4	83
Greenwood-Coxwell (65)	8.2	3.9	49
Guildwood (140)	27.5	6.2	51
Henry Farm (53)	15.6	5.4	45
High Park North (88)	30.9	6.2	55
High Park-Swansea (87)	46.9	5.1	96
Highland Creek (134)	20	4.5	80
Hillcrest Village (48)	11.5	3.6	78
Humber Heights-Westmount (8)	33.3	7.5	39
Humber Summit (21)	5.5	2.4	91
Humbermede (22)	6.9	3.3	58
Humewood-Cedarvale (106)	37.5	8.6	32
Ionview (125)	15.6	6.4	32
Islington-City Centre West (14)	11.4	2	246
Junction Area (90)	13	4.6	54
Keelesdale-Eglinton West (110)	5.9	4	34
Kennedy Park (124)	16.2	6.1	37
Kensington-Chinatown (78)	10.4	4.4	48
Kingsview Village-The Westway (6)	11	3.7	73
Kingsway South (15)	30.6	6.6	49
Lambton Baby Point (114)	37.5	7	48
L'Amoureaux (117)	16.7	3.5	114
Lansing-Westgate (38)	38.3	5.4	81
Lawrence Park North (105)	35	7.5	40
Lawrence Park South (103)	31.3	6.7	48
Leaside-Bennington (56)	35.6	5.6	73
Little Portugal	2.4	2.4	42
Long Branch (19)	14.7	6.1	34
Malvern (132)	13.3	2.8	143
Maple Leaf (29)	22	5.9	50
Markland Woods (12)	21.2	5.7	52
Milliken (130)	3.5	1.4	173
Mimico (17)	6.2	2.4	97
Morningside (135)	43.8	5.5	80
Moss Park (73)	6.8	3.8	44
Mount Dennis (115)	20.5	6.5	39

Neighbourhood Name & Number	Average tree cover (%)	Standard Error	n (sample size)
Mount Olive-Silverstone-Jamestown (2)	23.7	4.9	76
Mount Pleasant East (99)	61.9	7.5	42
Mount Pleasant West (104)	7	3.9	43
New Toronto (18)	10.9	4.6	46
Newtonbrook East (50)	30.2	5.8	63
Newtonbrook West (36)	22.5	4.4	89
Niagara (82)	11.1	4.3	54
North Riverdale (68)	11.8	5.5	34
North StJamestown (74)	8.8	4.9	34
Oakridge (121)	23.1	5.8	52
Oakwood-Vaughan (107)	14.5	4.8	55
O'Connor-Parkview (54)	30	5.1	80
Old East York (58)	20.9	6.2	43
Palmerston-Little Italy (80)	14.6	5.1	48
Parkwoods-Donalda (45)	24.3	4.2	103
Pelmo Park-Humberlea (23)	13.1	4.3	61
Playter Estates-Danforth (67)	15.4	5.8	39
Pleasant View (46)	13.2	5.5	38
Princess-Rosethorn (10)	40.3	6.2	62
Regent Park (72)	13.5	5.6	37
Rexdale-Kipling (4)	19.4	6.6	36
Rockcliffe-Smythe (111)	22.5	4.4	89
Roncesvalles (86)	8.9	4.2	45
Rosedale-Moore Park (98)	51.5	6.1	68
Rouge (131)	27.3	1.7	656
Runnymede-Bloor West Village (89)	35.6	7.1	45
Rustic (28)	21.6	5.8	51
Scarborough Village (139)	34	6.9	47
South Parkdale (85)	28.2	7.2	39
South Riverdale (70)	10.6	2.5	151
StAndrew-Windfields (40)	23.4	3.7	128
Steeles (116)	5.3	2.6	76
Stonegate-Queensway (16)	16.5	3.5	115
Tam O'Shanter-Sullivan (118)	15.9	3.9	88
The Beaches (63)	40.3	6.2	62
Thistletown-Beaumond Heights (3)	36	6.8	50
Thorncliffe Park (55)	22.4	6	49
Trinity-Bellwoods (81)	7.7	3.7	52
University (79)	19.4	6.6	36
Victoria Village (43)	17.7	4.3	79
Waterfront Communities-The Islands (77)	8	1.9	201

Neighbourhood Name & Number	Average tree cover (%)	Standard Error	n (sample size)
West Hill (136)	28.8	3.6	156
West Humber-Clairville (1)	6.1	1.1	475
Westminster-Branson (35)	21.2	5.7	52
Weston (113)	21.7	6.1	46
Weston-Pellam Park (91)	8.3	4	48
Wexford/Maryvale (119)	11	2.3	181
Willowdale East (51)	21.6	4.8	74
Willowdale West (37)	28.3	6.2	53
Willowridge-Martingrove-Richview (7)	22.1	4.5	86
Woburn (137)	20.4	3	186
Woodbine Corridor (64)	24.5	5.9	53
Woodbine-Lumsden (60)	12.8	5.4	39
Wychwood (94)	14.3	5	49
Yonge-Eglinton (100)	25	6.3	48
Yonge-StClair (97)	23.4	6.2	47
York University Heights (27)	6.7	1.7	223
Yorkdale-Glen Park (31)	4.9	2.4	82

Appendix 7: Average Home Sale Value Compared to Average Tree Cover in Toronto Neighbourhoods



Appendix 8: Complete List of Tree Species by % of Population and % of Leaf Area

Importance value (IV) where IV = % pop + % leaf area

Genus	Species	Common Name	% Population	% Leaf Area	IV (%Pop + %LA)
Abies	balsamea	Balsam fir	0.1	0.1	0.2
Abies	concolor	White fir	0.1	0.1	0.2
Acer	campestre	Hedge maple	0.1	0.1	0.2
Acer	ginnala	Amur maple	0.1	0.1	0.2
Acer	negundo	Boxelder	5	5.5	10.5
Acer	nigrum	Black maple	0.5	1	1.5
Acer	palmatum	Japanese maple	0.3	0.1	0.4
Acer	platanoides	Norway maple	6.5	14.9	21.4
Acer	rubrum	Red maple	0.2	0.8	1
Acer	saccharinum	Silver maple	0.9	4.5	5.4
Acer	saccharum	Sugar maple	10.2	11.6	21.8
Acer	x freemanii	Freeman maple	0.1	0.3	0.4
Aesculus	hippocastanum	Horsechestnut	0.1	0.2	0.3
Ailanthus	altissima	Tree of heaven	0.7	0.7	1.4
Alnus	glutinosa	European alder	0.2	0.1	0.3
Alnus	incana	Grey alder	0.4	0.1	0.5
Amelanchier	alnifolia	Western service berry	0.1	0	0.1
Amelanchier	arborea	Downy serviceberry	0.5	0.1	0.6
Amelanchier	canadensis	Eastern service berry	0.3	0	0.3
Amelanchier	laevis	Smooth service berry	0	0	0
Aralia	spinosa	Devils walking stick	0.1	0	0.1
Betula	alleghaniensis	Yellow birch	0.2	0.4	0.6
Betula	nigra	River birch	0	0	0
Betula	papyrifera	Paper birch	1.4	2.5	3.9
Carpinus	caroliniana	American hornbeam	0.2	0.1	0.3
Carya	cordiformis	Bitternut hickory	0.3	0.8	1.1
Catalpa	speciosa	Northern catalpa	0.3	0.3	0.6
Celtis	occidentalis	Common hackberry	0	0.1	0.1
Chamaecyparis	lawsoniana	Port orford cedar	1.5	0.1	1.6
Cornus	alternifolia	Alternateleaf dogwood	0.1	0	0.1
Cornus	florida	Flowering dogwood	0	0	0
Cornus	mas	Cornelian cherry	0	0	0
Crataegus	calpodendron	Pear hawthorn	0.3	0	0.3
Crataegus	chrysocarpa	Fireberry hawthorn	0.1	0.1	0.2
Crataegus	crus-galli	Cockspur hawthorn	1	0.4	1.4

Genus	Species	Common Name	% Population	% Leaf Area	IV (%Pop + %LA)
Crataegus	mollis	Downy hawthorn	0.1	0.1	0.2
Cydonia	oblonga	Quince	0	0	0
Elaeagnus	angustifolia	Russian olive	0.1	0.1	0.2
Euonymus	atropurpureus	Eastern wahoo	0	0	0
Euonymus	europaea	European spindle tree	0	0	0
Fagus	grandifolia	American beech	0.7	0.5	1.2
Fagus	sylvatica	European beech	0.2	0.2	0.4
Fraxinus	americana	White ash	5.3	2.7	8
Fraxinus	excelsior	European ash	0.1	0.2	0.3
Fraxinus	pennsylvanica	Green ash	3.6	5	8.6
Ginkgo	biloba	Ginkgo	0	0	0
Gleditsia	triacanthos	Honeylocust	1.5	1.2	2.7
Hamamelis	virginiana	Witch hazel	0.1	0	0.1
Hibiscus	syriacus	Rose-of-sharon	0	0	0
Juglans	cinerea	Butternut	0.2	0.6	0.8
Juglans	nigra	Black walnut	0.2	0.7	0.9
Juniperus	chinensis	Chinese juniper	0	0	0
Juniperus	communis	Common juniper	0.1	0	0.1
Juniperus	pinchotii	Pinchot juniper	0	0	0
Juniperus	virginiana	Eastern red cedar	0.7	0.2	0.9
Larix	laricina	Tamarack	0	0.1	0.1
Ligustrum	lucidum	Chinese privet	0.1	0	0.1
Magnolia	acuminata	Cucumber tree	0.2	0.1	0.3
Magnolia	x soulangeana	Saucer magnolia	0.1	0	0.1
Malus	angustifolia	Southern crabapple	0	0	0
Malus	baccata	Siberian crabapple	0.1	0.3	0.4
Malus	coronaria	Sweet crabapple	0.2	0.1	0.3
Malus	sylvestris	European crabapple	2.3	1.5	3.8
Malus	tschonoskii	Crabapple	0.2	0.2	0.4
Morus	alba	White mulberry	0.5	0.3	0.8
Morus	nigra	Black mulberry	0.2	0.2	0.4
Morus	rubra	Red mulberry	0	0	0
Ostrya	virginiana	Eastern hophornbeam	3.2	2.4	5.6
Other	species	Other species	0.8	0.4	1.2
Picea	abies	Norway spruce	1.2	1	2.2
Picea	glauca	White spruce	3.3	4.6	7.9
Picea	pungens	Blue spruce	0.6	1.4	2
Pinus	nigra	Austrian pine	1.4	2.7	4.1
Pinus	resinosa	Red pine	1.1	0.3	1.4
Pinus	strobus	Eastern white pine	1.5	0.9	2.4
Pinus	sylvestris	Scotch pine	0.6	0.4	1

Genus	Species	Common Name	% Population	% Leaf Area	IV (%Pop + %LA)
Populus	balsamifera	Balsam poplar	0.4	0	0.4
Populus	deltoides	Eastern cottonwood	0.3	0.4	0.7
Populus	grandidentata	Bigtooth aspen	0.5	0.6	1.1
Populus	tremuloides	Quaking aspen	2	1	3
Populus	x canadensis	Carolina poplar	0.1	0.3	0.4
Prunus	americana	American plum	0.2	0.1	0.3
Prunus	armeniaca	Apricot	0.1	0.1	0.2
Prunus	avium	Sweet cherry	0.6	0.6	1.2
Prunus	domestica	Common plum	0.3	0.1	0.4
Prunus	pensylvanica	Pin cherry	0.1	0	0.1
Prunus	persica	Nectarine	0	0	0
Prunus	sargentii	Sargent cherry	0	0.1	0.1
Prunus	serotina	Black cherry	2.3	1.8	4.1
Prunus	virginiana	Common chokecherry	1.9	0.9	2.8
Pyrus	communis	Common pear	0.7	0.4	1.1
Quercus	alba	White oak	1	2	3
Quercus	macrocarpa	Bur oak	0.2	0.1	0.3
Quercus	robur	English oak	0	0.1	0.1
Quercus	rubra	Northern red oak	0.6	1.3	1.9
Rhamnus	cathartica	European buckthorn	1.6	0.5	2.1
Robinia	pseudoacacia	Black locust	0.2	0.9	1.1
Salix	alba	White willow	0.3	1.5	1.8
Salix	babylonica	Weeping willow	0.1	0.5	0.6
Salix	discolor	Pussy willow	0.1	0	0.1
Salix	nigra	Black willow	0.1	0.6	0.7
Sorbus	americana	American mountain ash	0.1	0	0.1
Sorbus	aucuparia	European mountain ash	0	0	0
Sorbus	decora	Showy mountain ash	0	0	0
Syringa	reticulata	Japanese tree lilac	0	0	0
Syringa	vulgaris	Common lilac	0.2	0.1	0.3
Taxus	baccata	English yew	0.3	0.1	0.4
Taxus	canadensis	Canada yew	0.4	0.1	0.5
Thuja	occidentalis	Northern white cedar	15.6	2.8	18.4
Thuja	plicata	Western redcedar	0	0	0
Tilia	americana	American basswood	1.4	1.5	2.9
Tilia	cordata	Littleleaf linden	0.8	1.1	1.9
Tsuga	canadensis	Eastern hemlock	0.2	0.5	0.7
Ulmus	americana	American elm	1.5	3.7	5.2
Ulmus	pumila	Siberian elm	2.7	2.3	5
Ulmus	rubra	Slippery elm	0.2	0.3	0.5

Appendix 9: Leaf Area and Biomass Estimates for all Shrub Species by Land Use

Generalized Land Use	Species Common Name	Leaf Area (m2/ha)	Leaf Biomass (kg/ha)
Open Space 2	Northern white cedar	488.67	93.98
	Chinese juniper	344.5	95.69
	European buckthorn	144.36	6.42
	Winged burningbush	130.48	9.73
	American basswood	129.24	3.77
	Staghorn sumac	115.97	11.07
	Eastern white pine	104.73	6.74
	Tartarian honeysuckle	97.02	4.78
	Red osier dogwood	73.58	4.21
	Alternateleaf dogwood	53.77	3.58
	American mountain ash	41.84	3.32
	Common lilac	38.74	3.74
	Other species	33.4	2.49
	Grey alder	28.15	2.05
	European crabapple	24.51	2.11
	Green ash	16.84	1.1
	Sweet crabapple	15.56	1.34
	Common box	14.09	1.05
	Common barberry	12.95	0.97
	Witch hazel	5.54	0.33
	Sugar maple	2.02	0.12
	Downy serviceberry	1.65	0.1
	Boxelder	1.34	0.12
	Norway maple	0.71	0.04
	White ash	0.57	0.03
	Total	**1920.24**	**258.88**
Commercial	Other species	31.53	2.35
	English yew	20.87	2.31
	Boxelder	17.12	1.57
	European buckthorn	13.32	0.59
	Common chokecherry	9.11	0.71
	Japanese meadowsweet	9.09	0.68
	Green ash	3.72	0.24
	European crabapple	2.82	0.24
	American fly honeysuckle	1.52	0.07
	American elm	0.44	0.03
	Siberian elm	0.34	0.02
	Norway maple	0.24	0.01
	Total	**110.11**	**8.83**
Industrial	Common juniper	134.29	37.3
	Port orford cedar	39.89	9.97

Generalized Land Use	Species Common Name	Leaf Area (m2/ha)	Leaf Biomass (kg/ha)
Industrial	Winter creeper	34.06	2.54
	Skunkbush sumac	33.71	3.22
	Northern white cedar	24.38	4.69
	White willow	18.74	1.16
	Common pear	17.28	1.29
	Boxelder	12.46	1.14
	Japanese meadowsweet	11.37	0.85
	Winged burningbush	7.72	0.58
	Eastern white pine	7.35	0.47
	Common box	6.36	0.47
	English yew	5.26	0.58
	Chinese juniper	4.01	1.12
	Canada yew	3.7	0.41
	Staghorn sumac	2.28	0.22
	Norway maple	1.74	0.09
	Siberian elm	1.15	0.08
	Pin oak	1.11	0.1
	Alternateleaf dogwood	0.82	0.05
	American elm	0.76	0.05
	Common lilac	0.53	0.05
	European buckthorn	0.35	0.02
	European crabapple	0.09	0.01
	Other species	0.07	0
	Total	**369.48**	**66.46**
Residential Multifamily	Winged burningbush	146.36	10.92
	Cornelian cherry	142.96	9.47
	Common lilac	105.02	10.13
	Common box	101.73	7.59
	Dog rose	99.53	7.42
	Common chokecherry	95.07	7.37
	English yew	93.81	10.36
	Japanese tree lilac	57.44	5.54
	Japanese meadowsweet	38.81	2.89
	Tree of heaven	35.99	2.68
	Eastern redbud	32.14	2.06
	Green ash	31.1	2.03
	Boxelder	26.95	2.47
	Other species	25.07	1.87
	Northern white cedar	23.65	4.55
	Multiflora rose	18.97	1.41
	Flowering dogwood	17.61	1.02
	Oldfashioned weigela	16.63	1.24
	Shrubby cinquifoil	16.42	1.22
	Glossy buckthorn	15.21	0.68
	English holly	14.54	1.94

Generalized Land Use	Species Common Name	Leaf Area (m2/ha)	Leaf Biomass (kg/ha)
Residential Multifamily	White cyprus pine	13	0.97
	Fleshy hawthorn	11.84	0.89
	White mulberry	10.52	0.77
	Winter creeper	9.61	0.72
	Canada yew	9.55	1.05
	Eastern white pine	6.84	0.44
	Purpleleaf sand cherry	6.05	0.47
	Western service berry	4.16	0.42
	White spruce	4.1	0.66
	American plum	3.12	0.24
	Pussy willow	2.82	0.17
	White ash	1.23	0.07
	Norway maple	0.84	0.05
	Siberian elm	0.1	0.01
	Eastern red cedar	0	0
	Total	**1238.79**	**101.79**
No Data	Other species	407.7	30.41
	Tartarian honeysuckle	267.59	13.18
	Staghorn sumac	132.27	12.62
	Common chokecherry	67.62	5.24
	European buckthorn	67.57	3
	Norway maple	30.73	1.66
	Common lilac	23.86	2.3
	Total	**997.33**	**68.42**
Open Space 1 (Parks and TRCA lands)	Northern white cedar	1363	262.11
	Alternateleaf dogwood	478.4	31.89
	Eastern service berry	227.1	17.2
	Common chokecherry	148.33	11.5
	Tartarian honeysuckle	145.31	7.16
	European buckthorn	142.88	6.35
	Common lilac	129.14	12.46
	Chinese juniper	118.78	32.99
	Norway maple	112.68	6.08
	White ash	76.53	4.35
	American fly honeysuckle	60.65	2.99
	Sugar maple	57.57	3.47
	Western service berry	52.24	5.22
	European alder	41.57	3.03
	Other species	38.14	2.84
	European spindle tree	29.1	2.17
	Flowering dogwood	28.58	1.66
	Black cherry	28.03	2.17
	White willow	24.68	1.52
	Red osier dogwood	23.33	1.34
	Butternut	22.47	1.24

Generalized Land Use	Species Common Name	Leaf Area (m2/ha)	Leaf Biomass (kg/ha)
Open Space 1 (Parks and TRCA lands)	False spiraea	20.58	1.54
	Black maple	19.67	1.11
	Downy serviceberry	18.31	1.12
	Cornelian cherry	18.31	1.21
	Common box	17.81	1.33
	Winged burningbush	16.33	1.22
	Eastern hophornbeam	13.63	0.89
	Boxelder	13.6	1.24
	English yew	12.89	1.42
	American red raspberry	12.55	0.47
	White oak	12.2	0.89
	Cockspur hawthorn	11.25	0.85
	Grey alder	9.67	0.71
	Littleleaf linden	9.05	0.68
	Green ash	8.16	0.53
	Staghorn sumac	5.56	0.53
	European crabapple	4.79	0.41
	American hazlenut	3.84	0.27
	White mulberry	3.67	0.27
	Dog rose	3.22	0.24
	Fireberry hawthorn	3.18	0.24
	Black willow	2.5	0.15
	Bur oak	2.28	0.21
	Black walnut	1.74	0.14
	White spruce	1.72	0.28
	Common barberry	1.7	0.13
	Bigtooth aspen	1.64	0.08
	Purpleleaf sand cherry	1.09	0.08
	Black locust	1.02	0.05
	Eastern cottonwood	0.59	0.04
	Total	**3601.08**	**438.08**
Single Family Residential	Northern white cedar	658.01	126.54
	Common box	193.28	14.42
	Common lilac	167.49	16.16
	Chinese juniper	146.39	40.66
	Winter creeper	144.74	10.8
	Rose-of-sharon	135.28	6.54
	Winged burningbush	127.7	9.52
	Other species	115.1	8.58
	Eastern red cedar	98.33	27.31
	Canada yew	77.15	8.52
	English yew	74.16	8.19
	Tartarian honeysuckle	73.5	3.62
	Flowering dogwood	73.23	4.25
	Alternateleaf dogwood	72.16	4.81

Generalized Land Use	Species Common Name	Leaf Area (m2/ha)	Leaf Biomass (kg/ha)
Single Family Residential	Black cherry	61.92	4.8
	Alipne currant	53.9	4.02
	Cornelian cherry	52.73	3.49
	Western juniper	47.02	2.6
	American basswood	46.49	1.36
	Dog rose	42.43	3.16
	White mulberry	41.24	3.02
	Horsechestnut	40.86	2.86
	European spindle tree	38.64	2.88
	American beech	37.44	1.6
	Oldfashioned weigela	36.14	2.7
	European buckthorn	34.08	1.51
	Purpleleaf sand cherry	30.42	2.35
	Japanese meadowsweet	24.01	1.79
	White spruce	23.35	3.75
	Common chokecherry	22.35	1.73
	Boxelder	21.89	2
	Common barberry	21.67	1.62
	Smooth service berry	21.05	1.59
	Eastern hemlock	20.11	1.87
	Showy forsythia	19.89	1.48
	Winged burning bush	18.87	1.41
	American red raspberry	17.71	0.66
	Port orford cedar	17.39	4.35
	Norway maple	16.89	0.91
	Mugo pine	13.52	1.3
	Nannyberry	13.1	0.98
	White willow	12.91	0.8
	European cranberry bush	12.68	0.95
	English holly	11.09	1.48
	Green ash	10.41	0.68
	Japanese maple	10.15	0.57
	White ash	9.46	0.54
	Japanese barberry	8.91	0.66
	Wayferry tree	8.9	0.66
	American fly honeysuckle	7.94	0.39
	Evergreen euonymus	6.98	0.52
	Japanese false-cypress	6.63	1.66
	California privet	6.46	0.59
	Sweet crabapple	6.45	0.56
	Common ninebark	5.75	0.43
	Dwarf ninebark	5.57	0.42
	Azalea	5.37	1.07
	Black mulberry	5.3	0.45
	American plum	5.27	0.41

Generalized Land Use	Species Common Name	Leaf Area (m2/ha)	Leaf Biomass (kg/ha)
Single Family Residential	Sugar maple	5.21	0.31
	Siberian pea tree	5.07	0.38
	Manchu cherry	4.99	0.39
	Smoke tree	4.92	0.37
	Devils walking stick	4.72	0.35
	Common juniper	4.45	1.24
	European crabapple	4.05	0.35
	Roundleaf dogwood	3.72	0.22
	Sweet cherry	3.53	0.27
	Sand cherry	3.43	0.27
	Chinese rose	3.32	0.25
	Chinese magnolia	3.26	0.22
	Downy hawthorn	3.25	0.24
	Red osier dogwood	2.98	0.17
	Shrubby cinquifoil	2.65	0.2
	Pussy willow	2.54	0.16
	Red huckleberry	2.43	0.18
	Crimson weigela	2.39	0.18
	Siberian elm	2.39	0.16
	Balsam fir	2.38	0.25
	American elm	2.12	0.15
	Common privet	2.05	0.19
	Eastern service berry	2.04	0.15
	Common pear	1.97	0.15
	Blue spruce	1.93	0.33
	Bitternut hickory	1.81	0.11
	Early forsythia	1.8	0.13
	Eastern redbud	1.77	0.11
	White spirea	1.75	0.13
	Nectarine	1.68	0.13
	Pin cherry	1.58	0.08
	Pond cypress	1.27	0.14
	Black walnut	1.26	0.1
	White oak	1.25	0.09
	Japanese rose	1.16	0.09
	Western service berry	1.16	0.12
	Inkberry	1.1	0.15
	White meadowsweet	1.09	0.08
	American elder	1.05	0.08
	Maple leaved arrowood	0.89	0.07
	European filbert	0.87	0.06
	Staghorn sumac	0.82	0.08
	Smooth sumac	0.82	0.05
	Strawberry bush	0.8	0.06
	Hinoki cypress	0.79	0.2

Generalized Land Use	Species Common Name	Leaf Area (m2/ha)	Leaf Biomass (kg/ha)
Single Family Residential	European black elderberry	0.72	0.05
	Common plum	0.7	0.05
	Eastern cottonwood	0.68	0.05
	Euonymus	0.62	0.05
	Japanese holly	0.62	0.08
	Tree of heaven	0.6	0.04
	Kousa dogwood	0.52	0.03
	Purple sage	0.48	0.12
	Cockspur hawthorn	0.47	0.04
	Apricot	0.45	0.04
	Red elderberry	0.39	0.03
	Canada plum	0.38	0.03
	Silver fir	0.35	0.05
	Rhodora	0.35	0.07
	Caryopteris	0.33	0.02
	Northern catalpa	0.31	0.02
	European mountain ash	0.3	0.02
	Rose spiraea	0.28	0.02
	Smallleaf mulbery	0.23	0.02
	Black locust	0.23	0.01
	American mountain ash	0.21	0.02
	Norway spruce	0.18	0.03
	Chinese sumac	0.17	0.02
	Black willow	0.15	0.01
	Silver maple	0.15	0.01
	Austrian pine	0.15	0.01
	Common snowberry	0.14	0.01
	Prickly rose	0.11	0.01
	English lavander	0.11	0.01
	Cherry plum	0.1	0.01
	Littleleaf linden	0.1	0.01
	Bur oak	0.08	0.01
	Total	**3254.99**	**374.69**
Utility and Transportation	Staghorn sumac	605.83	57.82
	Russian olive	386.87	28.85
	Common lilac	385.71	37.21
	Tartarian honeysuckle	259.48	12.78
	Northern white cedar	93.78	18.03
	Eastern red cedar	42.93	11.92
	European buckthorn	42.09	1.87
	White ash	33.44	1.9
	Tree of heaven	18.64	1.39
	Scotch pine	17.15	1.65
	Bigtooth aspen	10.51	0.54
	Boxelder	5.14	0.47

Generalized Land Use	Species Common Name	Leaf Area (m2/ha)	Leaf Biomass (kg/ha)
Utility and Transportation	Common chokecherry	4.85	0.38
	Red osier dogwood	2.8	0.16
	Total	**1909.22**	**174.98**
	Alternateleaf dogwood	146.82	9.79
	Northern white cedar	73.1	14.06
	Canada yew	39.46	4.36
	Common box	30.16	2.25
	Japanese meadowsweet	12.82	0.96
	Bear oak	12.54	1.15
	Sweet cherry	11.52	0.89
	White ash	8.45	0.48
	Other species	7.38	0.55
	Dog rose	5.44	0.41
	Honeylocust	4.13	0.43
	Shrubby cinquifoil	3.81	0.28
	American red raspberry	3.5	0.13
	Winter creeper	2.15	0.16
	Azalea	1.69	0.34
	Common lilac	1.35	0.13
	Siberian elm	1.15	0.08
	Norway maple	0.88	0.05
	European buckthorn	0.55	0.02
	Total	**366.92**	**36.52**
	Common lilac	409.95	39.55
	Tartarian honeysuckle	263.43	12.98
	Staghorn sumac	167.28	15.97
	Alipne currant	109.19	8.14
	Other species	71.66	5.34
	White willow	66.28	4.09
	Alternateleaf dogwood	63.54	4.24
	Boxelder	45.91	4.2
	Eastern cottonwood	21.72	1.57
	White ash	20.53	1.17
	Western service berry	19.82	1.98
	Balsam fir	15.2	1.58
	Eastern wahoo	13.55	1.01
	Black cherry	12.66	0.98
	Eastern white pine	12.04	0.77
	Rose-of-sharon	11.22	0.54
	Japanese knotweed	10.82	0.81
	American mountain ash	8.51	0.68
	European spindle tree	7.09	0.53
	Winter creeper	6.61	0.49
	Cockspur hawthorn	5.43	0.41
	European black elderberry	5.26	0.39

Generalized Land Use	Species Common Name	Leaf Area (m2/ha)	Leaf Biomass (kg/ha)
	Red osier dogwood	5.16	0.3
	Balsam poplar	4.12	0.3
	Common chokecherry	2.79	0.22
	Sugar maple	2.47	0.15
	Japanese meadowsweet	2.29	0.17
	English holly	2.19	0.29
	Dog rose	2.12	0.16
	Quaking aspen	2.02	0.16
	Bloodtwig dogwood	1.74	0.1
	European buckthorn	1.51	0.07
	Norway maple	1.47	0.08
	Purpleleaf sand cherry	0.11	0.01
	Total	**1395.72**	**109.41**
CITY TOTAL		**2145.95**	**245.13**

Appendix 10: Land and Forest Cover Change by Land Use:1999 to 2005

n = sample size
SE = standard error

Land Cover Percentage by Land Use (1999 and 2005)						
Land Use	n	Cover type	1999		2005	
			% cover	SE	% cover	SE
Commercial	684	Grass	6.0	0.9	6.4	0.9
		Tree	6.3	0.9	5.3	0.9
		Building	25.0	1.7	26.2	1.7
		Road	17.5	1.5	18.3	1.5
		Impervious other	35.1	1.8	37.1	1.8
		Water	0.3	0.2	0.3	0.2
		Soil	9.8	1.1	6.4	0.9
Industrial	1,089	Grass	6.0	0.7	5.8	0.7
		Tree	4.4	0.6	4.1	0.6
		Building	31.0	1.4	32.0	1.4
		Road	8.5	0.8	8.9	0.9
		Impervious other	35.4	1.4	36.5	1.5
		Water	0.2	0.1	0.2	0.1
		Soil	14.4	1.1	12.5	1.0
Institutional	664	Grass	23.8	1.7	23.9	1.7
		Tree	16.3	1.4	15.4	1.4
		Building	17.2	1.5	18.2	1.5
		Road	8.0	1.1	8.4	1.1
		Impervious other	24.4	1.7	24.8	1.7
		Water	0.0	0.0	0.0	0.0
		Soil	10.4	1.2	9.2	1.1
MF residential	586	Grass	18.1	1.6	17.9	1.6
		Tree	16.7	1.5	16.2	1.5
		Building	24.7	1.8	26.3	1.8
		Road	13.8	1.4	14.3	1.4
		Impervious other	20.3	1.7	20.6	1.7
		Water	0.0	0.0	0.0	0.0
		Soil	6.3	1.0	4.6	0.9
Parks	887	Grass	15.8	1.2	15.9	1.2
		Tree	44.3	1.7	44.2	1.7
		Building	2.0	0.5	2.0	0.5
		Road	4.7	0.7	5.0	0.7
		Impervious other	4.5	0.7	4.7	0.7
		Water	4.3	0.7	4.2	0.7
		Soil	24.4	1.4	24.0	1.4

Land Cover Percentage by Land Use (1999 and 2005)						
Land Use	n	Cover type	1999		2005	
			% cover	SE	% cover	SE
Open Space	609	Grass	27.9	1.8	26.4	1.8
		Tree	25.3	1.8	26.6	1.8
		Building	3.6	0.8	3.6	0.8
		Road	4.8	0.9	4.8	0.9
		Impervious other	6.2	1.0	5.9	1.0
		Water	2.1	0.6	2.5	0.6
		Soil	30.0	1.9	30.2	1.9
Other	659	Grass	8.6	1.1	9.6	1.1
		Tree	14.6	1.4	14.0	1.4
		Building	4.2	0.8	4.4	0.8
		Road	12.9	1.3	13.1	1.3
		Impervious other	13.4	1.3	13.5	1.3
		Water	7.4	1.0	7.6	1.0
		Soil	38.8	1.9	37.9	1.9
SF residential	4,212	Grass	24.4	0.7	25.1	0.7
		Tree	25.3	0.7	24.0	0.7
		Building	21.4	0.6	22.2	0.6
		Road	12.5	0.5	12.7	0.5
		Impervious other	13.7	0.5	14.3	0.5
		Water	0.1	0.1	0.2	0.1
		Soil	2.6	0.2	1.6	0.2
Utility & Trans	406	Grass	3.2	0.9	1.5	0.6
		Tree	10.3	1.5	11.6	1.6
		Building	3.2	0.9	3.0	0.8
		Road	6.7	1.2	6.9	1.3
		Impervious other	23.6	2.1	25.4	2.2
		Water	1.0	0.5	1.2	0.5
		Soil	52.0	2.5	50.5	2.5
Unknown	192	Grass	8.3	2.0	8.3	2.0
		Tree	7.3	1.9	6.3	1.7
		Building	6.8	1.8	7.3	1.9
		Road	13.5	2.5	13.5	2.5
		Impervious other	10.4	2.2	10.9	2.3
		Water	28.1	3.2	28.6	3.3
		Soil	25.5	3.1	25.0	3.1

Appendix 11: Tree Species Rankings for Improving Air Quality

Source: www.fs.fed.us/ccrc/topics/urban-forests/docs/Nowak_Trees%20for%20air%20quality.pdf

Top rated species for improving air quality. List is based on rating the combined effects of pollution removal, VOC emissions, and air temperature reduction of 242 tree species at maturity under average U.S. urban conditions (Nowak et al., in prep). Trees listed area tolerant to pollutant under which it is ranked unless otherwise noted. Overall ranking is based on individual pollutant effects weighted by the average pollutant externality value (estimate of societal cost of pollutant in the atmosphere).

OZONE	CARBON MONOXIDE	OVERALL
Ulmus procera *I	Tilia Americana *	Ulmus procera *
Tilia europea	Fagus grandifolia	Tilia europea
Fagus grandifolia	Tilia tomentosa *	Liriodendron tulipifera *
Betula alleghaniensis I	Ulmus rubra	Metasequoia glyptostroboides *
Lirodendron tulipifera *S	Fagus sylvatica	Fagus grandifolia
Tilia Americana *	Betula alleghaniensis	Tilia platyphyllos *
Fagus sylvatica	Tilia euchlora *	Betula alleghaniensis
Tilia platyphyllos *S	Ulmus procera *	Fagus sylvatica
Metasequoia glyptostroboides *	Ginkgo biloba *	Tilia Americana *
Betula papyrifera	Liriodendron tulipifera *	Ulmus americana
		Ulmus thomas
PARTICULATE MATTER	**SULFUR/NITROGEN DIOXIDE**	**OVERALL**
Ulmus procera *	Ulmus procera *I/U	Chamaecyparis lawsoniana
Platanus occidentalis *	Tilia europea *T/S	Tsuga heterophylla
Chamaecyparis lawsoniana	Populus deltoids T	Tilia cordata *
Cupressocyparis x leylandii	Platanus occidentalis *T	Tsuga mertensiana
Juglans nigra	Platanus x acerifolia *T	Tilia tomentosa
Eucalyptus globulus	Metasequoia glyptostroboides *T	Betula papyrifera
Tilia europea	Liriodendron tulipifera	Celtis laevigata *
Abies alba	Juglans nigra S/U	Fraxinus excelsior *
Larix decidua	Betula alleghaniensis S	Ulmus crassifolia
Picea rubens	Fagus grandifolia	Betula nigra *
		Larix decidua

* Species or various cultivars of species rated as recommended trees for street use or urban conditions (Bassuk et al., 1998; Bridwell, 1994; Flint; 1997). Note: Hardiness zone and other tree factors need to be considered in urban tree selection.

I intermediate tolerance to pollutant

S sensitive to pollutant

T tolerant to sulphur dioxide (SO_2); unknown tolerance to nitrogen dioxide (NO_2)

I/U intermediate tolerance to SO_2; unknown tolerance to NO_2

T/S tolerant to SO_2; sensitive to NO_2