



TOWN OF AURORA
URBAN FOREST STUDY

TECHNICAL REPORT
SEPTEMBER 2014

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Executive Summary

The *Town of Aurora Urban Forest Study – Technical Report* has been prepared by the Toronto and Region Conservation Authority (TRCA), in partnership with York Region, the Town of Aurora, and Lake Simcoe Region Conservation Authority (LSRCA). The purpose of the study was to assess the distribution, structure and function of the urban forest, and to provide management recommendations for enhancing the sustainability of both the urban forest resource and the community as a whole. The study serves as a baseline for future research and monitoring, and will equip managers with information necessary to direct forest structure to deliver desired ecosystem services, including climate change mitigation and adaptation, air pollution removal, stormwater management, residential energy savings, wildlife habitat, and community aesthetics.

Summary of Results

A suite of tools of analysis created by the United States Department of Agriculture (USDA) Forest Service, Northern Research Station and the University of Vermont, Spatial Analysis Laboratory were used to quantify the distribution, structure and function of the urban forest.

Tree Cover and Leaf Area:

Aurora's 1.95 million trees contribute to 28 per cent tree canopy cover and provide 99 km^2 of total leaf area. The greatest proportion of the existing urban forest is located in residential areas of the municipality; approximately 41 per cent of the total tree and shrub cover in the municipality is found within this land use. The greatest opportunity to increase canopy cover through tree planting efforts is also found in the residential areas; approximately 32 per cent of the total area available for additional tree establishment is located in the residential land use category.

Tree Cover by Land Use:

- Residential: 29%
- Industrial: 7%
- Commercial: 12%
- Agriculture: 27%
- Open Space: 33%
- Institutional: 17%
- Natural Cover: 51%
- Utilities and Transportation: 41%
- Other: 39%

Tree Size:

The proportion of large, mature trees in Aurora is low. Approximately 74% of all trees are less than 15.3cm in diameter at breast height (dbh). As urban trees increase in size, their environmental, social and economic benefits increase as well. For example, in Aurora a tree that is 65 cm dbh stores 62 times more carbon than a tree that is 11 cm dbh.

Most Common Tree Species by Land Use (expressed as a per cent of the total leaf area):

Residential
- Norway maple: 15%
- Sugar maple: 13%
- Eastern white cedar: 12%

Commercial + Industrial
- Manitoba maple: 15%
- Silver maple: 15%
- European buckthorn: 14%

Open Space + Natural Cover
- Sugar maple: 30%
- Eastern hemlock: 17%
- American basswood: 8%

Institutional + Utilities & Transportation
- Manitoba maple: 31%
- Eastern white cedar: 25%
- White spruce: 22%

Agriculture
- Eastern white cedar: 20%
- Black walnut: 9%
- European buckthorn: 9%

Other
- Sugar maple: 21%
- Eastern hemlock: 19%
- Blue spruce: 10%

Structural Value of Trees in Aurora:

The estimated structural value of all trees in Aurora as of 2013 is approximately **$627 million**. This value does not include the ecological or societal value of the forest, but rather it represents an estimate of tree replacement costs and/or compensation for loss of a tree.

Carbon Storage and Sequestration:

As a tree grows, it removes carbon dioxide from the atmosphere; this process is referred to as *carbon sequestration*, which is expressed as an annual rate of removal. Carbon is then stored in the woody biomass of the tree; this can be expressed as total *carbon storage*. When a tree dies, much of the stored carbon is slowly released back to the atmosphere through decomposition. Trees in Aurora sequester approximately 4,050 metric tonnes of carbon per year, with an associated annual value of $313,000. Trees in Aurora store approximately 103,000 metric tonnes of carbon, with an associated value of $7.97 million.

Air Quality Improvements:

The urban forest can improve local air quality by absorbing and intercepting airborne pollutants. Aurora's urban forest removes 93 metric tonnes of air pollution annually; this ecosystem service is valued at approximately $711,380 annually.
- Ozone: 55 metric tonnes
- Particulate matter (< 10 microns): 26 metric tonnes
- Nitrogen dioxide: 7 metric tonnes
- Sulfur dioxide: 3.3 metric tonnes
- Carbon monoxide: 0.66 metric tonnes

The average adult consumes approximately 0.84kg of oxygen per day, or 306.6kg per year (Perry and LeVan, 2003). The Town of Aurora's urban forest produced an estimated 7,100 tonnes of oxygen in 2013. It follows that the oxygen released by the urban forest in 2013 was enough to support approximately 23,160 adult residents of Aurora, or 43.5% of the Town's population.

Residential Energy Savings:

Trees reduce local air temperature due to shading effects, wind speed reductions, and the release of water vapor through evapotranspiration. In Aurora the urban forest reduces the annual residential energy consumption by approximately 30,295 MBTUS and 2,117 MWH, with an associated annual financial savings of approximately $475,000. As a result of this reduced demand for heating and cooling the production of 622 metric tonnes of carbon emissions is avoided annually (associated annual savings of $48,143).

Hydrologic Effects of the Urban Forest:

Urban forest studies conducted across York Region have used the i-Tree Hydro model to simulate the effects of tree and impervious cover on stream flow in local watersheds. These analyses found that trees in two of York Region subwatersheds (used as sample study areas) can reduce levels of stream flow by intercepting rainfall. For example, in the Upper Rouge subwatershed a loss of all existing tree cover (27 percent) would increase stream total flow by approximately 2.9 per cent. Simulated reductions of impervious ground cover in these same subwatersheds produced more substantial reductions in total stream flow. Increases in tree cover correspondingly showed comparatively small reductions in total flow. For example, increasing tree cover to 20 per cent in the West Don subwatershed showed a reduction in total flow of 0.9 per cent.

Summary of Recommendations

Recommendation 1: Refine the results of the urban tree canopy (UTC) analysis to develop an urban forest cover target.

Recommendation 2: Build on the results of the urban tree canopy analysis (UTC) and the priority planting index to prioritize tree planting and establishment efforts to improve the distribution of ecosystem services, including urban heat island mitigation and stormwater management.

Recommendation 3: Increase leaf area in canopied areas by planting suitable tree and shrub species under existing tree cover. Planting efforts should continue to be focused in areas of the municipality that currently support a high proportion of ash species.

Recommendation 4: Utilize the Pest Vulnerability Matrix during species selection for municipal tree and shrub planting.

Recommendation 5: Establish a diverse tree population in which no species represents more than five per cent of the tree population, no genus represents more than 10 per cent of the tree population, and no family represents more than 20 per cent of the intensively managed tree population both municipal-wide and at the neighbourhood level.

Recommendation 6: Utilize native planting stock grown from locally adapted seed sources in both intensively and extensively managed areas.

Recommendation 7: Evaluate and develop the strategic steps required to increase the proportion of large, mature trees in the urban forest. This can be achieved using a range of tools including Official Plan planning policy, by-law enforcement and public education. Where tree preservation cannot be achieved, Official Plan policy can be considered that will require compensation for the loss of mature trees and associated ecosystem services.

Recommendation 8: Develop municipal guidelines and regulations for sustainable streetscape and subdivision design that ensure adequate soil quality and quantity for tree establishment and eliminate conflict between natural and grey infrastructure.

Recommendation 9: Explore the application of subsurface cells and other enhanced rooting environment techniques for street trees. Utilizing these technologies at selected test-sites in the short-term may provide a cost-effective means of integrating these systems into the municipal budget.

Recommendation 10: Reduce energy consumption and associated carbon emissions by providing direction, assistance and incentives to residents and businesses for strategic tree planting and establishment around buildings.

Recommendation 11: Research and pursue new partnerships and opportunities to enhance urban forest stewardship in Aurora.

Recommendation 12: Pursue the development of an urban forest communication plan that guides the dissemination of key messages to target audiences.

Recommendation 13: Explore the development and implementation of a municipal staff training program to enhance awareness of tree health and maintenance requirements generally, and of proper tree protection practices to be used during construction activities more specifically.

Recommendation 14: Establish an interagency Urban Forest Working Group to liaise with existing stakeholders and build new partnerships in the implementation of urban forest program objectives.

Recommendation 15: Explore and develop targets that achieve a comprehensive distribution of ecosystem services and improve overall landscape function.

Recommendation 16: Monitor the distribution, structure and function of the urban forest using the methods employed in this baseline study. A potential monitoring scenario may consist of a cover mapping assessment (UTC) at a five year interval and a field-based assessment (i-Tree Eco) at a ten year interval.

Recommendation 17: Support research partnerships that pursue the study of climate change and its impacts on the urban forest and that evaluate the potential for planting more hardy and southern species in select locations.

Recommendation 18: Develop and implement an urban forest management plan for the Town of Aurora.

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1.0 Introduction

Aurora's urban forest is a dynamic system that includes all trees and shrubs, as well as the soils that sustain them, located on public and private property. It is a mix of intensively managed trees located in the urban matrix as well as extensively managed natural areas consisting of remnant woodlots and plantation forests, and riparian forest patches. Aurora's urban forest is efficient and cost-effective natural infrastructure that provides an array of benefits and services to all of the Town's residents. A healthy and resilient urban forest can help to mitigate the effects of climate change, improve local air quality, aid in urban stormwater management, decrease residential energy use, provide habitat for local wildlife, and enhance community cohesion.

An evaluation of Aurora's urban forest is timely in light of the many challenges currently facing municipal urban forest managers. To accommodate projected population growth, density within the built-up urban areas of the municipality will increase and new residential zones will be created on lands that previously undeveloped. Urban intensification will have implications for the existing and future urban forest. Competing demands for limited growing space will force managers to identify creative approaches to creating and protecting tree habitat in order to grow and sustain trees in small or sub-optimal spaces. The impacts of climate change are also cause for concern. Summer drought, extreme weather events and shifting plant hardiness zones will place cumulative stress on the urban forest. At the same time climate change and unforeseen events may lead to an increase in the abundance of exotic insect pests and diseases. Notable among such pests is the emerald ash borer (*Agrilus planipennis*), which now threatens a significant portion of Aurora's urban forest. Careful consideration of the implications of climate change will enable managers to increase ecosystem resilience and effectively integrate the urban forest into municipal and regional climate change mitigation and adaptation strategies. In order to successfully address such challenges, a comprehensive understanding of urban forest structure and function will be necessary.

1.1 Purpose

The *Town of Aurora Urban Forest Study – Technical Report* has been prepared by the Toronto and Region Conservation Authority (TRCA), in partnership with York Region, the Town of Aurora, and Lake Simcoe Region Conservation Authority (LSRCA). The study provides an assessment of the distribution, structure and function of the urban forest. Ultimately, the study will inform and guide the creation of an Urban Forest Management Plan that will assist the Town of Aurora in fulfilling multiple social, environmental, and economic objectives through sustainable urban forest management.

1.2 Objectives

The objectives of the Technical Report are:

- To quantify the existing distribution, structure (e.g. composition and condition), and function (e.g. carbon sequestration and air pollution removal) of Aurora's urban forest;
- To establish a baseline for future monitoring and applied research; and
- To recommend preliminary actions that can be taken to enhance the capacity of the urban forest to provide essential ecosystem services.

2.0 Background

2.1 Demographic and Ecological Context

The Town of Aurora is a lower-tier municipality within the Regional Municipality of York. Aurora is a growing municipality that experienced a population increase of 11.7% from 2006 to 2011 (Statistics Canada 2012). According to the 2011 census the total population of Aurora was 53,203; population density at this time was 1,069 persons per square kilometre.

Approximately half of the Town of Aurora is located within the Oak Ridges Moraine Physiographic Region. The same portion of the municipality also falls within the Ontario Greenbelt. The Moraine supports significant ecological and hydrological features, including wetlands, post-glacial kettle lakes, and aquifers. The abundance of wetlands supports a rich diversity of flora and fauna, including a high density of species of regional concern. Headwater features of the Humber River, Holland River, and Rouge River watersheds are also located within the municipality.

Aurora is located in Plant Hardiness Zones 5a and 5b (according to the Natural Resources Canada Plant Hardiness Zone Map of 2000), as well as ecodistrict 6E-7, which corresponds to the Great Lakes-St. Lawrence forest region. This region is characterized by a mixture of broad-leaf and coniferous trees, such as eastern white pine (*Pinus strobus*), eastern hemlock (*Tsuga canadensis*), red oak (*Quercus rubra*), sugar maple (*Acer saccharum*), red pine (*Pinus resinosa*), white ash (*Fraxinus americana*), American beech (*Fagus grandifolia*), and eastern white cedar (*Thuja occidentalis*). While Aurora lies just north of the Carolinian forest region that covers the southernmost portion of Ontario, some tree species representative of that region, such as tulip tree (*Liriodendron tulipifera*) and American sycamore (*Platanus occidentalis*), have been cultivated and planted in the Town.

Several decades of urbanization, agricultural and industrial activity has led to the loss of nearly all pre-European settlement natural cover in the region. From 1975 to 1988 York Region's forest cover declined between 30 to 50 per cent (Schmitt and Suffling, 2006). Concurrent with the loss of natural cover has been a decline in the services provided by natural systems, including water management and climate regulation. Some of these services are mimicked by man-made grey infrastructure, which has a limited ability to meet the demands of a growing urban population. However, in recent years mainstream thinking has begun to recognize the importance of natural infrastructure in maintaining sustainable options for the future.

2.2 Policy and Management Context

This section provides a brief summary of policies and programs that are currently applied in the governance or management of the urban forest.

Provincial Policy

Numerous pieces of provincial legislation relate to the stewardship and management of urban forests in the Town of Aurora. The majority of land in Aurora falls within the boundaries of both the Ontario Greenbelt and the Oak Ridges Moraine. Consequently, the Greenbelt Act and Plan (2005) and the Oak Ridges Moraine Conservation Act and Plan (2001) are applicable to land use, planning, and development in the town of Aurora. Both acts are intended to protect environmentally significant land from the pressures of urban development. The Environmental Assessment Act (1990) applies to public sector and large private sector projects with the aim of conserving and wisely managing the environment. The Planning Act (1990) provides for land use planning systems, including the integration of urban forest features. The Endangered Species Act (2007) provides for the protection of endangered species and their habitats, including some, such as butternut (*Juglans cinerea*), that are found in the Town of Aurora.

Town of Aurora Official Plan

The Town of Aurora Official Plan was adopted by Council in September, 2010. Section 9 relates to the development of new residential neighbourhoods, including the incorporation of green infrastructure in the development process. Section 9.1 outlines general policies for the Greenfield Residential Area designation. Under subsection d), pertaining to secondary plans, consideration is given to policies that establish urban greening targets, which may be achieved with the combined inputs of urban forest canopy, green walls, and requirements for landscaping.

Section 12 outlines the policies that "protect and complement key natural heritage features and key hydrologic features" in an effort to establish a linked Greenlands system. This section contains numerous items related to the maintenance of urban forests for natural environmental values and human enjoyment.

Section 12.5 details policies related to the designation and management of Environmental Protection Areas. This section mandates that human intervention in such areas be limited to low impact recreation or development that, having undergone an environmental assessment, will not be detrimental to the environmental values of the area.

Section 12.6 pertains to general environmental protection policies. Section 12.6.1, which contains policies related to site alterations, contains the following items:

> *e) Where, through an application for development or site alteration, a buffer or vegetation protection zone is required to be established as a result of the application of the policies in this Plan, the buffer or vegetation protection zone shall be composed of native, non-cultivar, non-invasive species, and maintained as natural self-sustaining vegetation.*
>
> *i) Any development proposal on land which contains trees may be required to undertake a Tree Preservation Plan prepared by a qualified professional, which shall inventory and assess the present conditions of the trees on the site and shall make recommendations on tree preservation with the objective of maximizing the number of trees that can be conserved on site.*
>
> *j) In the case of development applications that result in a net loss of trees, the developer shall compensate this loss on the development site or in another suitable location as determined by Council. In determining appropriate compensation, consideration should be given to the significance and value of the ecological function the trees provided, in accordance with the International Society of Arboriculture Vegetation Evaluation criteria or other nationally recognized standard.*

Section 12.6.3, part of the General Environmental Protection Policies, outlines specific forest management policies, including the following:

> *a) Maintain, protect, refurbish and where necessary reforest significant forest areas as outlined in Schedule 'E' of this Plan.*

c) Ensure the ongoing capacity of forest areas to sustain forest wildlife. To this end, Council may require buffers of up to 10 metres from the dripline of forest resource areas.

g) Encourage forested areas to be left in their entirety in subdivision and site plan designs and to be supported by the proposed Tree By-Law.

h) Council shall develop and implement a woodland strategy in cooperation with the Ministry of Natural Resources and [Lake Simcoe Region and Toronto and Region] Conservation authorities.

Town of Aurora Strategic Plan

The Town of Aurora Strategic Plan, released in 2011, outlines goals and objectives for the next 20 years that support a collective vision for the municipality. The Strategic Plan contains a goal for "supporting environmental stewardship and sustainability"; with corresponding objectives for encouraging the stewardship of the municipality's natural resources and promoting and advancing green initiatives. The following strategies, as outlined in the Strategic Plan, have direct or indirect implications for urban forest management:

- *Assess the merits of measuring the Town's natural capital assets;*
- *Continue to support and enhance community planting programs in appropriate locations;* and
- *Implement and regularly update the Trails Master Plan to improve connectivity.*

By-Laws and Tree Maintenance

In October, 2003, the Town of Aurora enacted By-law 4474-03.D to manage the injury or destruction of trees on private property. The by-law requires a permit for the injury or destruction of five or more trees with a diameter of at least 20 cm, measured at 1.4 metres from the ground, or a 40 cm base diameter, within the span of one year. A permit is not required for work such as tree pruning, dead branch removal, emergency maintenance, or for trees located in rooftop gardens, interior courtyards, solariums, nurseries, or golf courses. In 2013 the Town of Aurora pursued the enactment of a Tree Protection by-law.

In December, 2005, the Town enacted By-law 4734-05.P to regulate the planting of trees on highways under the jurisdiction of the municipality. The by-law controls the planting of specific tree species and prohibits the injury or destruction of highway trees.

The Town has developed a Memorial Tree Planting Policy which regulates the planting or designation of memorial trees on municipal property. The policy provides a pre-approved list of tree species that may be planted and maintains records of memorial trees.

The Regional Municipality of York also regulates the destruction or injury of trees in woodlots through By-law TR-0004-2005-036. The By-law applies to all woodlots 0.5 acres or greater in size. York Region Forestry is also responsible for the maintenance of trees on all regional roads.

Stewardship and Education Programs

In partnership with York Region, Local Enhancement and Appreciation of Forests (LEAF) offers a Backyard Tree Planting Program to residents of Markham, Vaughan, Richmond Hill, Aurora, and Newmarket. The program provides residents with native trees and shrubs at subsidized prices, as well as site and tree care consultations, and a full tree planting service.

The Town of Aurora, together with the Towns of Newmarket, East Gwillimbury and LSRCA, partners with Neighbourhood Network to engage youth volunteers in an annual community tree planting event that occurs in Aurora each April.

2.3 Collaborative Urban Forest Studies

In April 2007, TRCA coordinated the meeting of key stakeholders from across southern Ontario to explore the possibility of using compatible methodologies in the Greater Toronto Area (GTA) and beyond. Consequently, the Regional Municipalities of Peel and York, Cities of Toronto, Mississauga, Brampton, Vaughan and Pickering, and the Towns of Markham, Richmond Hill, Ajax, and Caledon all became part of an informal collaborative that ensued from the discussions. Following these preliminary discussions the members of this collaborative agreed to move forward with urban forest studies using the i-Tree Eco model (formerly known as UFORE) and the additional suite of tools offered by the USDA Forest Service and partners. To date, the TRCA has coordinated the studies for the municipalities of Mississauga, Brampton, Caledon, Vaughan, Markham, Richmond Hill, Aurora, Pickering and Ajax. The City of Toronto led its own concurrent urban forest study using the same methodology and tools. Please see Figure 1 for an illustration of the municipalities engaged in collaborative urban forest studies. Such advancements in regional urban forest studies comprise important strides toward enhancing urban well-being in the GTA. These results also encourage positive momentum for further studies in York Region municipalities.

The primary objective of this collaborative effort was to develop a standardized methodology that would allow for further comparative and complimentary research at the regional scale. Carreiro and Zipperer (2008) highlight the value of such research, asserting that comparative ecological research will lay a foundation for distinguishing common urban effects and responses from those specific to a particular city or group of cities due to variations in factors such as geography, climate, soil, urban morphology, cultural values, and political and economic systems.

2.4 Literature Review

Please see Appendix A for a review of the relevant literature and research. This review explores the variables that affect and shape urban forest structure and function, and highlights the existing threats to urban forest health. Theories and concepts of sustainable urban forest management are also examined.

3.0 Methodology

Four complementary tools of analysis have been utilized in the study:

1) i-Tree Eco model
2) Urban Tree Canopy (UTC) spatial analysis
3) Priority Planting Index (PPI)

4) i-Tree Forecast

Each tool is examined in more detail below. Taken together, these analyses provided a broad understanding of Aurora's urban forest. These tools have been developed by the United States Department of Agriculture (USDA) Forest Service, Northern Research Station in partnership with the Spatial Analysis Laboratory at the Rubenstein School of the Environment and Natural Resources at the University of Vermont.

While the i-Tree Eco analysis and the UTC analysis each represent stand-alone assessments capable of supporting an urban forest management plan, the technical working group opted to employ both of these complementary tools. By incorporating the data collected in the field the i-Tree Eco analysis quantified critical attributes such as tree species and tree height, which cannot be obtained from aerial imagery. In contrast, using high resolution satellite imagery, the UTC analysis conducted by the University of Vermont's Spatial Analysis Laboratory digitally mapped the actual and potential location of all individual trees in the study area (rather than only those trees measured within the i-Tree Eco sample plots), and projected future cover estimates based on a variety of different planting and mortality scenarios.

3.1 The i-Tree Eco Model

Several models and software packages have been developed to assist urban forest managers in obtaining quantitative structural data. Following a review of the various applications, the technical working group, together with the regional collaborative, concluded that the i-Tree Eco model would provide the level of structural detail required for urban forest studies across the Greater Toronto Area (GTA). Furthermore, the i-Tree Eco model has been previously employed by other Canadian cities and can therefore produce standardized and comparable results at both the provincial and national levels.

3.1.1 Study Design

Study area boundaries were defined by the municipal boundaries of Aurora. In accordance with the randomized grid sampling method recommended by the USDA Forest Service, a grid was overlaid on a GIS-based map of the entire study area and a sample plot was generated randomly within each grid cell. A total of 205 plots were used in the analysis, with a density of approximately 1 plot for every 24 hectares. Each circular plot was approximately 0.04 hectares in size. Data from the plots were then statistically extrapolated upward to estimate totals and standard errors for the entire study area.

Although increasing the number of plots would have led to lower variances and increased certainty in the results, it would also have increased the cost of the data collection. Thus, the number of plots surveyed provided an acceptable level of standard error when weighed against the time and financial costs required for additional field data collection. As a general rule, 200 (0.04 ha) plots in a stratified random sample in a city will yield a standard error of approximately 10 per cent (USDA, 2007). In the past, large cities such as New York and Baltimore have used 200 sample plots and have obtained accurate results with acceptable levels of standard error.

A high resolution aerial orthophotograph that illustrated the location of plot centre and plot boundaries was generated for each plot (Figure 2). GPS coordinates were also generated to aid crews in navigation to plot centre.

3.1.2 Study Area Stratification

Stratifying the study area into smaller units can aid in understanding variations in the structure of the urban forest according to land use types (e.g. residential, commercial, etc.) or neighbourhoods. The study area was stratified by land use after the plots had been randomly distributed. If the distribution of land use categories changes in the future, this method of post-stratification will allow the municipality to revisit the sample plots and monitor change over time, while still reporting on trends within land use categories. In other words, the permanent sample plots are not dependent on a static land use distribution.

The study area was stratified into 10 land use categories. These categories were comprised of substrata represented by the Municipal Property Assessment Corporation (MPAC) codes assigned to each property in the municipality.[1] Each MPAC code, or substrata, was grouped into one of the 10 generalized categories based on similarities in ownership and management type. Please see Appendix C for a complete description of each land use category and the corresponding MPAC codes. This list is drawn from the most recent iteration of MPAC codes, completed in 2012. Given that land use changes are likely to occur within each four year period, MPAC codes should be screened and adjusted to reflect approved developments since the previous update in order to provide the most accurate projected urban forest calculations by land use.

The *utilities and transportation* category and *natural cover* category both represented relatively small portions of the total study area. In order to produce statistically accurate results the USDA Forest Service recommends that a minimum of 15 to 20 plots fall within a distinct category. Consequently, the aforementioned categories were collapsed into a category with other similar land use types, to create a total of six land use categories:

- agriculture;
- open space + natural cover;
- residential;
- commercial and industrial;
- institutional + utilities and transportation; and
- other (comprised predominately of vacant land scheduled for development).

Categories were grouped together based on similarities in vegetation cover and management needs. Please see Appendix D for a generalized land use map depicting these six land use categories.

[1] MPAC is an independent body established by the *Ontario Property Assessment Corporation Act, 1997. MPAC* administers a uniform, province-wide property assessment system based on current value assessment.

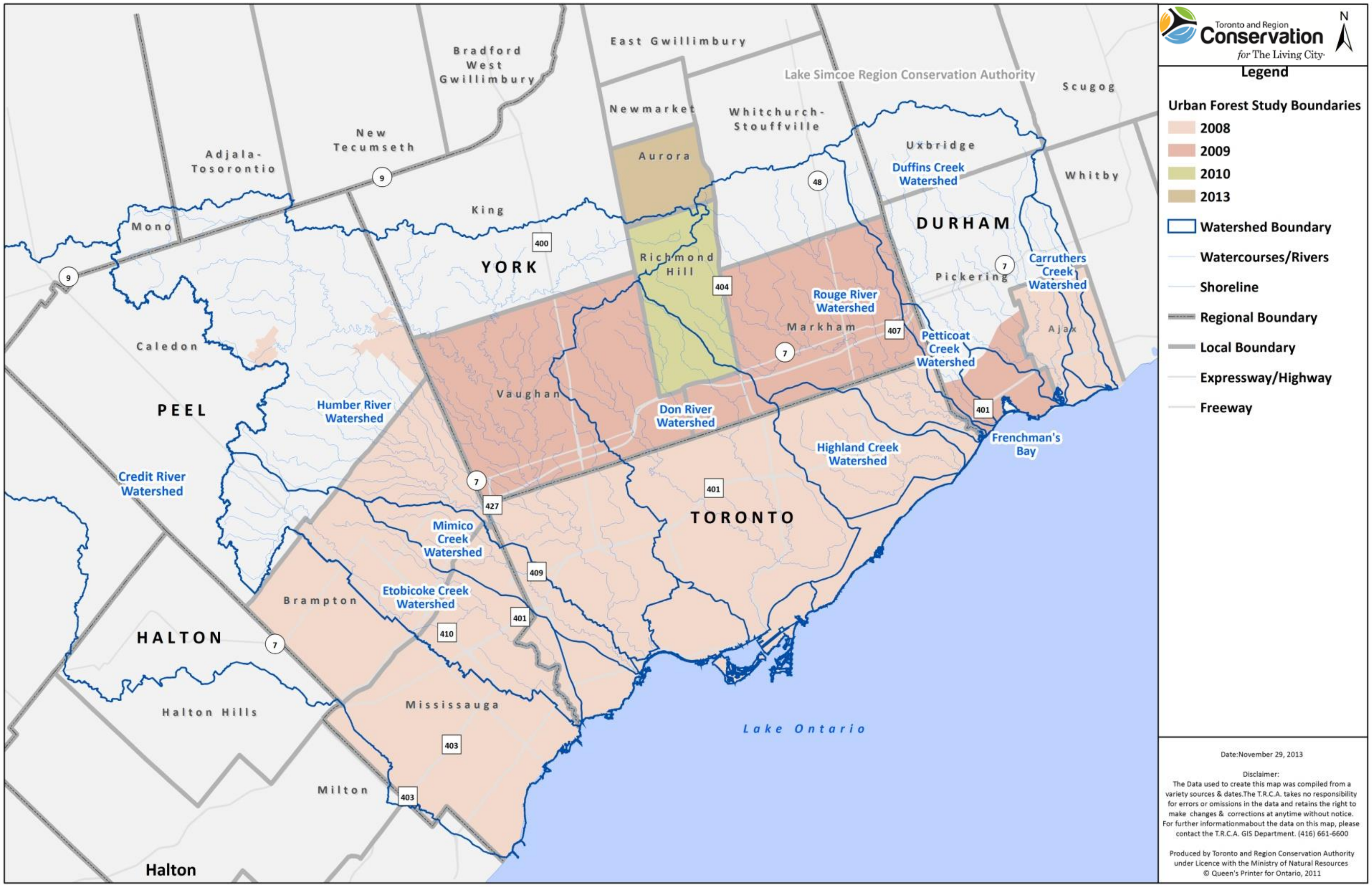

Figure 1: Municipalities in the Greater Toronto Area that have participated in urban forest studies

3.1.3 Landowner Contact

Permission to access plots located on private property was sought initially through written communication. Prior to entry, all property owners were mailed a request for access form in addition to a letter outlining the scope and duration of the study. If no response was given, field staff requested permission to access the property in person. In the event that permission was not granted, access was restricted due to physical barriers, or the site was deemed unsafe, field staff recorded measurements at the nearest representative location.

3.1.4 Field Data Collection

Field data collection was conducted by a two member field crew during the summer leaf-on season of 2013. At each sample plot field staff recorded the distance and direction from plot centre to permanent reference objects, where possible, so that plots could be relocated for future re-measurement. Once plot centre had been located, detailed vegetation information was recorded in accordance with the i-Tree manual specifications. The following general plot data were recorded:

- per cent tree cover
- per cent shrub cover
- per cent plantable space
- land use as observed in the field
- per cent of plot within each observed land use
- per cent ground cover of each:
    - building
    - cement
    - tar-blacktop/asphalt
    - soil
    - rock
    - duff/mulch
    - herbaceous (exclusive of grass and shrubs)
    - maintained grass
    - wild/unmaintained grass
    - water

For each shrub mass, the following data were recorded:

- genus and, if possible, species
- height
- per cent of shrub mass volume occupied by leaves
- per cent of total shrub area in the plot occupied by the shrub mass

For each tree with the centre of its stem in the plot and a minimum diameter at breast height (dbh) of at least 2.5 cm, the following data were recorded:

- species
- status (planted, naturally in-seeded, or unknown)
- direction and distance from centre point
- land use in which the tree is growing
- number of stems
- diameter at breast height for each stem up to a maximum of 6 stems

- tree height
- height to top of live crown, if different from total height
- height to base of live crown
- crown width (average of two perpendicular measurements)
- per cent canopy missing
- tree condition (based on per cent of branch dieback in crown):
    - excellent (< 1 dieback)
    - good (1-10)
    - fair (11-25)
    - poor (26-50)
    - critical (51-75)
    - dying (76-99)
    - dead (100 - no leaves)
- per cent of area under tree canopy occupied by impervious ground surface
- per cent of area under tree canopy occupied by shrub mass
- crown light index (number of the tree's sides out of a total of 5 that are exposed to direct sunlight)
- distance and direction from the building (for trees ≥ 6.1m in height and located within 18.3m of a residential building)
- tree site (indicated whether the tree is a municipally managed street tree)

3.1.5 Pollution Data Compilation

Hourly 2011 pollution concentrations of sulphur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), particulate matter of 2.5 microns or less ($PM_{2.5}$), and nitrogen dioxide (NO_2) were obtained from the Ontario Ministry of the Environment. Measurements of CO and SO_2 were recorded at the Toronto West Monitoring Station; measurements of NO_2, $PM_{2.5}$ and O_3 were recorded at the Newmarket Monitoring Station. PM_{10} measurements were provided by Environment Canada and were recorded at the downtown Toronto Monitoring Station, located at the Gage Institute. Measurements of PM_{10} were not recorded on an hourly or daily basis, but rather once every three days, on average.

3.1.6 Data Analysis

The i-Tree Eco model used standardized field, air pollution-concentration, and meteorological data for Aurora to quantify urban forest structure and function. Five model components were utilized in this analysis:

1) Urban Forest Structure: quantifies urban forest structure (e.g., species composition, tree density, tree health, leaf area, leaf and tree biomass) based on field data.
2) Biogenic Emissions: quantifies 1) hourly urban forest volatile organic compound (VOC) emissions (isoprene, monoterpenes, and other VOC emissions that contribute to O_3 formation) based on field and meteorological data, and 2) O_3 and CO formation based on VOC emissions.
3) Carbon Storage and Annual Sequestration: calculates total stored C, and gross and net C sequestered annually by the urban forest based on field data.
4) Air Pollution Removal: quantifies the hourly dry deposition of O_3, SO_2, NO_2, CO, PM_{10}, and $PM_{2.5}$ by the urban forest and associated per cent improvement in air quality

throughout a year. Pollution removal is calculated based on local pollution and meteorological data.

5) Building Energy Effects: estimates effects of trees on building energy use and consequent emissions of carbon from power plants.

For a detailed description of the i-Tree Eco model methodology please see Appendix E.

3.2 Urban Tree Canopy Analysis

The Urban Tree Canopy (UTC) analysis was conducted by the Spatial Analysis Laboratory of the University of Vermont's Rubenstein School of the Environment and Natural Resources, in consultation with the USDA Forest Service Northern Research Station. Advanced automated processing techniques using high-resolution 2012 colour infrared aerial imagery and ancillary datasets were used to map land cover for the entire town with such detail that single trees were detected (Figure 2). The following land cover categories were mapped: tree canopy; grass/shrub; bare soil; water; buildings; roads; and other paved.

Figure 2: High resolution aerial imagery (left) and associated digitized land cover mapping (right).

Using the land cover data the following tree cover statistics were calculated: existing tree canopy; impervious possible tree canopy; and vegetated possible tree canopy (see Table 1 for a description of each metric). Tree canopy metrics were summarized for each property in the municipality's parcel database. For each parcel both the absolute area and per cent of existing and possible tree canopy were computed.

Table 1: Description of tree canopy metrics used in Urban Tree Canopy (UTC) analysis.

Tree Canopy Metric	Description
Existing tree canopy	The amount of tree canopy present when viewed from above using aerial or satellite imagery.
Impervious possible tree canopy	Asphalt or concrete surfaces - excluding roads and buildings - that are theoretically available for the establishment of tree canopy.
Vegetated possible tree canopy	Grass or shrub area that is theoretically available for the establishment of tree canopy. This estimate does not consider land use preferences.

Existing and possible tree canopy metrics were summarized for the following geographic categories: land use category; municipal right-of-way (ROW); census unit; dissemination area; municipal ward; and watershed.

3.3 Priority Planting Index

The digital cover maps described in section 3.2 together with 2011 census data were used to produce an index that prioritizes tree planting areas within dissemination areas in Aurora. The index combines three criteria:

1. Population density: The greater the population density, the greater the priority for tree planting.
2. Canopy green space: Canopy greenspace is the proportion of total greenspace area (non-impervious areas) filled with tree canopies. The lower the value, the greater the priority for tree planting.
3. Tree canopy cover per capita: The lower the amount of tree canopy cover per person, the greater the priority for tree planting.

Each criterion above was standardized on a scale of 0 to 1, with 1 representing the maximum population density and minimum canopy green space and tree cover per capita. The standardized values were weighted to produce a combined score:

$$I = (PD * 40) + (CG * 30) + (TPC * 30)$$

Where I is the combined index score, PD is the standardized population density value, CG is the standardized canopy green space value, and TPC is the standardized tree cover per capita value. The combined score was standardized again and multiplied by 100 to produce the planting priority index. The tree planting priority index (PPI) ranks the dissemination with values from 100 (highest priority) to 0 (lowest priority). Areas of higher human population density and lower canopy green space and tree cover per capita receive higher index values.

3.4 i-Tree Forecast

The i-Tree Forecast computer model, created by the USDA Forest Service, Northern Research Station, was used to estimate future canopy cover under the following two scenarios: 1) maintain existing canopy cover; and 2) increase canopy to 40 per cent. Both scenarios estimated future canopy cover using 5 different annual mortality rates, ranging from 2 per cent annual mortality to 6 per cent annual mortality. The actual mortality rate of trees in Aurora is not known, but is assumed to fall within this range.

Tree measurements collected for the i-Tree Eco analysis were utilized to simulate future canopy cover. Projections for each tree were based on various tree characteristics including: species (growth rate, longevity, height at maturity); diameter at breast height (dbh); crown light exposure; and per cent dieback in tree crown. Tree growth or annual increase in dbh was based on the number of frost free days (149), crown light exposure, dieback, growth rate classification and median height at maturity. Individual tree mortality was based on the per cent dieback in the crown, dbh and average height at maturity for each tree. Average per cent mortality was calculated for all trees measured.

In anticipation of wide-spread and potentially complete ash species mortality as a result of emerald ash borer (*Agrilus planipennis*), a scenario in which 100 per cent of existing ash trees were killed over a ten year period was also modeled. Under this scenario, a 0 per cent rate of natural regeneration for ash species was assumed.

4.0 Results

4.1 Urban Forest Distribution

The Urban Tree Canopy (UTC) analysis found that approximately 1,369 ha of the Town is covered by tree canopy (termed existing TC), representing 28 per cent of all land cover in Aurora (Figure 3). Grass, herbaceous cover (including agricultural crops) and bare soil represents 52 per cent of the municipal land cover, and impervious surfaces (roads, buildings, and other paved surfaces) cover 19 per cent of the Town. An additional 59 per cent (2,894 hectares) of the Town's land area could theoretically be modified to accommodate additional tree canopy (termed possible TC). Specifically, 50 per cent (2,448 hectares) of the total land area is classified as *vegetated* possible TC and another 9 per cent as *impervious* possible TC (447 hectares). When classifying possible TC the analysis did not consider socio-economic and cultural expectations for land use. Therefore, agricultural lands have been classified as vegetated possible TC. Agricultural lands represent approximately 22 per cent of the total land area within the municipality.

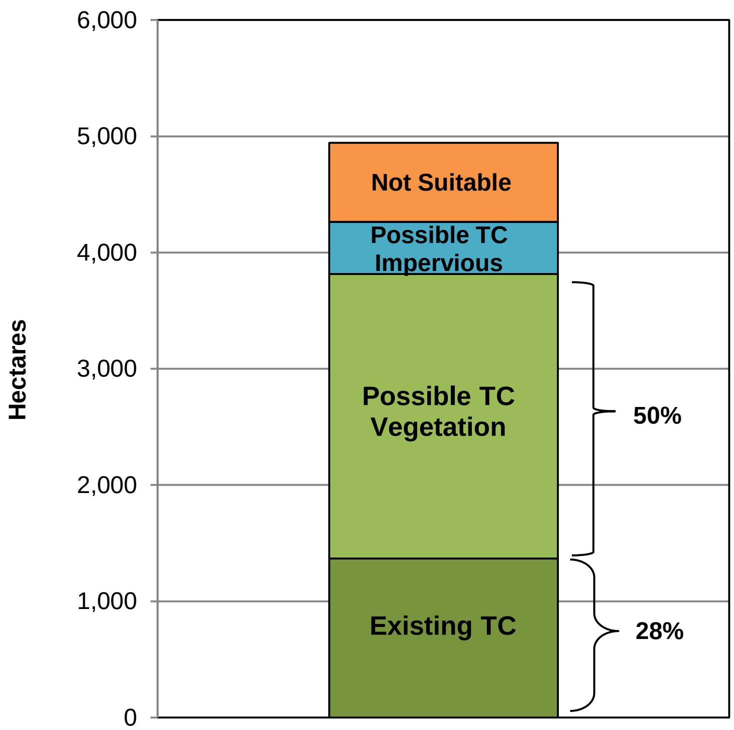

Figure 3: Tree canopy metrics for Aurora

Figure 4 illustrates the total area (ha) of existing and possible TC within each land use. Table 2 presents TC metrics for each land use calculated as a percentage of all land in the Town (%

Town), and as a percentage of land area within the specified land use category (% Land Use). The *natural cover* land use category supports the highest existing TC by land use, with 51 per cent tree cover (27 ha). However, due to the relative size of this land use, tree canopy within the *natural cover* category represents only 1 percent of the Town's total land area. The greatest proportion of the existing TC is found within the *residential* category (562 ha or 11 per cent of the Town's total land area). Existing TC is lowest in the *industrial* and *institutional* categories.

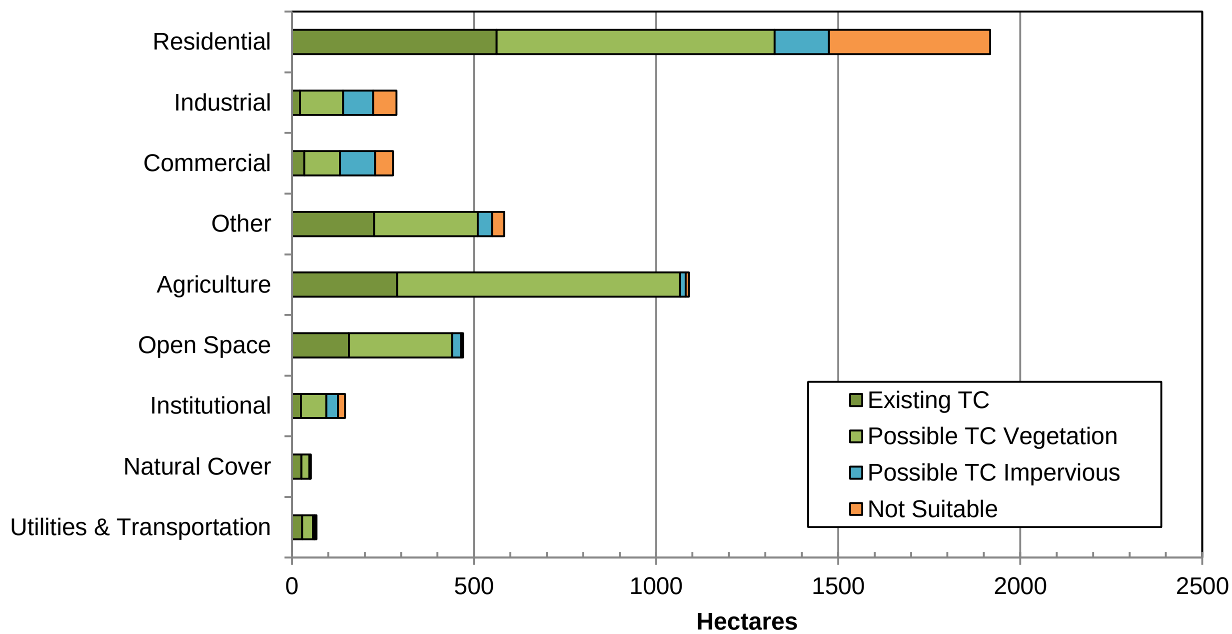

Figure 4: Tree canopy metrics summarized by land use in Aurora

Table 2: Tree canopy (TC) metrics summarized by land use in Aurora. For each land use category, TC metrics were calculated as a per cent of all land cover in the municipality (Town), and as a per cent of land cover within the specified land use category

Land Use	Existing Tree Canopy		Possible TC - Vegetation		Possible TC – Impervious	
	Town	Land Use	Town	Land Use	Town	Land Use
Residential	11%	29%	16%	40%	3%	8%
Industrial	0%	7%	2%	42%	2%	29%
Commercial	1%	12%	2%	35%	2%	35%
Other	5%	39%	6%	49%	1%	7%
Agriculture	6%	27%	16%	71%	0%	1%
Open Space	3%	33%	6%	60%	1%	5%
Institutional	1%	17%	1%	48%	1%	22%
Natural Cover	1%	51%	0%	41%	0%	6%
Utilities & Transportation	1%	41%	1%	45%	0%	5%

The greatest opportunity to increase total municipal tree cover is theoretically found in the *residential* land use category. Approximately 913 ha of residential land (19 per cent of the Town's total land area) are classified as possible TC. The results indicate that the *agricultural* land use offers 792 ha of possible TC (16 per cent of the Town's total land area). However, this characterization considers only the physical requirements of tree planting and does not recognize social or economic expectations for each land use. As such, parcels on which active agriculture practices are currently occurring can be excluded from the total possible TC estimate. An interpretation of the results for this land use is challenging given that a portion of the land currently classified as *agriculture* may be designated as future residential or mixed-use development. It follows that if this land will not be managed for agricultural purposes and will instead be converted to another land use, then it can indeed be considered possible TC. With that in mind, there may be opportunities to incorporate significant urban forest cover into the design of these future communities.

Approximately 70 percent of both the *commercial* and *industrial* land uses are classified as possible impervious TC. Although establishing tree canopy in impervious surfaces is likely more challenging than doing so in pervious cover, it will reduce the heat transfer from such surfaces and reduce the volume of storm water runoff.

Tree canopy metrics have been generated for dissemination areas in Aurora (Figures 5 and 6). High existing TC is indicated by dark green shading; high possible TC (both vegetated and impervious) is indicated by dark brown shading.

In areas where tree canopy has been removed, surface temperatures can be substantially higher than adjacent forested areas. The effect may be most pronounced in areas with extensive impervious surfaces, which absorb and hold thermal radiation from the sun. Analysis of recent thermal data (Landsat, July 18, 2013) illustrated this effect in Aurora (Figures 7 and 8). A significant inverse relationship was found to exist between tree canopy and surface temperature providing clear evidence that trees help to reduce the urban heat island effect.

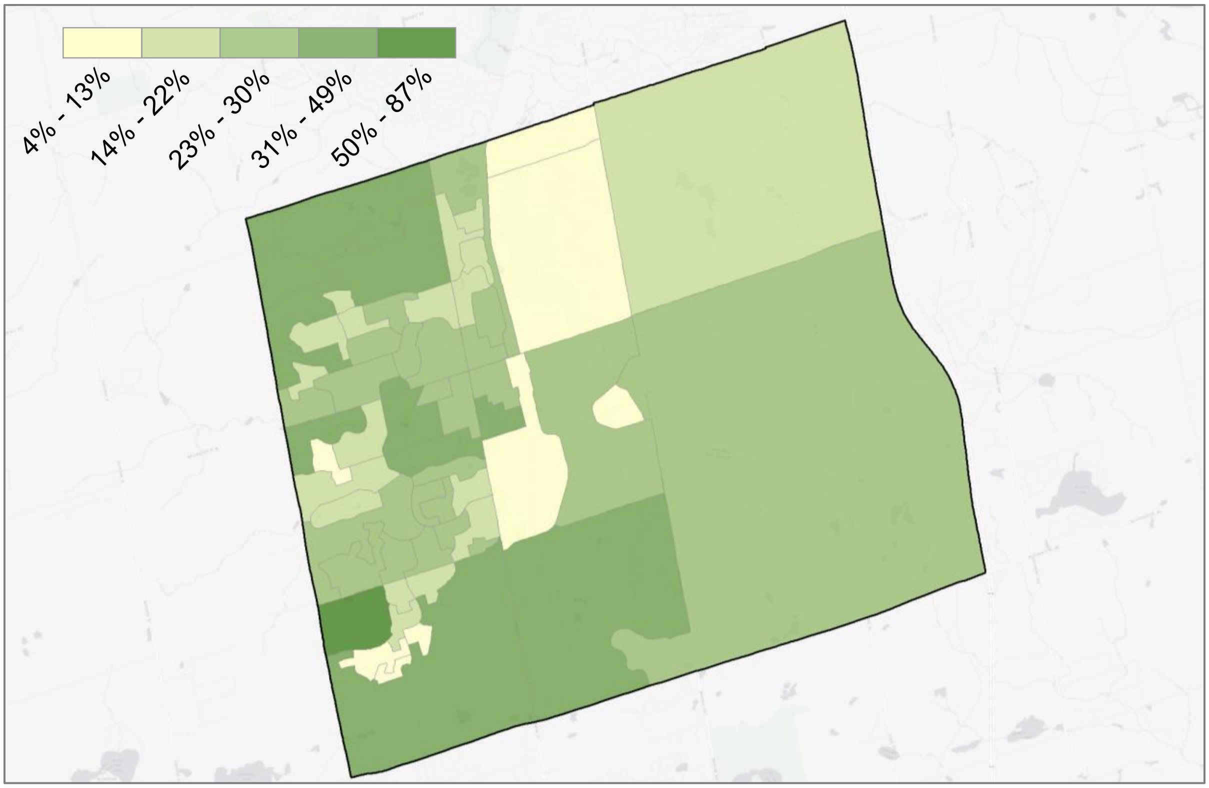

Figure 5: Existing tree canopy summarized by dissemination areas in Aurora

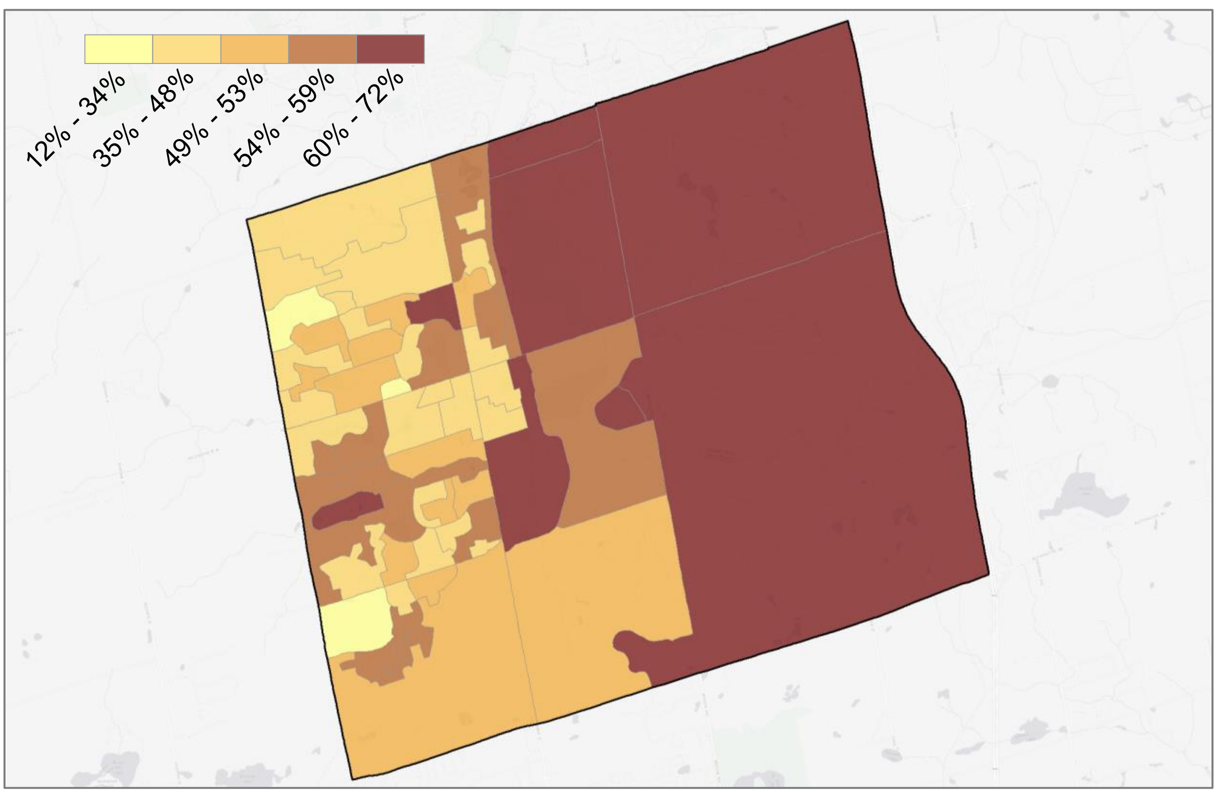

Figure 6: Possible tree canopy summarized by dissemination areas in Aurora

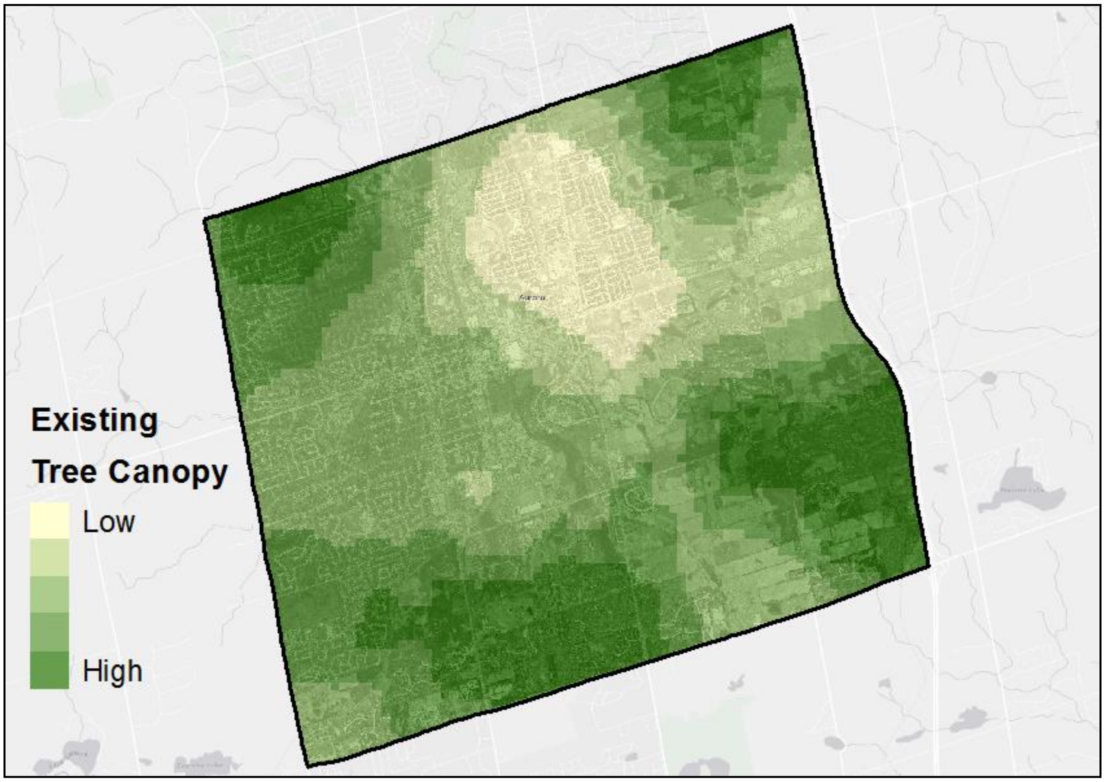

Figure 7: Existing tree canopy in Aurora

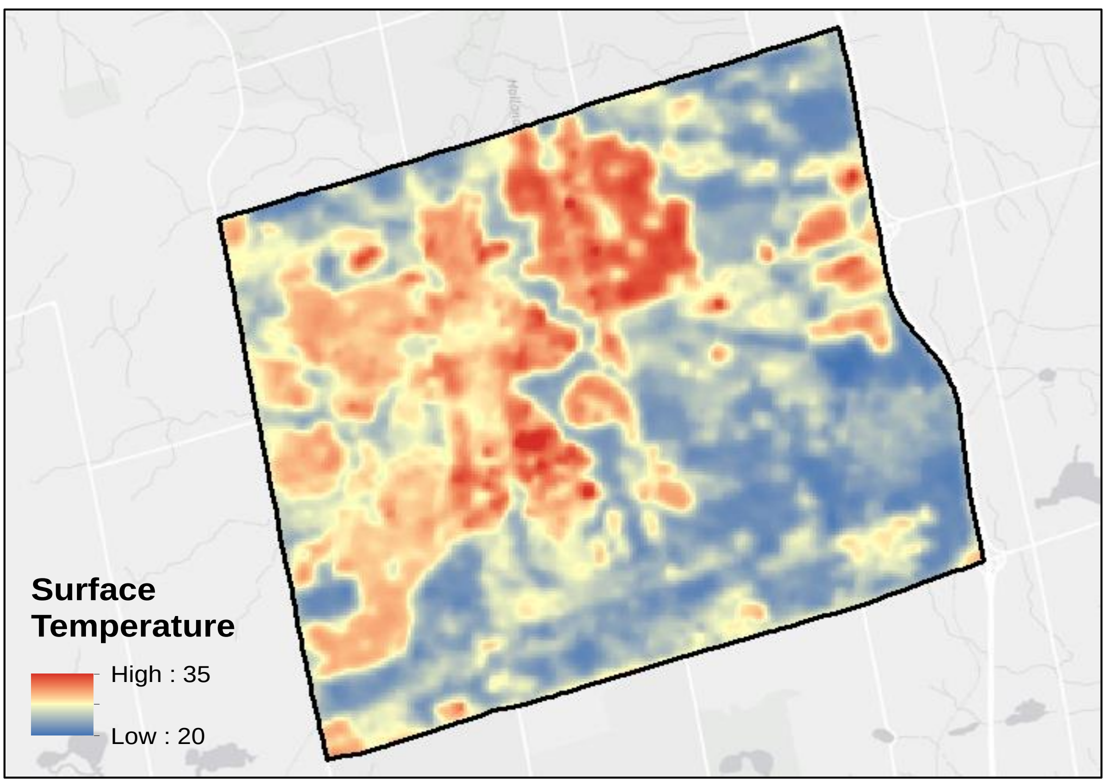

Figure 8: Surface temperature (degrees Celsius) in Aurora derived from Landsat satellite imagery, recorded July 18, 2014

4.2 Priority Planting Index

The priority planting index provides direction for tree planting and establishment. The index has been summarized at the scale of dissemination area (Figure 9). Each unit has been assigned a value between 0 (lowest priority) and 100 (highest priority). Units with a higher human population density and a lower tree canopy per capita have received a higher index value. Residential areas located throughout the western portion of municipality have been identified as high priority (shown in red), as these areas support a high population density but have a low relative tree canopy. Consequently, the ecosystem services provided by the urban forest are not currently distributed equitably across all neighbourhoods.

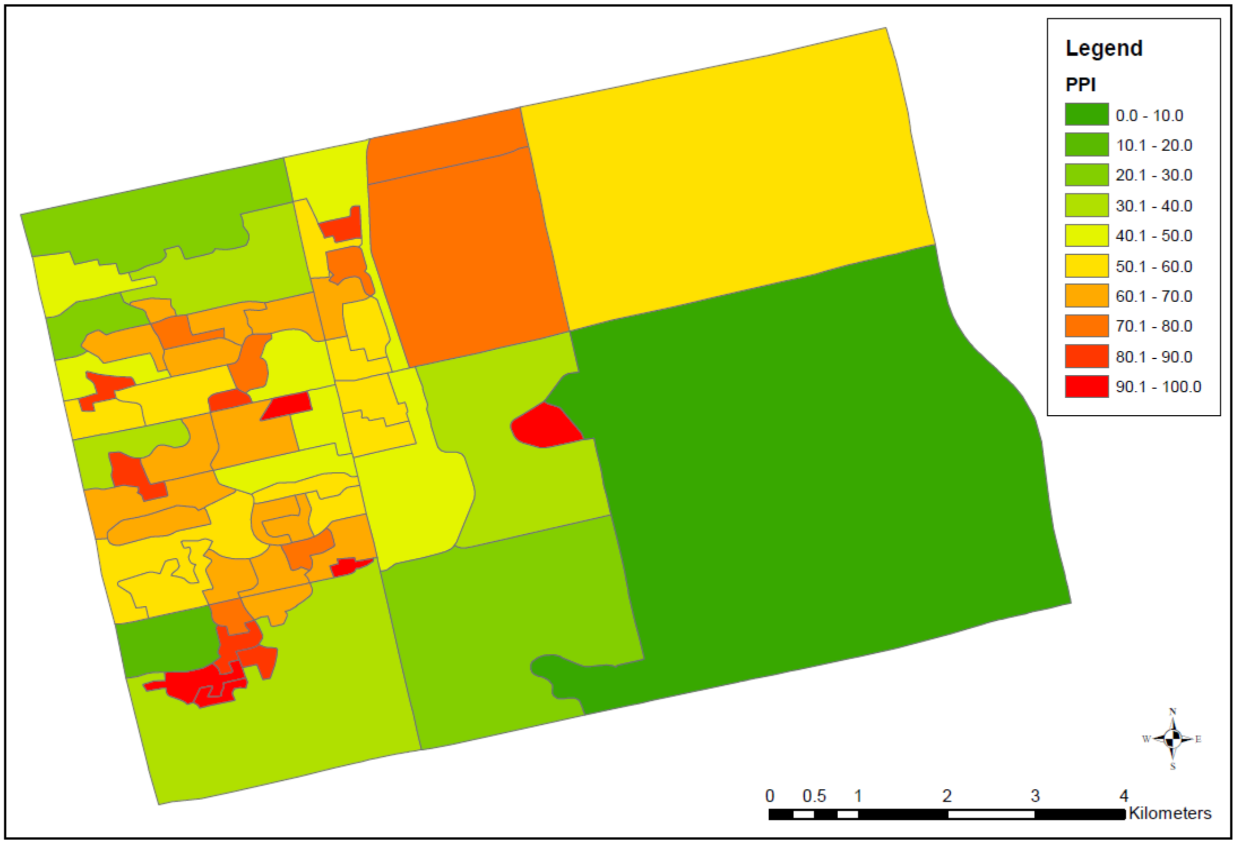

Figure 9: Priority planting index summarized by dissemination areas in Aurora

4.3 Urban Forest Structure

The i-Tree Eco model determined that there are approximately 1,953,000 trees in Aurora (with an acceptable standard error of 265,500). Average tree density in Aurora is 395 trees per hectare, which is considered relatively high in comparison to other North American cities. Tree density is highest in the *agriculture* category (485 trees/ha), followed by the *open space & natural cover* (475 trees/ha) and *commercial & industrial* (452 trees/ha) categories. In the *residential* land use category, tree density is low relative to the total number of trees in the category (Figure 10).

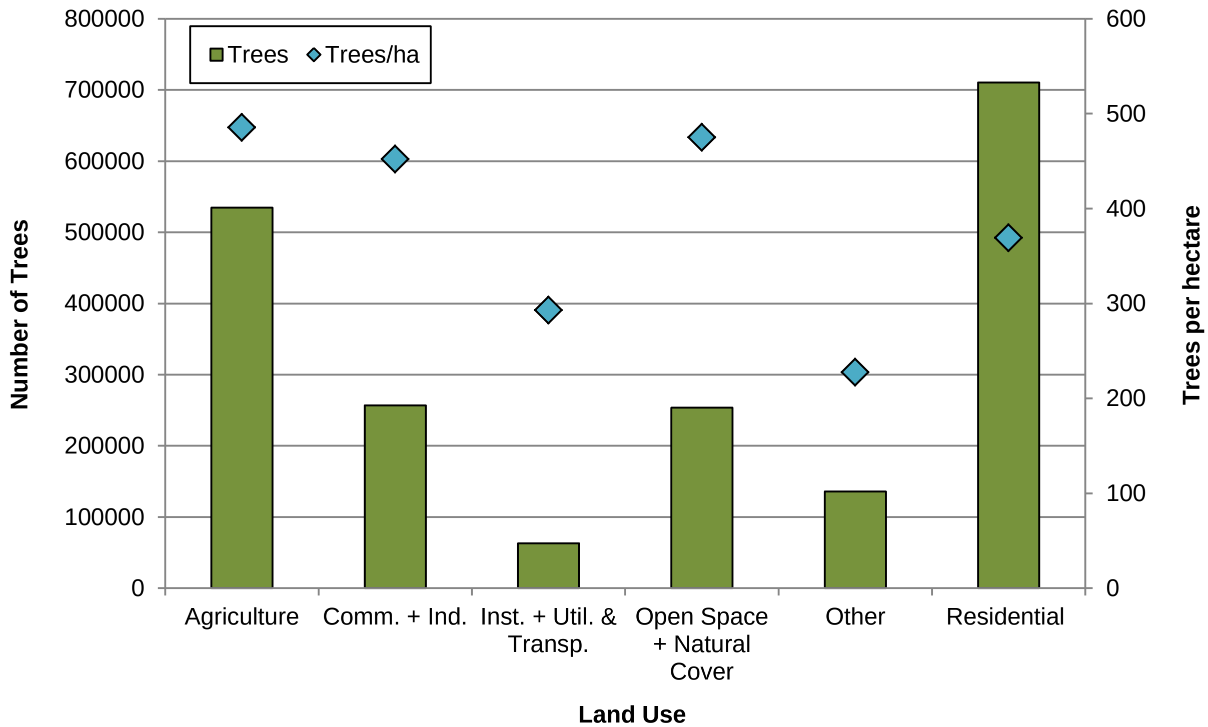

Figure 10: Total number of trees and tree density (trees per hectare) summarized by land use in Aurora.

Average leaf area density (including both trees and shrubs) in Aurora is approximately 20,050 m^2/ha, with a total of 99.14 km^2 of total leaf area across the municipality. This can also be expressed as 2 m^2 of leaf area for every 1.0 m^2 of land area. Leaf area varies between land uses and is concentrated in the *Open Space + Natural Cover* category (Figure 11). This land use represents 11% of the land in Aurora. Leaf area density is lowest in the *Institutional + Utilities & Transportation* category, which represents 4% of the land in Aurora.

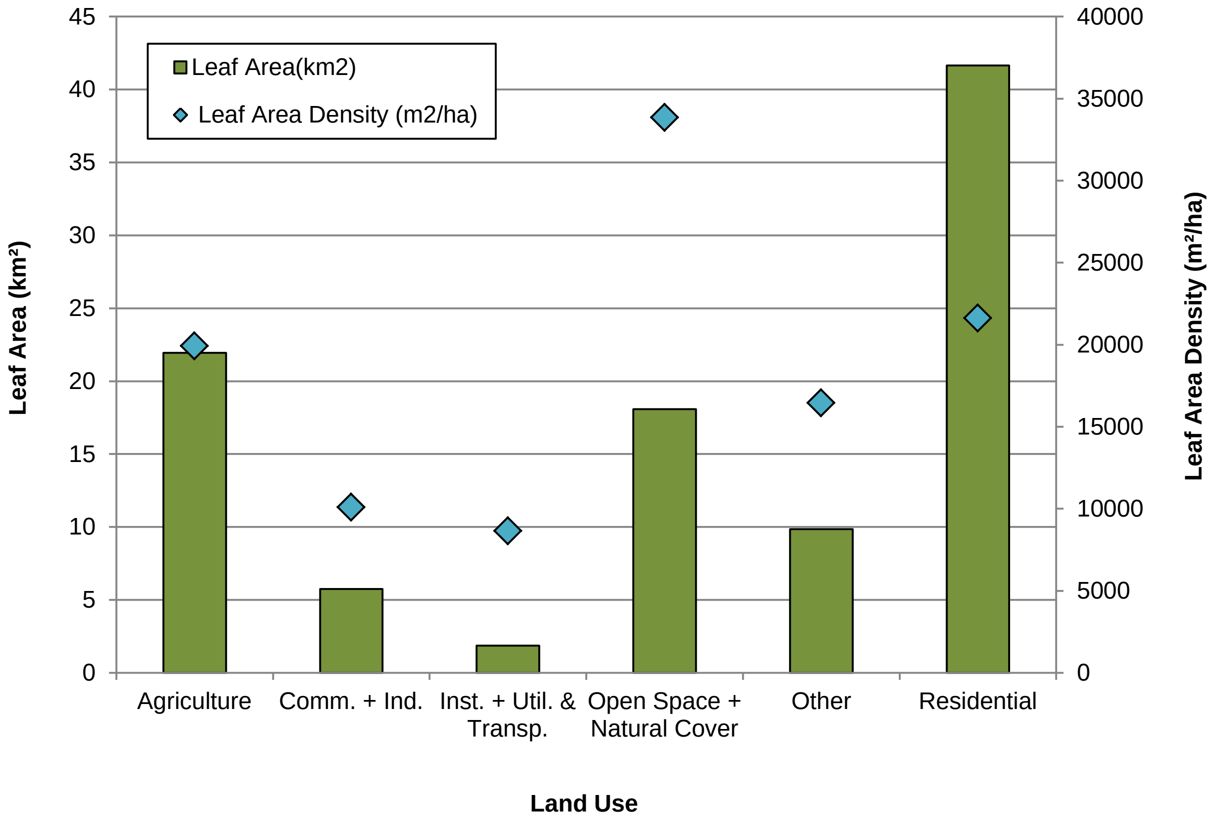

Figure 11: Leaf area (km²) and leaf area density (m²/ha) by land use in Aurora.

Tree species dominance can be expressed either as a percent of total leaf area or as a percent of the total number of stems (Figure 12). When the latter method is used, species that maintain a small growth form and that grow in high densities, such as buckthorn species (*Rhamnus* spp.), tend to dominate total species composition. In contrast, species composition expressed as a per cent of total leaf area captures the relative contribution made by each species to the canopy layer as well as to the provision of ecosystem services (as ecosystem services are generally a function of leaf area). With respect to total leaf area, the dominant tree species in Aurora are sugar maple (*Acer saccharum*, with 15% of total leaf area), eastern white cedar (*Thuja occidentalis*, 12%), and Norway maple (*Acer platanoides*, 8%).

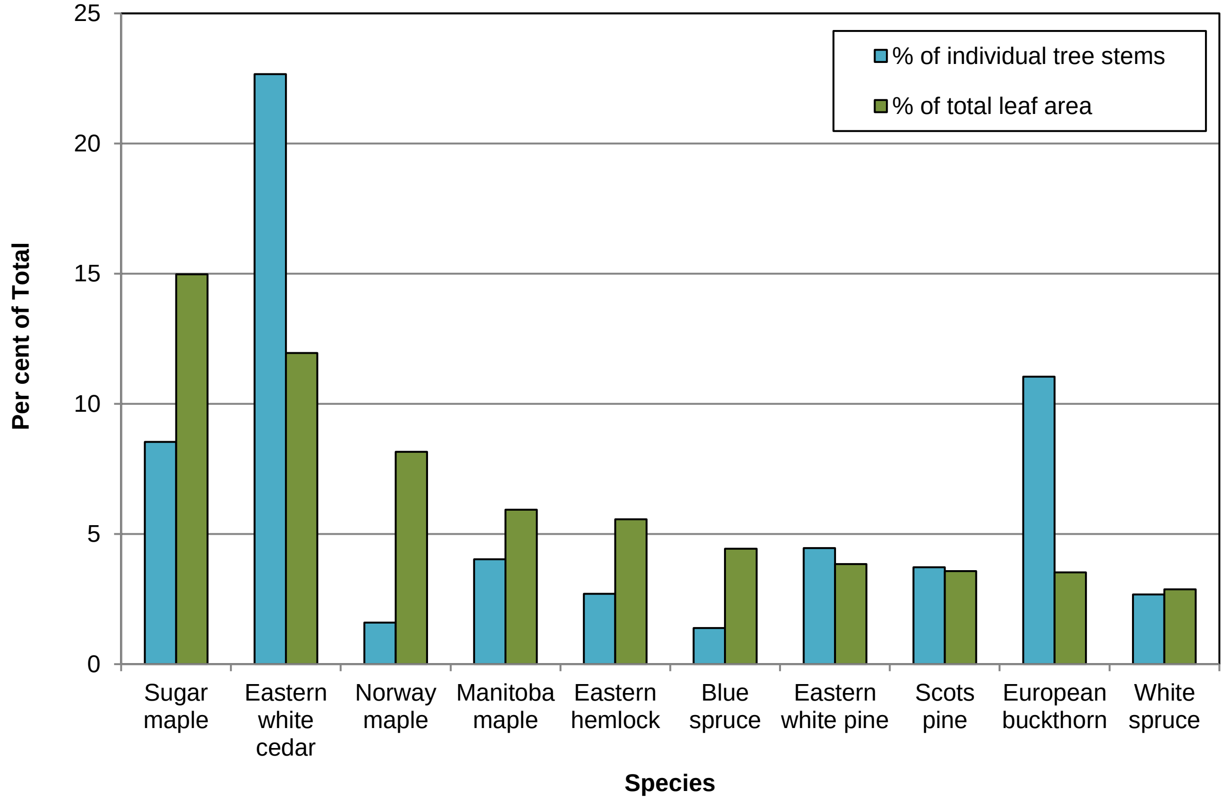

Figure 12: Top 10 tree species in Aurora expressed as a per cent of total stems and per cent of total leaf area.

With respect to the total number of individual tree stems, the most common tree species are eastern white cedar (*T. occidentalis*, 23%), European buckthorn (*R. cathartica*, 11%), and sugar maple (*A. saccharum*, 9%). Species dominance by land use is illustrated by Table 3. The most common genera in Aurora are Maple (*Acer* spp., 31% of total leaf area), Cedar (*Thuja* spp., 12% of total leaf area), Pine (*Pinus* spp., 10% of total leaf area), and Spruce (*Picea* spp., 10% of total leaf area).

A total of 91 species of trees and shrubs have been identified across all sample plots. Species richness is highest in the *residential* land use (69 species); this can likely be attributed to the number of exotic horticultural species found in residential yards and gardens. Thus, high species richness should not necessarily be viewed as an indication of ecosystem health. Rather, it may simply indicate an abundance of exotic species. Therefore, urban forests often have a species richness that is higher than surrounding rural landscapes. In Aurora, 77 per cent of the tree species identified are native to Ontario.

Table 3: Dominant tree species by per cent of total leaf area and per cent of total stems within land uses in Aurora. Estimates for the commercial + industrial and institutional + utilities & transportation land use categories are associated with high standard error.

Land Use	Percent of Total Leaf Area		Percent of Total Stems	
	Common Name	Per cent	Common Name	Per cent
Agriculture	Eastern white cedar	20	Eastern white cedar	21
	Black walnut	9	European buckthorn	19
	European buckthorn	9	White ash	10
Commercial + Industrial	Manitoba maple	15	European buckthorn	31
	Silver maple	15	Staghorn sumac	19
	European buckthorn	14	Red pine	16
Institutional + Utilities & Transportation	Manitoba maple	31	Eastern white cedar	68
	Eastern white cedar	25	White spruce	13
	White spruce	22	Norway maple	4
Open Space + Natural Cover	Sugar maple	30	Sugar maple	23
	Eastern hemlock	17	American beech	13
	American basswood	8	Eastern hemlock	13
Other	Sugar maple	21	Eastern white cedar	14
	Eastern hemlock	19	Eastern hemlock	12
	Blue spruce	10	Sugar maple	10
Residential	Norway maple	15	Eastern white cedar	34
	Sugar maple	13	Sugar maple	10
	Eastern white cedar	12	Eastern white pine	8

Table 4 presents the per cent of stems that have been planted for the most common tree species in Aurora. Many of the most common tree species in Aurora are high in abundance due to natural regeneration, including European buckthorn (100 per cent attributed to natural regeneration), sugar maple (99 per cent attributed to natural regeneration), and white ash (98 per cent attributed to natural regeneration). For the purposes of this study all stems ≥ 2.5 cm dbh were classified as tree species; stems < 2.5 cm dbh were classified as shrubs. This classification was independent of the projected long-term growth patterns for each species.

Common shrub species in Aurora include eastern white cedar and European buckthorn, comprising 14 and 9 per cent of the total shrub leaf area, respectively. Table 5 presents the most common shrub species for each land use in the study area.

Table 4: Per cent of stems planted (versus natural regeneration) for common tree species in Aurora, where "n" equals number of trees sampled.

Common Name	Scientific Name	% planted	n
Blue spruce	*Picea pungens*	100	45
White spruce	*Picea glauca*	86	84
Red pine	*Pinus resinosa*	82	102
Eastern white cedar	*Thuja occidentalis*	68	717
Norway maple	*Acer platanoides*	67	51
Scots pine	*Pinus sylvestris*	50	120
Eastern white pine	*Pinus strobus*	44	144
American beech	*Fagus grandifolia*	4	91
Manitoba maple	*Acer negundo*	4	133
White ash	*Fraxinus americana*	2	221
Alternate-leaf dogwood	*Cornus alternifolia*	2	62
Eastern hemlock	*Tsuga canadensis*	1	88
Staghorn sumac	*Rhus typhina*	1	91
Sugar maple	*Acer saccharum*	1	276
European buckthorn	*Rhamnus cathartica*	0	367

Table 5: Dominant shrub species by per cent of shrub area within land uses in Aurora.

Land Use	Common Name	% of shrub leaf area
Agriculture	European buckthorn Eastern white cedar	17 12
Commercial + Industrial	European buckthorn American fly honeysuckle	34 16
Institutional + Utilities & Transportation	Winged euonymus White spruce	36 28
Open Space + Natural Cover	Eastern white cedar European buckthorn	17 15
Other	Boxwood European buckthorn	18 9
Residential	Eastern white cedar Common lilac	16 8

Pest susceptibility was calculated for the following insects/ diseases: Asian long-horned beetle (*Anoplophora glabripennis*), emerald ash borer (*Agrilus planipennis*), gypsy moth (*Lymantria dispar*), and Dutch elm disease (*Ophiostoma* spp.) (Figure 13). Estimates represent the maximum potential pest damage expressed as a per cent of all live trees susceptible in Aurora. Approximately 21 per cent of Aurora's live tree population (live stems) is susceptible to Asian long-horned beetle. This equates to a potential loss in structural value of approximately $236,000,000. Gypsy moth is a threat to 11 per cent of the live tree population with a potential loss in structural value of $67,000,000. Emerald ash borer is a threat to 9 per cent of the live tree population, representing a potential loss of $20,000,000 in structural value. Although some elm species have shown varying degrees of resistance, Dutch elm disease could destroy the remaining elm population, representing approximately 1 per cent of the live tree population, valued at $1,000,000.

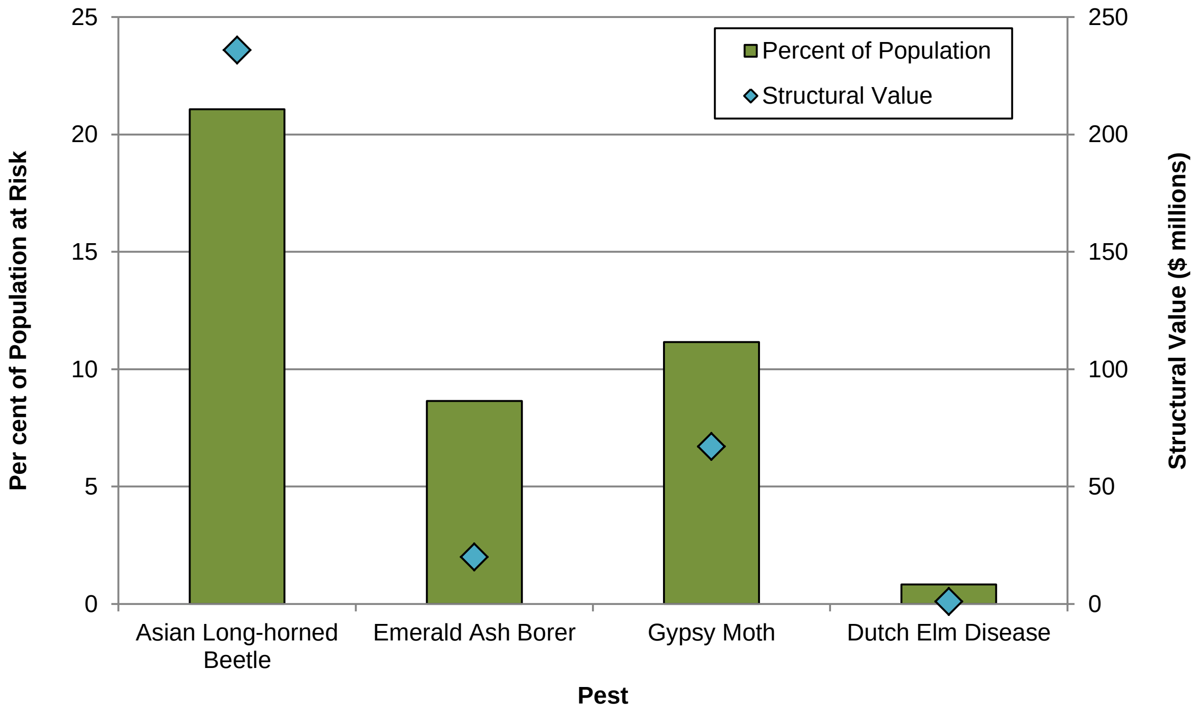

Figure 13: Per cent of the tree population in Aurora that is susceptible to Asian long-horned beetle, emerald ash borer, gypsy moth, and Dutch elm disease, and potential loss in associated structural value of host trees.

All trees measured have been grouped into size classes based on dbh; diameter classes increase in 7.6 cm increments. Approximately 51 per cent of all trees in Aurora fall within the smallest diameter class and 74 per cent of all trees are less than 15.3 cm dbh (Figure 14). The proportion of large trees is low; approximately four per cent of the tree population has a dbh of 38.2 cm or greater. Figure 15 presents the diameter class distribution by land use. Across all land uses the trend is similar, with the smallest diameter classes containing the large majority of trees, while very few trees are found in the larger (> 38.1 cm) diameter classes. Average tree diameter across the urban forest is 10.6 cm.

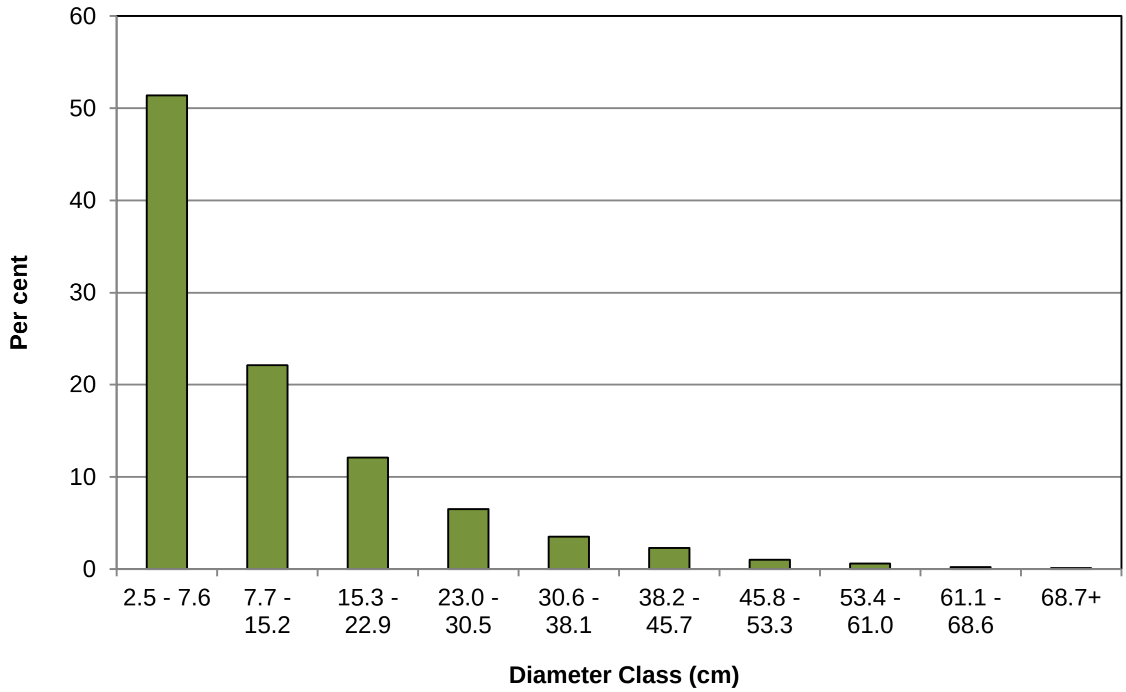

Figure 14: Diameter class distribution of trees in Aurora.

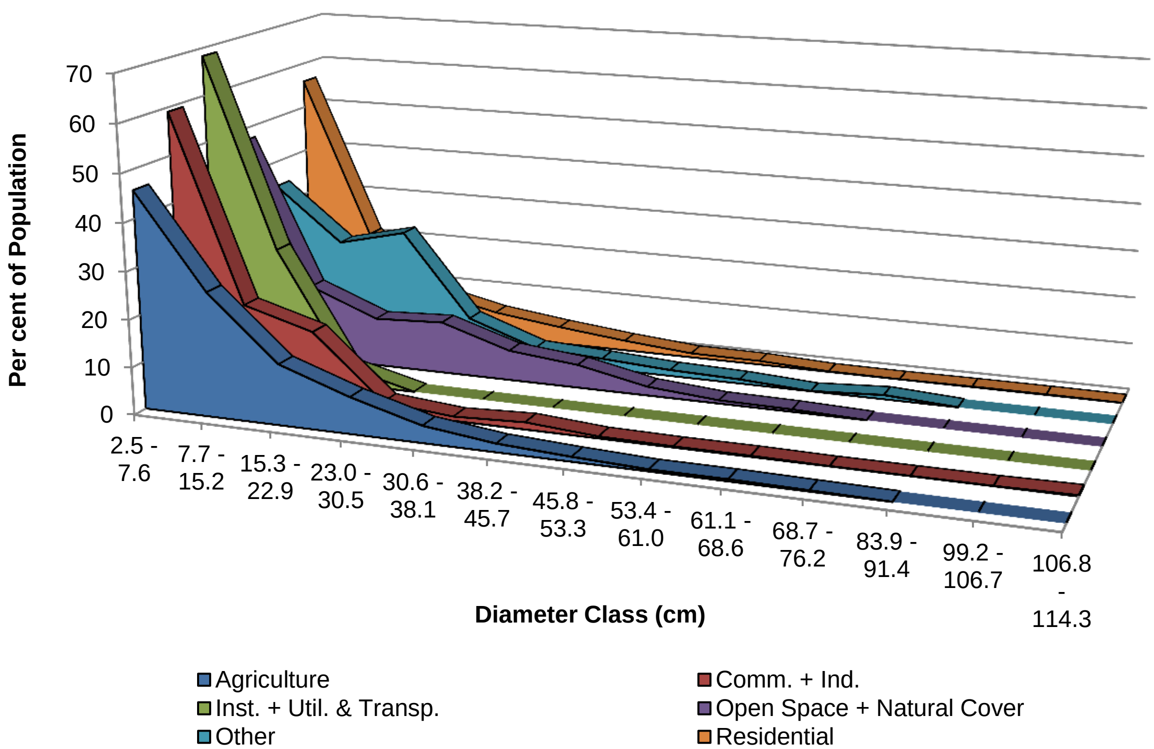

Figure 15: Diameter class distribution of trees by land use class in Aurora.

All trees measured were assigned a condition rating in the field based on the proportion of dieback in the crown. The crown condition ratings range from excellent (< 1 per cent dieback) to dead (100 per cent dieback). Approximately 75% of trees in Aurora were rated as being in excellent or good condition (Figure 16). Condition ratings do not incorporate stem defects and root damage.

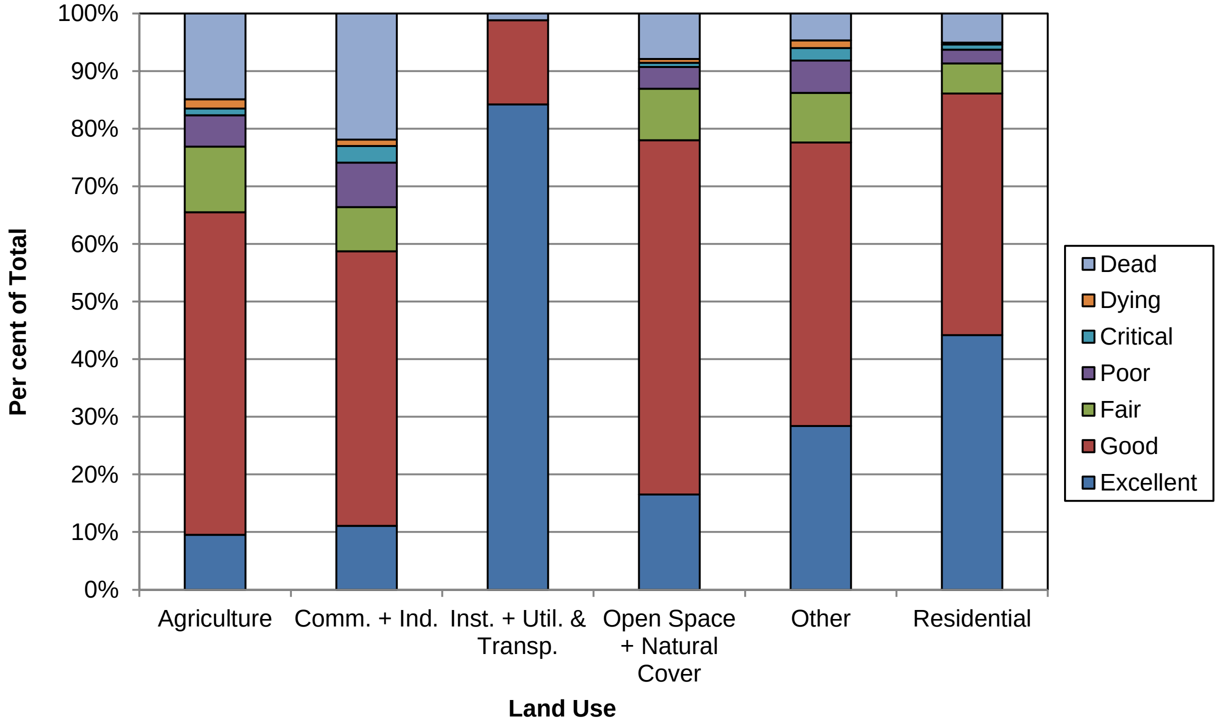

Figure 16: Average tree condition by land use in Aurora.

The estimated structural value of all trees in Aurora in 2013 is approximately $627 million. This value does not include the ecological or societal value of the forest, but rather it represents an estimate of tree replacement costs and/or compensation due to tree owners for tree loss. There is a positive relationship between the structural value of an urban forest and the number and size of healthy trees.

4.4 i-Tree Forecast

The i-Tree Forecast model simulations provide a general estimate of the level of annual tree planting required to meet multiple canopy cover targets within the next 50 years. The model simulates the growth of Aurora’s urban forest based on existing conditions as quantified by the i-Tree Eco analysis. Simulations are based on existing urban forest characteristics, including species growth rates and current tree health. The results are summarized into two scenarios: number of trees planted annually in order to maintain existing canopy cover (currently 22 per cent, as estimated by the i-Tree Eco model); and number of trees planted annually to increase canopy cover to 40 per cent. In addition, the anticipated impact of the emerald ash borer beetle has also been included in these scenarios by assuming 100 per cent mortality of all ash species over the next ten years, described in Table 6 as “Total Ash Kill”.

With an annual mortality rate of 4 per cent, approximately 25,000 trees will need to be planted to maintain the existing canopy cover over a 50 year period (Table 6). If the total ash population of Aurora is lost the number of trees required for annual planting climbs to 33,000. Under a 4 per cent annual mortality scenario, approximately 57,500 trees must be planted annually across the municipality to reach a 40 per cent canopy cover target over the next 50 years; when the loss of all ash species is factored into this scenario the number of trees required climbs to 70,000 annually. Results assume that mortality rates and maintenance practices are held constant over time.

Table 6: Estimated amount of tree planting required in Aurora to: 1) maintain existing canopy cover of 22 per cent; and 2) increase canopy cover to 40 per cent over a 50 year period, given 5 possible annual mortality rates.

Annual Mortality Rate	Annual tree planting to maintain 22% cover		Annual tree planting to increase to 40% cover	
	No Ash Kill	Total Ash Kill	No Ash Kill	Total Ash Kill
2%	0	0	4,000	11,000
3%	5,000	11,000	30,000	40,000
4%	25,000	33,000	57,500	70,000
5%	45,000	57,000	89,500	105,000
6%	67,000	80,000	123,000	140,000

4.5. Hydrologic Effects of the Urban Forest

Urban forest studies conducted across York Region have used the i-Tree Hydro model to simulate the effects of tree and impervious cover on stream flow in local watersheds. These analyses found that trees in two of York Region subwatersheds (used as sample study areas) can reduce levels of stream flow by intercepting rainfall. For example, in the Upper Rouge subwatershed a loss of all existing tree cover (27 percent) would result in an increase in stream total flow by approximately 2.9 per cent. Simulated reductions of impervious ground cover in these same subwatersheds produced more substantial reductions in total stream flow. Increases in tree cover correspondingly showed comparatively small reductions in total flow. For example, increasing tree cover to 20 per cent in the West Don subwatershed showed a reduction in total flow of 0.9 per cent.

4.6 Urban Forest Function

4.6.1 Annual Pollution Removal

The i-Tree Eco model quantified pollution removal by trees and shrubs in Aurora. Pollution removal is greatest for ozone (O_3), followed by particulate matter less than ten microns (PM_{10}), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO), and particulate matter less than two and a half microns ($PM_{2.5}$), (Figure 17).

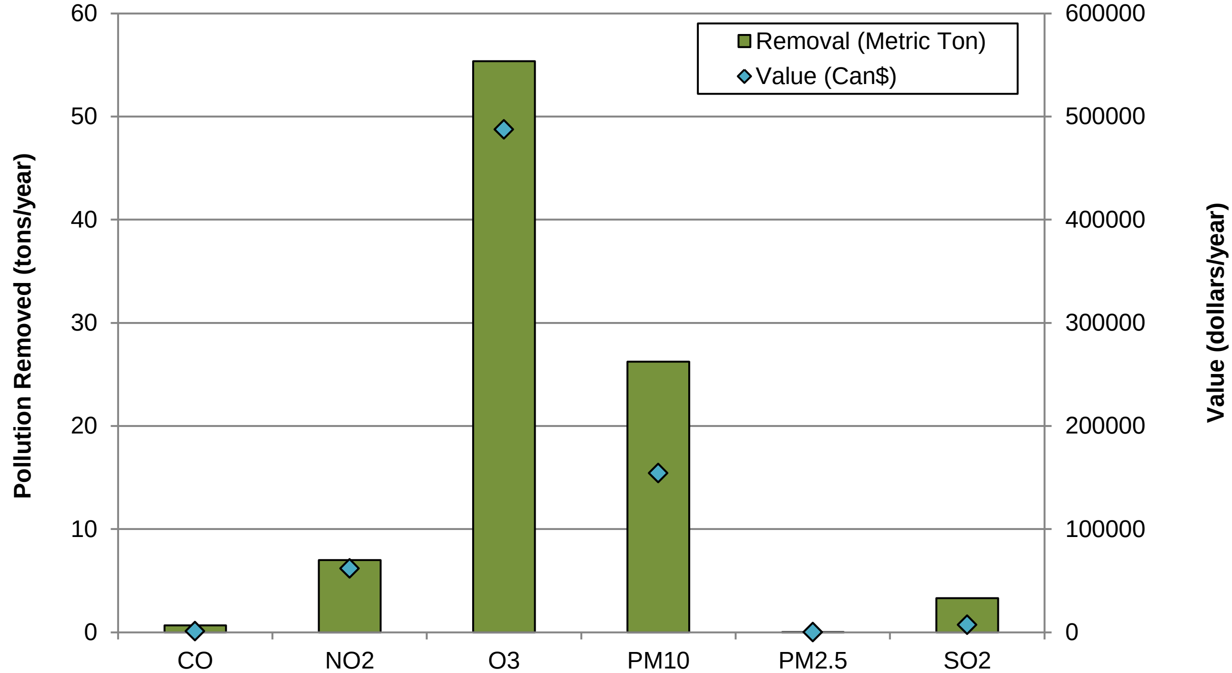

Figure 17: Annual pollution removal by trees and shrubs and associated removal value.

Trees and shrubs remove 93 tonnes of air pollution (CO, NO_2, O_3, PM_{10}, $PM_{2.5}$, SO_2) per year with an associated removal value of $711,380 (based on estimated national median externality costs associated with pollutants[2]). Average annual pollution removed per tree generally increases with tree size (Figure 18).

[2]Murray, F.J.; Marsh L.; Bradford, P.A. 1994.New York state energy plan, vol. II: issue reports. Albany, NY: New York State Energy Office. An externality is a side effect of an economic transaction whose damages or benefits are not taken into account in the price of the transaction. Water pollution from industries is an example of a negative externality. Values were adjusted to Canadian dollars with a conversion rate of 0.8 US dollars per Canadian dollar.

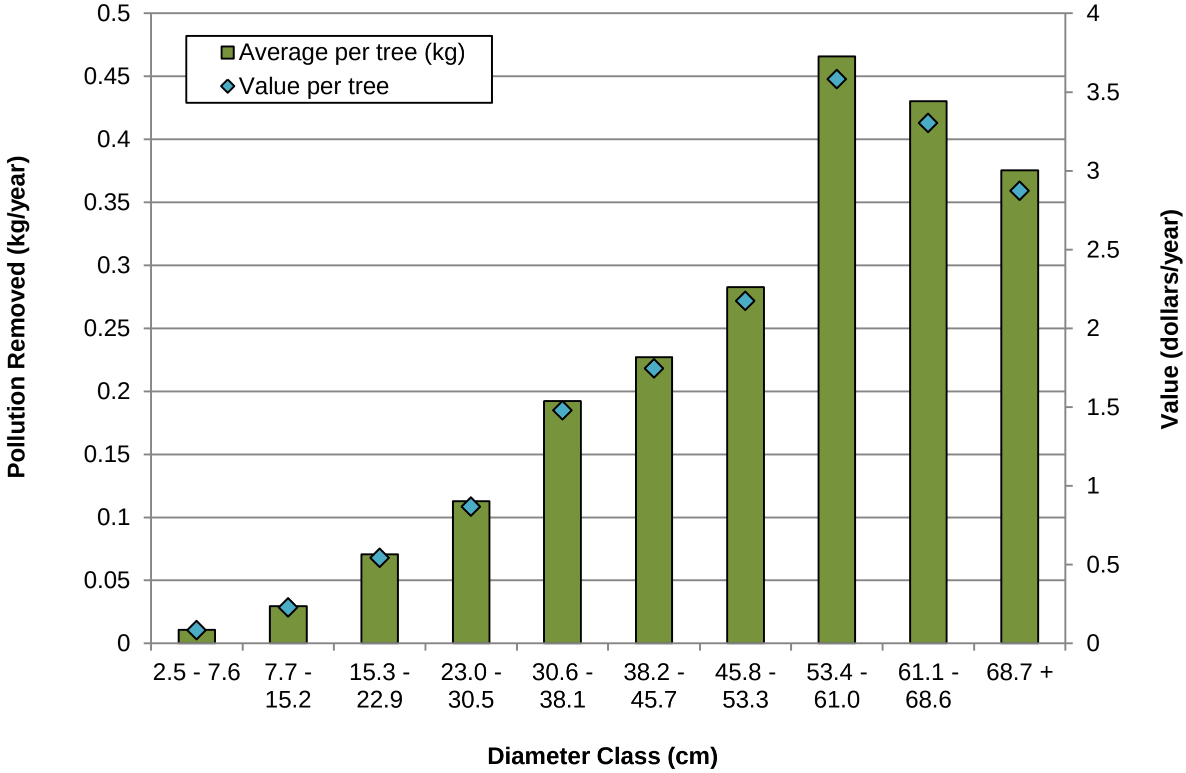

Figure 18: Average annual volume of pollution removed per tree and associated removal value summarized by diameter class.

4.6.2 Carbon Storage and Sequestration

According to the estimates produced by the i-Tree Eco model gross sequestration by trees in Aurora is approximately 4,050 tonnes of carbon per year (14,900 tonnes per year of carbon dioxide) with an associated value of $313,000 per year. Net carbon sequestration in Aurora is approximately 2,500 tonnes per year (9,200 tonnes per year of carbon dioxide) based on estimated carbon loss due to tree mortality and decomposition.[3]

Trees in Aurora are estimated to store 103,000 tonnes of carbon (378,000 tonnes of carbon dioxide); the value of this service is $7.97 million. Of all the species sampled, Sugar maple (*A. saccharum*) stores the greatest volume of carbon (approximately 20 per cent of total carbon stored) and annually sequesters the greatest gross volume of carbon (16 per cent of all gross sequestered carbon). Eastern white cedar sequesters the greatest net volume of carbon (13 per cent of all net sequestered carbon).

Figure 19 illustrates total carbon storage and total annual carbon sequestration distributed by diameter class. This graph should be viewed in the context of the diameter class distribution of the entire tree population (Figure 14). For example, trees greater than 68.6 cm dbh represent less than 1 per cent of the total tree population in Aurora, yet these trees store approximately 9 per cent of the total volume of carbon. In contrast the smallest trees (2.5 to 15.2 cm dbh) represent approximately 74 per cent of the tree population but store less than 10 per cent of the

[3] Net annual sequestration = gross sequestration minus estimated carbon emissions due to mortality or decomposition.

total volume of carbon. When the results are standardized to illustrate average *per tree storage capacity,* individual large trees are shown to store significantly larger volumes of carbon than individual small trees (Figure 20).

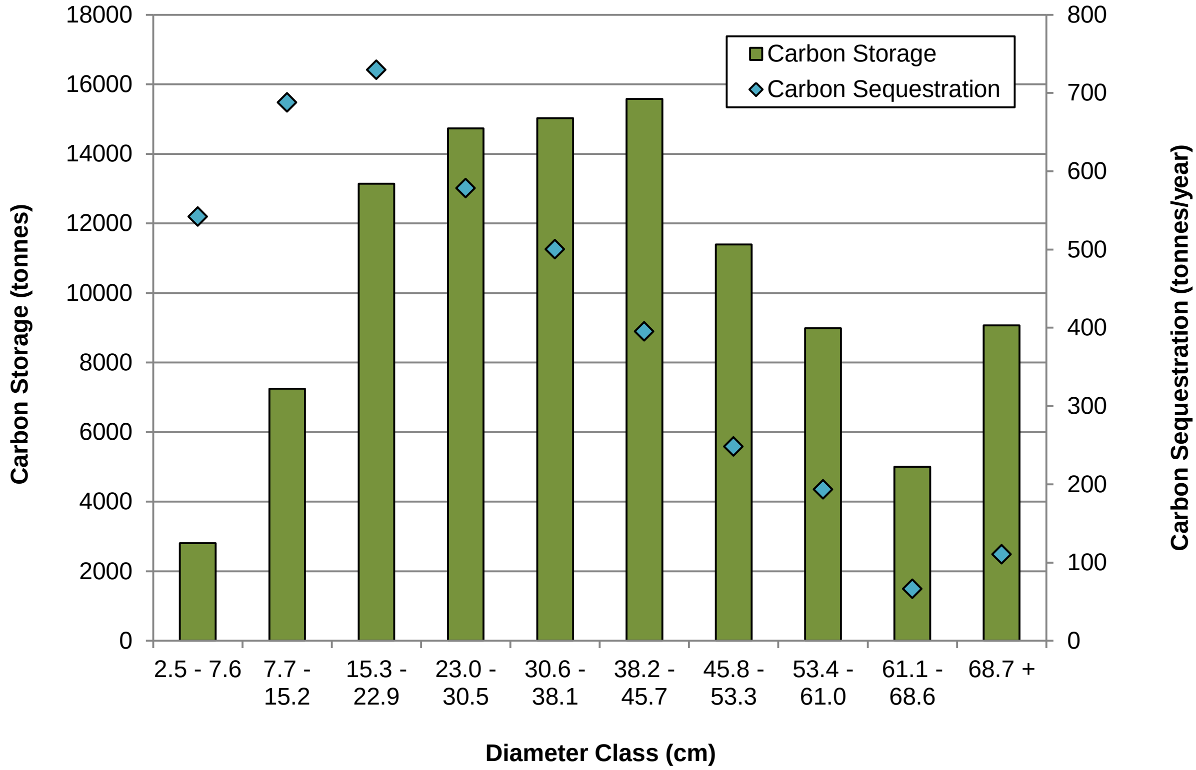

Figure 19: Total carbon storage and sequestration by diameter class

Average sequestration rates are also positively correlated with tree size. For example, the average tree in diameter class 7.7 – 15.2 cm stored 17 kg of carbon and sequestered 1.6 kg of carbon annually, while the average tree in diameter class 38.2 – 45.7 cm stored 346 kg of carbon and sequestered 8.8 kg of carbon annually.

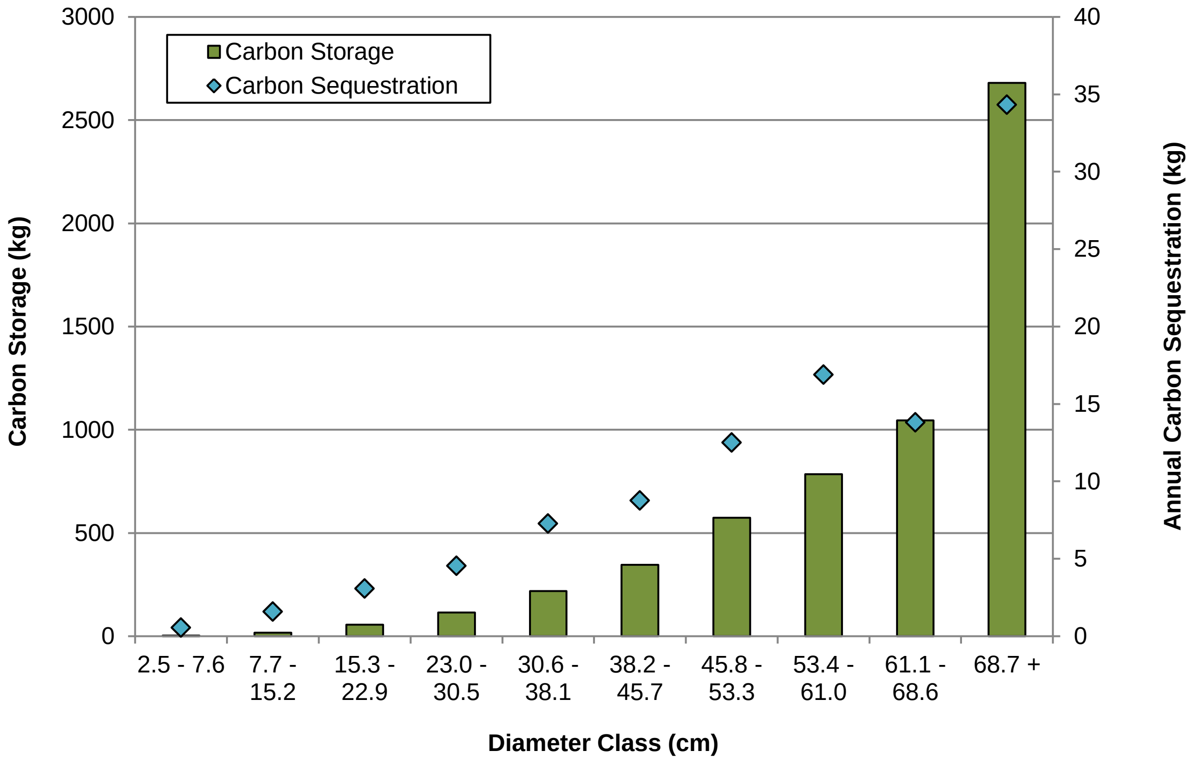

Figure 20: Average per tree carbon sequestration and storage by diameter class

4.6.3 Residential Energy Effects

The i-Tree Eco model estimates the effects of trees (≥ 6.1m in height and within 18.3m of a residential building) on building energy use as a result of shading, windbreak effects, and local micro-climate amelioration. Estimates are based on field measurements of tree distance and direction to space-conditioned residential buildings. Annually, trees adjacent to residential buildings in Aurora are estimated to reduce energy consumption by approximately 30,300 million British thermal units (MBTU) for natural gas use and 2,117 megawatt-hours (MWH) for electricity use (Table 7).

Table 7: Annual energy savings and carbon avoided due to trees near residential buildings.

Energy Units	Heating	Cooling	Total
Natural Gas (Million British Thermal Units)	30,300	n/a	30,300
Electricity (Megawatt-hour)	260	1,860	2,100
Carbon avoided (tonnes)	500	120	620

Based on average energy costs, trees in Aurora are estimated to reduce energy costs for residential buildings by $475,000 annually (Table 8). Trees also provide an additional $48,150 per year by reducing the amount of carbon released by fossil-fuel based power plants (a reduction of 620 tonnes of carbon emissions).

Table 8: Annual financial savings (Canadian $) in residential energy expenditures during heating and cooling seasons.

Energy Units	Heating	Cooling	Total
Natural Gas	$ 316,700	n/a	$ 316,700
Electricity	$ 19,425	$ 139,350	$ 158,775
Carbon avoided	$ 39,100	$ 9,050	$ 48,150

5.0 Discussion

This section offers a discussion of the results and presents recommendations for strategic management; these recommendations are listed at the end of each relevant section and summarized again in Section 6.0. The implementation of these recommendations will be dependent on available resources and will be subject to annual budget approval.

5.1 State of the Urban Forest

The discussion and recommendations presented in this Section pertain to three aspects of urban forest structure: distribution; species composition; and size. Many benefits attributed to the urban forest, as listed in Section 1.0, are largely influenced by these structural elements.

5.1.1 Existing and Possible Urban Forest Distribution

Aurora's urban forest covers approximately 28 per cent of the total land area. Total leaf area in the study area is approximately 99 km^2, with a leaf area density of 2 m^2/m^2. Urban forest cover is not evenly distributed across the municipality, and is strongly influenced by urban morphology, design, and land use.

Approximately 59 per cent of the municipality has been identified as possible tree canopy. These results have been produced from a spatial data set that can be further refined to address social and economic land use considerations. For example, agricultural areas and sports fields have been categorized as possible areas for tree establishment; however tree planting in these areas may be socially undesirable in the context of food production and recreation. By refining these data the municipality can generate a precise estimate of plantable space that is physically, socially and economically feasible. In turn, the refined digital cover maps can be used to generate realistic urban forest targets that consider existing and possible canopy cover.

The process of prioritizing tree planting and establishment efforts should consider a range of biophysical and social factors related to the *need* for tree planting as well as the *suitability* of sites for tree planting. A suite of criteria to guide this process can therefore be developed so that decision-makers can effectively prioritize sites and optimize the urban forest in a strategic manner. With respect to a *need* for tree planting, variables to consider may include urban heat island mitigation, stormwater management, localized air pollution, household income, human health, and natural system integrity; the number of variables included will be dependent on the range of tools and spatial datasets available. With respect to the *suitability* of sites for tree planting, variables to consider may include ownership type, land use designation (e.g. sports field, residential yard) and cost. For a detailed example of criteria-driven prioritization process please see the methodology developed by Locke *et al.* 2010.

Planting and establishment activities need not be focused only in areas lacking tree cover. Rather, a successful strategy for increasing the ecosystem services provided by the urban forest should include an under-planting program, which will not only increase leaf area density in the short-term, but will also ensure that aging trees are gradually replaced by a younger generation. Succession planning will be particularly important in areas that support a high proportion of ash trees that are likely to be killed *en masse* by the emerald ash borer (EAB). Although succession planning alone cannot mitigate the full impacts of EAB due to the speed at which the insect is projected to move through the municipality, it can ensure that replacement trees are established before full ash canopy loss. Municipal staff is now actively engaged in emerald ash borer mitigation activities, including succession planning and applying treatments to ash trees located along streets and boulevards. Tree removals are taking place where treatment is insufficient and where public safety is a concern. The Town has also developed two nursery sites specifically for the cultivation of replacement trees for boulevards and parks.

Increasing native shrub cover under canopied areas also represents an opportunity to increase total leaf area. Shrub cover that is established around mature trees can discourage trampling, compaction of root zones, and damage from mowers or other yard equipment. Shrubs can also add attractive visual elements to the landscape. Many of the benefits provided by the urban forest, such as microclimate amelioration and sequestration of gaseous pollutants, are directly related to leaf-atmospheric processes (e.g., interception, transpiration) (McPherson, 2003). It follows that an increase in the provision of these benefits can be best achieved by increasing total leaf area density.

Distribution of the urban forest is also an important social justice consideration. Ultimately the protection of trees equates to the protection of ecosystem services that are essential to the health of both humans and wildlife (e.g. clean air, cooler summer temperatures). The services provided by the urban forest are an asset that belong to the entire community, and must be managed in a manner that ensures equal access by all residents. For example, housing market inequalities may lead to uneven distribution of urban reforestation efforts, biased toward owner-occupiers. In Milwaukee, Wisconsin, an urban reforestation program offered both homeowners and renters the opportunity to obtain a free tree. However, the vast majority of trees planted in this program were done so on owner-occupied land, suggesting that renters were less willing to participate in tree planting efforts around their houses (Perkins *et al.*, 2004). Residents in higher density and newer housing areas may also receive fewer benefits from the urban forest as trees in these neighbourhoods tend to be smaller and less abundant. Urban forest management plans that seek to address such inequalities can more effectively contribute to community sustainability.

Recommendation 1: Refine the results of the urban tree canopy (UTC) analysis to develop an urban forest cover target.

Recommendation 2: Build on the results of the urban tree canopy analysis (UTC) and the priority planting index to prioritize tree planting and establishment efforts to improve the distribution of ecosystem services, including urban heat island mitigation and stormwater management.

Recommendation 3: Increase leaf area in canopied areas by planting suitable tree and shrub species under existing tree cover. Planting efforts should continue to be focused in areas of the municipality that currently support a high proportion of ash species.

5.1.2 Tree Species Effects

The dominant tree species in the study area is sugar maple (*Acer saccharum*), representing 15 per cent of the total leaf area. Species composition in Aurora is influenced by the pattern of vegetation distribution among land uses. As such, species common in the *residential* land use class can strongly influence municipal-scale species composition. For example, eastern white cedar (*Thuja occidentalis*) comprises approximately 34 per cent of all stems in the *residential* land use and is the most common species in Aurora when expressed as a per cent of total stems. This is largely due to the extensive use of the species in hedgerows in residential backyards, but large contributions may also be attributed to its use in plantation woodlots that fall under the *agriculture* and *other* categories.

The most common genera in Aurora are Maple (*Acer* spp., 31% of total leaf area), Arborvitae/ White cedar (*Thuja* spp., 12% of total leaf area), Pine (*Pinus* spp., 10% of total leaf area), and Spruce (*Picea* spp., 10% of total leaf area). Together, these four genera represent 63 per cent of the total leaf area. These native genera (which also contain some non-native species) are found across land use categories, as they are able to thrive in sheltered natural areas as well as high-traffic urban zones. A high relative abundance of maple species in particular is typical to the forests of this eco-region; however, the lack of diversity among genera is a potential threat to the sustainability of the urban forest. Species diversity is a crucial element of ecological resiliency. Dominance by a single tree species or genus will increase the possibility of large-scale tree mortality in the event of pest outbreaks that are species-specific (Sanders, 1978). Thus, an urban forest that is not sufficiently diverse is at risk of widespread canopy loss. For example, the spread of Dutch elm disease (*Ophiostoma* spp.) virtually eliminated the once ubiquitous American elm from the urban landscape during the twentieth century. Unfortunately, when the elms were replaced – largely by ash and maple – the guiding principle that influenced planting was once again informed by visual uniformity rather than ecological resiliency.

The risk associated with a lack of species diversity is currently exemplified by the emerald ash borer infestation. Ash species (*F. americana, F. pennsylvanica*, *F. nigra*) are distributed across all land uses in Aurora, reflecting the ability of these species to thrive in both natural areas and high traffic urban environments where soil quality is poor. Unfortunately, Aurora is now at risk of losing all ash species in the municipality, which represents a significant portion of the urban forest (9 per cent of the tree population). Since emerald ash borer has been a presence on the landscape for several years now, it is possible that this number already represents a reduction in the ash population from an earlier, healthier state. Asian long-horned beetle is another cause for concern, as it targets a range of hardwood species that comprise approximately 21 per cent of the tree population, with a preference for multiple species of maple, which account for 31 per cent of the total leaf area.

In order to avoid future canopy loss, Santamour (1990) recommends that an urban forest contain no more than 10 per cent of any single species, no more than 20 per cent of any single genus, and no more than 30 per cent of any single family. However, the “10-20-30” approach has been criticized for its inability to account for potential damage by multi-host pests, such as the Asian long-horned beetle (Raupp *et al.*, 2006). To address this concern, Lacan and McBride (2008) created the Pest Vulnerability Matrix (PVM), which provides a rapid analysis and graphic display of the interaction between urban tree species diversity and the susceptibility of the urban forest to insects and diseases. The model predicts how the introduction of certain tree species, or a new pest species, will affect the overall vulnerability of the urban forest. Consideration must be given to multi-host pests; thus, vulnerable species assemblages should also be accounted for when designing diversification programs.[4]

Aurora is located in an ecoregion capable of supporting a high level of diversity (utilizing Great Lakes St. Lawrence, and to a lesser extent, Carolinian flora species), relative to most other ecoregions in Canada. Furthermore, the frequency and severity of pest outbreaks is increasing, creating an ever greater need for diversity and resilience. Therefore, more aggressive diversity targets may be feasible. By utilizing a diverse mix of species from both the Great Lakes St. Lawrence and Carolinian forest zones Aurora's urban forest will be more adaptable to both the predicted and unknown impacts of climate change. The Town is advised to establish a species composition in which no species represents more than 5 per cent of the tree population, no genus represents more than 10 per cent of the tree population, and no family represents more than 20 per cent of the total tree population. Diversity targets must also include a spatial scale in order to ensure that a sufficient amount of diversity is observed at the neighbourhood and land use level. Such diversity is not likely feasible within the street tree population as a smaller range of species can survive the harsh growing conditions found along high traffic boulevards and streetscapes

Numerous invasive tree and shrub species were identified at the sample plots, most notably European buckthorn (*Rhamnus cathartica*), Norway maple (*Acer platanoides*), and exotic honeysuckles (*Lonicera japonica, L. maackii, L. morrowi, L. tartarica*).

European buckthorn (*R. cathartica*) is common in both tree and shrub forms in Aurora (4 per cent of total tree leaf area and 9 per cent of total shrub leaf area). The species is abundant across land uses in Aurora as it can successfully invade a wide range of habitats, including forests, thickets, meadows and savannas. Once established, European buckthorn spreads rapidly, out-competes native vegetation, and is very difficult to control.

In Aurora, Norway maple (*A. platanoides*) represents approximately 8 per cent of the total leaf area. Norway maple has been favoured in the GTA for landscaping and streetscaping projects because it is tolerant of urban conditions and it produces a desirable growth form. However, the Ontario Invasive Plant Council (OIPC) has listed this prolific seed producer as invasive because it is known to spread into natural areas and threaten sensitive native vegetation.

Future planting of known invasive plants must be avoided, particularly at sites adjacent to natural areas, where they would inflict the maximum damage. Control measures vary between species but generally require a long-term commitment to rigorous site management and the application of bio-controls where appropriate. Municipal strategies for the management and restoration of infested areas will benefit from collaboration and partnership with LSRCA, York Region and adjacent municipalities.

Residential property owners and tenants in Aurora can play an important role in preventing the spread of invasive species. Horticultural species that escape from residential gardens are a common cause of invasions in natural areas. By purchasing and planting only native or non-invasive exotic plant species in yards and gardens the incidence of future invasions may be

[4] For detailed methodology, please see Lacan and McBride (2008). The PVM tool can be obtained by contacting the authors.

greatly reduced. In addition, the horticultural industry can play a significant role by phasing out the sale of highly invasive species, such as Norway maple and winged euonymus (*Euonymus alatus*), and offering as replacements similar native plants, such as red maple (*Acer rubrum*) and nannyberry (*Viburnum lentago*).[5] Targeted outreach for residents surrounding the natural system should be provided by the municipality via stewardship and education programs.

The use of high quality native planting stock grown from locally adapted seed sources is strongly encouraged in all municipal planting projects. Genetic variability within a species facilitates the survival of that species by increasing the likelihood that some individuals will be adapted to withstand a major stress or disturbance event. A reliance on clones in the urban forest will have the opposite effect and will increase the risk of catastrophic loss of leaf area and tree cover in the event of a pest or disease outbreak.

In an effort to simplify the planting process, municipalities may rely on a stock list of pre-approved tree species for planting projects and draw upon this list in a somewhat arbitrary manner. Unfortunately, this may result in a lack of species diversity, trees that are poorly suited to their growing environments, or trees that do not offer the optimal ecological services in a certain area. A more context-sensitive approach is likely advantageous. For example, Kirnbauer *et al*. (2009) developed a prototype decision support system (PDSS) that would allow managers to plan tree planting according to numerous small-scale variables, and select trees that are appropriate for local conditions.

Recommendation 4: Utilize the Pest Vulnerability Matrix during species selection for municipal tree and shrub planting.

Recommendation 5: Establish a diverse tree population in which no species represents more than five per cent of the tree population, no genus represents more than 10 per cent of the tree population, and no family represents more than 20 per cent of the intensively managed tree population both municipal-wide and at the neighbourhood level.

Recommendation 6: Utilize native planting stock grown from locally adapted seed sources in both intensively and extensively managed areas.

5.1.3 Tree Size Effects

The proportion of large trees in Aurora is low; approximately 4 per cent of the tree population has a dbh of 38.2 cm or greater. Diameter class distribution of the tree population will be influenced by a variety of factors. Most notably, the natural growth patterns and forms of the dominant species will strongly influence average tree size. For example, eastern white cedar (*Thuja occidentalis*) is the dominant species with respect to the total number of stems. This species typically maintains a comparatively medium-sized form at maturity, but its abundant use as a small-stature hedgerow tree in residential areas strongly influences this population

[5] The Ontario Invasive Plant Council (OIPC), TRCA and CVC have coordinated a Horticultural Outreach Program called *Grow Me Instead* with the following objectives: to work with the nursery and landscape industry to phase-out the sale of highly invasive horticultural plants and phase-in the provision of non-invasive alternatives, including native species; and to promote the sale, use and production of native plant species within the horticultural and landscape industry.

dynamic. Tree age will also impact diameter class distribution. Much of the urban development in Aurora has occurred relatively recently. Consequently, the trees planted at these new development sites have not yet reached maturity. Nevertheless, large trees are clearly underrepresented in the existing population.

As urban trees increase in size, their environmental, social and economic benefits increase as well. By virtue of their increased stature and leaf area, large trees provide much greater energy savings, air and water quality improvements, runoff reduction, visual impact, increase in property values, and carbon sequestration.

Due to the highly modified and intensively managed nature of the urban forest, there is no appropriate historic/pre-settlement age-class distribution for which to strive. In other words, the intensively managed areas of the urban forest will necessarily maintain a very different diameter or age-class distribution than that observed in extensively managed woodlands. Typically, woodlands maintain an inverse j-shaped curve that reflects the abundance of small trees in the understory as a result of natural regeneration.[6] This pattern was observed in the diameter class distribution in the *open space + natural cover* land use. However, natural regeneration occurs infrequently in the intensively managed urban forest. Consequently, active management is needed in order to facilitate regeneration. In areas of the municipality where mature trees are dominant, managers should plan for future succession by planting replacement trees well in advance of mature tree decline and removal.

Richards (1983) proposed the primary age diversity model, which suggests a diameter class distribution designed to ensure continuous canopy cover over time. The City of Davis, California, modified this model slightly to produce the following guidelines: 40 per cent of municipal trees less than 15.2 cm dbh, 30 per cent between 15.3 and 30.5 cm, 20 per cent between 30.6 and 61 cm, and 10 per cent greater than 61 cm. The results of the i-Tree Eco analysis revealed the following diameter class distribution in Aurora: approximately 74 per cent of municipal trees were less than 15.3 cm dbh, 19 per cent were between 15.3 and 30.5 cm, 7 per cent were between 30.6 and 61 cm, and less than 1 per cent were greater than 61 cm (Figure 21). According to these guidelines the proportion of small trees in Aurora is significantly higher than recommended and the proportion of large trees is significantly lower.

[6] The ‘inverse j-shaped curve’ is commonly associated with natural multi-age forest stands with relatively constant recruitment and mortality rates. These populations are believed to persist indefinitely in the absence of exogenous disturbance (Oliver and Larson, 1996).

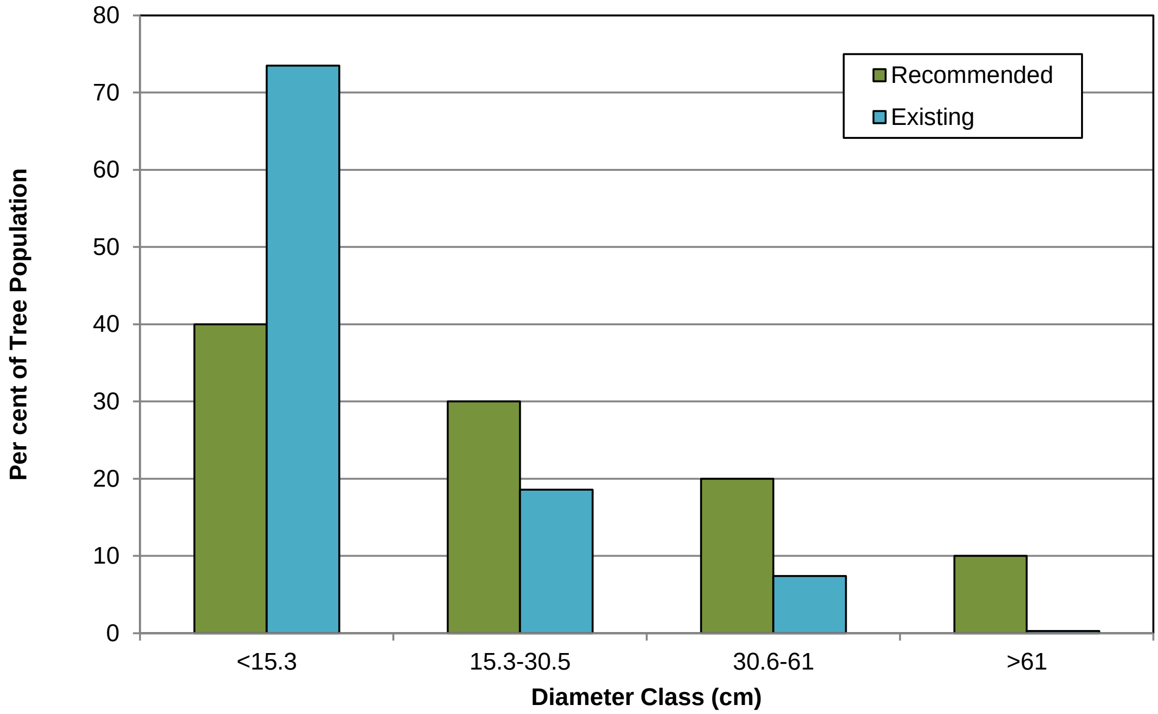

Figure 21: Recommended diameter class distribution and actual diameter class distribution in Aurora.

The planning process can address the protection of mature large-stature trees that are outside of the natural heritage system by preventing tree cutting prior to development application approval or incorporating existing mature large-stature trees into development plans. This will be particularly important for the preservation of trees in agricultural lands designated for residential or commercial development.

Recognizing that tree size will naturally vary by species, it is important to understand the physiological requirements of different species and incorporate this understanding into planting schemes in order to ensure that each newly planted tree reaches its full size potential. For example, anticipating conflicts with power lines, sidewalks, and underground utilities and selecting appropriate species accordingly will reduce premature mortality. Soil compaction under pavement and in construction sites tends to increase tree mortality and reduce tree vigor, thereby exacerbating susceptibility to pests and diseases. To achieve a desirable age-class structure, it is necessary to take a proactive approach to urban design by providing adequate tree habitat in the initial stages of urban planning. By increasing soil volume in tree habitat, improving soil moisture and fertility, and maintaining a healthy soil profile, the longevity of urban trees can be significantly extended.

When properly integrated into urban design, trees can deliver multiple engineering benefits including increased pavement life and a reduction in stormwater runoff. A balance between grey and green infrastructure must be sought in order to create a healthy urban environment. Interdepartmental collaboration will be critical to achieving success in this regard, as it will be necessary to foster common knowledge, methods, and goals related to the optimal integration of trees into the urban environment.

The Green Streets Program implemented by the City of Portland, Oregon, offers an example of sustainable streetscape design.[7] The Green Street design was first created for the purpose of stormwater management and has since evolved into an integrated application that provides multiple benefits, such as greenspace and habitat connectivity, enhancement of the bicycle and pedestrian environment, and neighbourhood livability. The Town of Markham has also developed a Streetscape Design Guidelines Manual to ensure that adequate replacement and increased numbers of new tree plantings occur in a sustainable manner.[8] The manual provides specifications and required design features for applications for Site Plan and Subdivision as well as Town boulevard tree planting. Minimum soil volumes standards for Aurora can be drawn from this manual as well as the City of Toronto's Green Development Standard; the suggested minimum is 15 m^3 of high quality soil per tree if in a shared planter, and a minimum volume of 30 m^3 of soil per tree if located in a single planter. In softscape areas (e.g. lawns, open space) a minimum of 30m^3 of high quality, non-compacted, well-drained soil per tree is suggested.

Technologies such as subsurface cells (e.g. Silva cell) will further enhance growing conditions and can be incorporated into urban design. To minimize costs, tree habitat construction activities can be incorporated into planned capital works projects and other infrastructure maintenance where possible. An evaluation of the budget requirements for the use of such technologies can be completed during the development of a strategic urban forest management plan.

Recommendation 7: Evaluate and develop the strategic steps required to increase the proportion of large, mature trees in the urban forest. This can be achieved using a range of tools including Official Plan planning policy, by-law enforcement and public education. Where tree preservation cannot be achieved, Official Plan policy can be considered that will require compensation for the loss of mature trees and associated ecosystem services.

Recommendation 8: Develop municipal guidelines and regulations for sustainable streetscape and subdivision design that ensure adequate soil quality and quantity for tree establishment and eliminate conflict between natural and grey infrastructure.

Recommendation 9: Explore the application of subsurface cells and other enhanced rooting environment techniques for street trees. Utilizing these technologies at selected test-sites in the short-term may provide a cost-effective means of integrating these systems into the municipal budget.

5.2 Urban Forest Function

The following is a discussion of the services (benefits) that have been quantified by the i-Tree Eco analysis. Urban forest benefits will increase in Aurora as a result of the implementation of the previous recommendations for urban forest distribution, composition, and size. However, several additional recommendations are provided here to address needs and opportunities.

5.2.1 Effect on Air Quality

[7] For more information visit: http://www.portlandonline.com/BES/index.cfm?c=44407
[8] For more information visit: https://goo.gl/uh6jGQ

Particulate matter less than 10 microns (PM_{10}) removal by trees in Aurora is equivalent to:
- Annual PM_{10} emissions from 77,100 automobiles or
- Annual PM_{10} emissions from 7,450 single family houses

Sulphur dioxide removal by trees in Aurora is equivalent to:
- Annual sulphur dioxide emissions from 5,300 automobiles or
- Annual sulphur dioxide emissions from 89 single family houses

Nitrogen dioxide removal by trees in Aurora is equivalent to:
- Annual nitrogen dioxide emissions from 487 automobiles or
- Annual nitrogen dioxide emissions from 325 single family houses

Trees and shrubs in Aurora remove approximately 93 tonnes of air pollution (CO, NO_2, O_3, PM_{10}, $PM_{2.5}$, and SO_2) annually, with an associated value of $711,380 annually. Pollution removal was greatest for ozone (O_3), accounting for over half of the total pollution removed. Ozone has been identified as the primary component of photochemical smog and is known to irritate and damage the respiratory system, reduce lung function, and inflame airways (EPA, 2012). Health effects of other pollutants include increased rates of acute bronchitis, asthma attacks and respiratory and cardiovascular conditions, and elevated rates of mortality (e.g. Burnett, 1999; Steib, 2002; Brook, 2002).

A study by Pollution Probe suggests that climate change (coupled with the urban heat island effect) could further exacerbate the degree of health effects associated with air pollution (Chiotti *et al*., 2002). For example, the occurrence of oppressive air masses that bring hot, humid and smoggy conditions are projected to increase from the current level of five per cent of summer days to 23-39 per cent by 2080. This means that the Greater Golden Horseshoe Region will likely experience more frequent, more severe and possibly longer smog episodes in the future. Thus, by mitigating the human health risks associated with air pollution, as well as mitigating both the causes and effects of climate change, Aurora's urban forest plays an essential role in community wellness, particularly for those more vulnerable members of the population.

The i-Tree Eco results revealed that large diameter trees remove more pollution on a per tree basis than small diameter trees. Similarly, trees were found to remove greater volumes of pollution than shrubs. In both instances, pollution removal capacity was a direct function of leaf area. Planting species that require little maintenance, that are well adapted to local conditions, and that have long life spans will offset emissions of air pollutants from maintenance and removal activities required for these species. In addition, Nowak *et al.* (2002) suggested that in areas with high levels of ground-based emissions (e.g., highways), tree and shrub cover located adjacent to the highway, with minimal overhead canopy, will allow pollutants to disperse upwards while increasing removal immediately adjacent to the sources.

Trees and shrubs emit biogenic volatile organic compounds (VOCs), including isoprene and monoterpenes. These compounds are natural chemicals that make up essential oils, resins, and other plant products (Kramer and Kozlowski, 1979). VOCs emissions by trees can contribute to the formation of ground level ozone and carbon monoxide. However, this process is temperature dependent. Given that trees generally lower air temperature, the net result is often still positive with respect to the effects of trees on air quality.

5.2.2 Climate Change Mitigation

Trees can mitigate climate change by sequestering atmospheric carbon (from carbon dioxide) in tissue and by reducing carbon dioxide emissions from fossil-fuel based power plants through energy use reductions in buildings. In Aurora, trees store approximately 103,000 tons of carbon (value of $7.97 million), and sequester approximately 4,050 tonnes of carbon annually (value of

$313,000 annually).[9] The amount of carbon stored and sequestered per hectare in Aurora is relatively high in comparison to other southern Ontario cities; this is likely due to high tree density (Table 9). However, carbon storage and sequestration capacities are still constrained by the large proportion of small trees in the municipality.

Annual carbon sequestration by trees in Aurora is equivalent to:

- Annual carbon emissions from 2,700 automobiles; or
- Annual carbon emissions from 1,300 single family homes.

The urban forest can also influence CO_2 levels by reducing the demand for heating and cooling in residential buildings, thereby decreasing carbon emissions by power plants. In Aurora, the annual demand for heating and cooling was reduced by approximately 30,300 MBTU and 2,100 MWH, with an associated annual financial savings of approximately $475,500. As a result of this reduced demand for heating and cooling, the production of 62 tonnes of carbon emissions were avoided annually (associated annual savings of $48,150).

Table 9: Tree density, carbon storage and annual carbon sequestration by urban forests in Canadian cities that have completed an i-Tree Eco analysis.

City	Tree Density (trees/ha)	Carbon Storage (tonnes/ha)	Carbon Sequestration (tonnes/ha/yr)
Aurora, ON	395.5	20.8	0.8
Richmond Hill, ON	250.9	16.2	0.7
Vaughan, ON	182.6	13.1	0.5
Markham, ON	148.3	10.8	0.4
Pickering, ON	354.4	22.1	0.9
Oakville, ON	192.9	13.4	0.6
London, ON	185.5	15.3	0.5
Toronto, ON	160.4	17.4	0.7
Brampton, ON	134.3	6.5	0.3

Proper species selection and tree placement can have significant impact on potential energy savings. For example, conifer species planted along the south facing wall of a building will block the heat from the winter sun and will increase the need for daytime heating. In contrast, a large deciduous tree planted at the south and west sides of a house will shade buildings during hot summer months and, after leaves have dropped, will allow solar heat to reach homes in the winter. Public education and outreach will be required to communicate these benefits and to provide direction for strategic planting around buildings to enhance energy savings. Maximizing energy savings will not only yield financial savings but will assist in efforts to mitigate climate change.

Nowak and Crane (2002) argued that carbon released through tree management activities must be accounted for when calculating the net effect of urban forestry on atmospheric carbon dioxide. Tree care practices often release carbon into the atmosphere as a result of fossil fuel emissions from maintenance equipment. In order to compensate for the carbon emissions associated with planting, establishment, pruning, and tree removal, trees planted in the urban landscape must live for a minimum amount of time.[10] If trees succumb to early mortality,

[9] When estimated mortality rates and tree removal were considered, net annual carbon sequestration was approximately 2,500 tons annually.

[10] According to Nowak and Crane (2002) the minimum necessary life span for a red maple (*Acer rubrum*) with conservative maintenance and mulching decomposition scenarios was between 5 and 10 years.

sustaining the tree population will lead to net emissions of carbon throughout the life cycle of that population (Nowak and Crane, 2002). This observation further highlights the importance of selecting low maintenance, well-adapted and resilient species, as well as proper planting sites, with the goal of maximizing tree health and longevity. A reduction in emissions associated with urban forest maintenance will also have a positive impact on local carbon levels and contribute to a healthier and more livable community.

Recommendation 10: Reduce energy consumption and associated carbon emissions by providing direction, assistance and incentives to residents and businesses for strategic tree planting and establishment around buildings.

5.2.3 Heat Island Mitigation

The urban heat island (UHI) effect occurs in urban and suburban areas where surface temperatures are significantly warmer than nearby rural areas. As cities replace natural land cover with pavement, buildings, and other grey infrastructure, urban surface temperatures increase due to the high heat absorption and retention properties of the impervious materials. Higher surface temperature can then lead to higher air temperatures as the heat retained in impervious materials is slowly emitted. Typically, UHI intensity is greatest at the urban centre with a large temperature gradient at the urban-rural edge (NRCan, 2009).

Research has shown that by increasing the amount of urban vegetation, UHI effects can be mitigated (Rosenzweig *et al.*, 2006; Solecki *et al*., 2005). Specifically, the shade generated by tree canopies can reduce the amount of solar radiation transmitted to underlying surfaces. Consequently, increased canopy cover lessens UHI effect by reducing heat transfer from these surfaces to the surrounding air. Furthermore, evapotranspiration by urban vegetation can result in peak summer temperature reductions of 1 - 5°C in urban areas (EPA, 2013). According to Simpson (1998), every one per cent increase in canopy cover results in a maximum mid-day air temperature reduction of 0.04 to 0.2°C.

Natural Resources Canada (NRCan) recently evaluated the potential to characterize and map UHI in the GTA using remote sensing data (NRCan, 2009). The research utilized both satellite imagery and in-situ air and surface temperature measurements. Although the study was not designed to directly evaluate the influence of urban trees and shrubs on UHI, the results are relevant to urban forest management. On a GTA-wide scale, suburban land use was found to have distinctly higher thermal admittance properties. A direct relationship was observed between urbanization and substantial increases in surface temperatures in extreme heat event conditions, which can have a direct impact on human and wildlife mortality and morbidity.

Effective heat island mitigation strategies should incorporate both “green” technology (e.g. green roofs) and natural infrastructure (e.g. urban forest).[11] Installing green roofs in high density areas can also be an effective way of adding greenspace to spaces with low planting potential at street level. Establishing trees and other forms of greenspace in hot-spots identified in the thermal mapping exercise can reduce surface temperatures and the formation of VOCs and ground level ozone, which will in turn have direct public health benefits.

[11] Please visit the Sustainable Technologies Evaluation Program (STEP) for information on the local application of a variety of sustainable technologies: http://www.sustainabletechnologies.ca/.

5.3 Growing a Sustainable Urban Forest

The preceding discussion of results offered a number of recommendations related to the urban forest distribution, species composition and tree size. This section outlines the prerequisites for their implementation in four operational themes: tree preservation and protection, stewardship and education, urban landscape ecology, and adaptive urban forest management.

5.3.1 Tree Preservation and Protection

The protection and stewardship of existing trees is the most effective means of achieving greater tree cover and leaf area. Trees that grow to reach a large mature size provide the highest benefit-cost ratio with respect to the provision of ecosystem services. Aurora's private tree by-law (No. 4474-03.D) affords protection to urban trees in the municipality. A tree protection by-law, potentially consisting of greater conservation measures, was under development at the time of report writing.

Increased funding will likely be required to implement future management plan actions and address the threats posed by EAB. Possible revenue streams for additional staff and resources include funds gained from compensation for development applications, by-law infractions and tree removal permits. The generation of subsequent funding for operations (i.e. tree planting and management) can be determined through the development of a strategic management plan.

The most critical time for tree care, including watering, mulching, and pruning, is in the first three to five years following planting. Without this care tree mortality will be high during the early stages of tree establishment and few trees will survive to reach their full size potential. Effective tree protection in newer residential developments will be of critical importance to ensuring that young trees become fully established. In addition, protection of roots zones during construction activities can partially safeguard trees against root damage caused by soil compaction or trenching. Typically a tree protection barrier includes as a minimum the area within the drip line of the tree. However, protection to the drip line is rarely sufficient for large mature trees, as tree roots commonly extend two to three times the distance of the drip line.

5.3.2 Stewardship and Education

The majority of Aurora's urban forest is located on private property. Thus, the residents of Aurora are the most influential stewards of the town's urban forest and their cooperation is essential to achieving all future urban forest targets. Recognizing that the lack of tree care is a significant threat to tree health, and that municipal resources are finite, it is clear that the public must share the responsibility for tree care and preservation. While by-laws designed to prevent the damage and destruction of trees can serve as a critical safety net, it is ultimately a strong collective stewardship ethic that will ensure the growth and long-term health of the urban forest on both public and private property. For example, tenants and property owners can reduce the mortality of public trees planted in residential boulevards and along commercial rights-of-way by providing regular care and maintenance, such as watering and mulching, particularly to newly planted trees.

Trees and vegetation in the private domain are managed by a socially diverse group of stakeholders including homeowners, community associations, utility companies, and businesses. Preferences for urban forest structure will naturally differ among user groups and will likely have a strong cultural dimension. TRCA's Multicultural Connections Program engages new Canadians in environmental initiatives and stewardship projects by reducing language as well as cultural and economic barriers – factors that have traditionally limited new Canadian participation in such programs.[12]

Aurora can further explore means of building on existing partnerships to increase participation in stewardship activities. Additionally, the municipality is advised to conduct an assessment of opportunities to pursue new partnerships. Potential connections may be found with agencies that share a common objective but which are currently achieving it through different means. For example, public health departments are also working to improve community health and would more readily meet this objective if urban forest cover were enhanced in the municipality. Similar synergies likely exist with public and private schools interested in promoting children's health.

> An average adult consumes 0.84kg of oxygen per day, or 306.6kg per year (Perry and LeVan, 2003). The Town of Aurora's urban forest produced an estimated 7,100 tonnes of oxygen in 2013.
>
> It follows that the oxygen released by the urban forest in 2013 was enough to support approximately 23,160 adult residents of Aurora, or 43.5% of the Town's population.

The Town can also establish partnerships to facilitate tree establishment on commercial and industrial lands. Partners in Project Green – a multi-partner program led by TRCA – engages business members in tree planting activities in order to increase tree canopy in commercial and industrial areas, improve the matrix influence, beautify employment lands, and facilitate corporate team building and leadership development.[13] Such programs not only strengthen the joint public-private mandate of urban forest stewardship, but also help to raise private companies' environmental profiles.

Municipal staff must also be equipped with the expertise necessary to effectively manage Aurora's natural and grey infrastructure in an integrated manner. Objectives for each form of infrastructure should be made compatible at all scales and valued equally. Unintentional damage to trees may be prevented through a more comprehensive understanding and appreciation of acceptable root protection zones during construction activities. A municipal staff training program can therefore be developed and implemented for all relevant employees. This will facilitate a harmonization of approaches to urban forest assets and mitigate the "silo" effect of municipal departments operating independently and employing incongruent methods to manage complementary resources.

Together with York Region and the surrounding area municipalities, Aurora is also advised to establish an interagency Urban Forest Working Group. This working group can liaise with stakeholders in urban forest management and establishing new partnerships. Stakeholders include those who are directly involved in urban forestry as well as those whose activities indirectly affect or are affected by the urban forest, such as municipal parks, operations and planning departments, transportation and health departments, and school boards. The working group can organize information sharing sessions for stakeholders to share the results of this urban forest study and to gain consensus on future targets and objectives established in management plans.

Recommendation 11: Research and pursue new partnerships and opportunities to enhance urban forest stewardship in Aurora.

[12] For more information visit: http://www.trca.on.ca/get-involved/stewardship/multicultural-connections.dot
[13] For more information visit: http://www.partnersinprojectgreen.com/

Recommendation 12: Pursue the development of an urban forest communication plan that guides the dissemination of key messages to target audiences.

Recommendation 13: Explore the development and implementation of a municipal staff training program to enhance awareness of tree health and maintenance requirements generally, and of proper tree protection practices to be used during construction activities more specifically.

Recommendation 14: Establish an interagency Urban Forest Working Group to liaise with existing stakeholders and build new partnerships that support shared urban forestry and community sustainability objectives.

5.3.3 Biodiversity Management and Urban Landscape Ecology

Aurora's Official Plan contains numerous measures aimed at protecting natural areas and environmental features during the development process and for their value on the urban landscape. Many of the natural areas of concern are also included in the provincial plans pertaining to the Oak Ridges Moraine and the Greenbelt, and also intersect with developed areas across a variable urban matrix.

Enhancing connectivity within the natural system will increase ecological function and adaptive capacity of the entire urban and peri-urban landscape. When weather conditions are good many migratory birds are able to fly over the municipality without stopping; however, in inclement conditions many will seek canopy cover in which to refuel, rest and find refuge. For these thousands of birds, the more trees there are distributed across the municipality, the better. In contrast, most summer or breeding species, especially ground-dwelling bird and amphibian species, find few options for nesting and local movement in the intensively managed urban forest. Similarly, habitat is often unsuitable for understory plants (e.g. wildflowers and ferns) within intensively managed urban areas as seeds do not germinate or plants are removed during regular maintenance. Therefore, most local movement of flora and fauna species will occur within established natural systems (the extensively managed urban forest), where there may also be competition with non-native invasive species.

While one should not expect the urban forest in Aurora to provide habitat for all species, it is reasonable to expect that the urban forest will assist in increasing the rate of breeding success of some, particularly canopy-dwellers, by providing them with additional resources. For example, the placement of trees adjacent to the natural system can provide resources (foraging areas and refuge from predators) near their nest location that can increase the survival rate of young birds. Many urban areas, notably commercial and industrial, can be inhospitable to migratory birds and other species. Increasing leaf area and canopy cover in the commercial and industrial land uses will provide a more positive matrix influence on the adjacent natural system, and increase the quality of habitat patches and the adaptive capacity of the species that inhabit them.

In urbanized watersheds the provision of a range of ecosystem services is essential to the health of community members. These services (e.g. heat island mitigation and air pollution removal) extend well beyond the provision of species habitat; many of such services are provided by the intensively managed urban forest located outside of the natural system. Furthermore, these services can be provided by new combinations of biotic and abiotic elements that have never been observed, a phenomenon now referred to as *novel ecosystems*

(Hobbs et al., 2006). For this reason it will be advantageous to collaboratively explore the development of targets for ecosystem services as part of a comprehensive approach to management at a broad, cross-jurisdictional landscape scale.

Research is now emerging that can guide the development of such targets. For example, Perrings *et al.* (2011) state that biodiversity and ecological function targets must be based on the ecosystem services they support, that the spatial and temporal characteristics of targets reflect the processes involved, and that interdependencies between ecosystem services be reflected in targets. They further suggest that where such interdependent targets exist, coordinated implementation across departments and agencies is necessary. It follows that a deeper understanding is needed of the connection between ecological function and the ensuing ecosystem services; this will better enable managers to cultivate the functions in a manner that provides desired services.

Recommendation 15: Explore and develop targets that achieve a comprehensive distribution of ecosystem services and improve overall landscape function.

5.3.4 Adaptive Urban Forest Management

Aurora's urban forest is facing an uncertain future due to threats from climate change, invasive species, and the effects of human encroachment. In order to manage for uncertainty and increase the adaptive capacity of the urban landscape, ecological resilience must be built into the urban forest (both the intensively and extensively managed components). A key strategy for building both resilience and adaptive capacity is to increase diversity at all scales, as discussed in Section 5.1.2. Careful monitoring of the urban forest resource will also facilitate adaptive management.

Aurora is encouraged to develop a comprehensive monitoring program that tracks trends in tree establishment and mortality, and more generally evaluates the distribution and structure of the urban forest over the next 20 years. The tools of analysis utilized for this study should form the basis of this program. Monitoring intervals can be determined in the context of funding and resource availability.

The full impact of current and future climate change on Aurora's urban forest is uncertain. Extreme high temperatures and increased drought in the growing season may reduce tree growth, although these negative impacts may be offset by the positive growth effects from rising atmospheric CO_2 levels (see for example, Saxe *et al*., 1998). The impacts of climate change are species specific, and species with larger genetic variability are likely more adaptable to a variety of climate conditions and as a result may be more successful (Colombo *et al*., 1998). Given the likelihood of increased summer temperature and drought under future climate change scenarios, the selection of hardy native species that are heat and drought tolerant is advised, especially at locations with harsh growing environments. A general trend towards northward migration of tree species is also being observed and projected for the future (see for example, Colombo *et al*., 1998), so it may be advantageous to select native species that are currently at or near the northern limit of their range (e.g., Kentucky coffee-tree (*Gymnocladus dioicus*), and tulip tree (*Liriodendron tulipifera*)).

The potential impacts of climate change on trees in Ontario are part of an emerging field of forestry research, but there is a lack of research on the potential effects of southern Ontario's urban trees. Research partnerships with local academic institutions can therefore be developed to further research goals and fill gaps in knowledge. Long-term monitoring programs will also be essential in order to evaluate the growth and survival of the urban tree population.

Native tree and shrub species under stress from climate change may also become more susceptible to introduced pests or may be out-competed by hardy generalist invasive plants. Controlling emerging invasive species is therefore more critical under future climate change scenarios. Managers must identify and address common pathways of introduction (i.e. dispersal by hikers, pets, yard waste, etc.), as an important step in the invasive species management strategy (please see Section 5.1.2).

It is now likely that the vast majority of ash trees in Aurora (5 per cent of the urban forest) will be eliminated by the EAB infestation that is moving across southern Ontario. There is a need to collect and store high quality seeds from native ash species before this component of the tree population is lost. Preserving seed from a wide range of healthy ash specimens in the local population will prevent the possible loss of native ash species and facilitate reintroduction once adequate environmental control measures for EAB are developed or trees resistant to the insect are bred and introduced (NRCan, 2010). Aurora can consider working with TRCA, LSRCA, the Ministry of Natural Resources (MNR) and the National Tree Seed Centre of Natural Resources Canada (NRCan) to implement a seed collection program for native ash species; the municipality should also participate in other EAB research opportunities as they arise.

Adaptive management practices will be critical to protecting the ecosystem services provided by the urban forest. Many of these services will become more valuable under future climate scenarios, including shading and space cooling, soil aeration and stabilization, and interception of storm water. Urban forests will play a major role in our ability to adapt to future climate change (please see Sections 5.1.5 and 5.1.6 for examples of how the urban forest can contribute to climate change and UHI mitigation).

Recommendation 16: Monitor the distribution, structure and function of the urban forest using the methods employed in this baseline study. A potential monitoring scenario may consist of a cover mapping assessment (UTC) at a five year interval and a field-based assessment (i-Tree Eco) at a ten year interval.

Recommendation 17: Support research partnerships that pursue the study of climate change and its impacts on the urban forest and that evaluate the potential for planting more hardy and southern species in select locations.

5.4 Urban Forest Management Plan

Urban forest management plans are becoming more common as urban populations expand and municipalities embrace the value urban forests represent for their residents. An urban forest management plan is the principal planning and operational tool through which the urban forest can be protected and enhanced. A management plan can set priorities and comprehensively address a wide range of management themes including: maintenance and pruning; strategic planting and establishment; stewardship and outreach; risk assessment and response; and long-term monitoring. Urban forest management plans should set scheduled intervals at which this work takes place. Five year intervals for pruning are standard and allow for forestry workers to conduct inspections and risk assessments. Additional stakeholder consultation will be a critical component of management plan development in order to determine the appropriate sequencing of actions within the context of existing resources and municipal goals. The successful development of urban forest management plans accounts for the influences of local conditions, attitudes, and resources to create a plan that meets local needs.

York Region provided to area municipalities the *Urban Forest Management Planning Toolkit*. The toolkit is intended to aid each area municipality in the development of a Strategic Urban Forest Management Plan and outlines the key components of a comprehensive plan, as well as supporting technical reference materials and templates.

Kenney *et al.* (2011) have developed a comprehensive list of criteria and performance indicators for sustainable urban forest management (See Appendix F for complete list, with highlighted sections pertaining to Aurora's current situation). This list was derived from the work of Clark *et al.* (1997) and can be used to assess the progress towards urban forest sustainability. Aurora is advised to use the criteria and indicators to inform the creation of the recommended management plan, monitor implementation and assess the progress made toward urban forest sustainability.

Recommendation 18: Develop and implement an urban forest management plan for Aurora.

6.0 Summary of Recommendations

Recommendation 1: Refine the results of the urban tree canopy (UTC) analysis to develop an urban forest cover target.

Recommendation 2: Build on the results of the urban tree canopy analysis (UTC) and the priority planting index to prioritize tree planting and establishment efforts to improve the distribution of ecosystem services, including urban heat island mitigation and stormwater management.

Recommendation 3: Increase leaf area in canopied areas by planting suitable tree and shrub species under existing tree cover. Planting efforts should continue to be focused in areas of the municipality that currently support a high proportion of ash species.

Recommendation 4: Utilize the Pest Vulnerability Matrix during species selection for municipal tree and shrub planting.

Recommendation 5: Establish a diverse tree population in which no species represents more than five per cent of the tree population, no genus represents more than 10 per cent of the tree population, and no family represents more than 20 per cent of the intensively managed tree population both municipal-wide and at the neighbourhood level.

Recommendation 6: Utilize native planting stock grown from locally adapted seed sources in both intensively and extensively managed areas.

Recommendation 7: Evaluate and develop the strategic steps required to increase the proportion of large, mature trees in the urban forest. This can be achieved using a range of tools including Official Plan planning policy, by-law enforcement and public education. Where tree preservation cannot be achieved, Official Plan policy can be considered that will require compensation for the loss of mature trees and associated ecosystem services.

Recommendation 8: Develop municipal guidelines and regulations for sustainable streetscape and subdivision design that ensure adequate soil quality and quantity for tree establishment and eliminate conflict between natural and grey infrastructure.

Recommendation 9: Explore the application of subsurface cells and other enhanced rooting environment techniques for street trees. Utilizing these technologies at selected test-sites in the short-term may provide a cost-effective means of integrating these systems into the municipal budget.

Recommendation 10: Reduce energy consumption and associated carbon emissions by providing direction, assistance and incentives to residents and businesses for strategic tree planting and establishment around buildings.

Recommendation 11: Research and pursue new partnerships and opportunities to enhance urban forest stewardship in Aurora.

Recommendation 12: Pursue the development of an urban forest communication plan that guides the dissemination of key messages to target audiences.

Recommendation 13: Explore the development and implementation of a municipal staff training program to enhance awareness of tree health and maintenance requirements generally, and of proper tree protection practices to be used during construction activities more specifically.

Recommendation 14: Establish an interagency Urban Forest Working Group to liaise with existing stakeholders and build new partnerships in the implementation of urban forest program objectives.

Recommendation 15: Explore and develop targets that achieve a comprehensive distribution of ecosystem services and improve overall landscape function.

Recommendation 16: Monitor the distribution, structure and function of the urban forest using the methods employed in this baseline study. A potential monitoring scenario may consist of a cover mapping assessment (UTC) at a five year interval and a field-based assessment (i-Tree Eco) at a ten year interval.

Recommendation 17: Support research partnerships that pursue the study of climate change and its impacts on the urban forest and that evaluate the potential for planting more hardy and southern species in select locations.

Recommendation 18: Develop and implement an urban forest management plan for the Town of Aurora.

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Appendix A: Literature Review

Urban Forest Structure

Multiple definitions of urban forest structure exist. Rowntree (1984) defines urban forest structure as the spatial arrangement of vegetation in relation to other objects within urban areas, while Sanders (1984) describes structure as the static assemblage of plant materials above, on, and below the ground surface within an urban area or its zone of influence. Generally, all such definitions refer to characteristics such as species composition, spatial distribution of vegetative cover, and tree size and condition.

Urban forest structure can be influenced by a number of variables. McBride and Jacobs (1986) suggest that the structure of an urban forest can be tied directly to pre-settlement forest composition. Nowak and Crane (2002) observed a direct relationship between pre-settlement forest cover and the extent of urban forest canopy in American cities, recording the highest tree cover in cities developed in naturally forested areas (34.4%), followed by grasslands (17.8%), and deserts (9.3%).[14] Sanders (1984) argues that urban vegetation patterns and their expected variations can be determined by the following three factors: urban morphology; the natural environment or natural processes that influence vegetation establishment, growth, competition, and decline; and human management systems. Nowak (1993) identifies four general forces that can alter urban forest structure: direct anthropogenic, e.g. planting and removals; indirect anthropogenic, e.g. war, economic depression; natural direct, e.g. storms, fire; and natural indirect, e.g. large earthquakes. Although forest managers have little control over indirect forces, proper planning will facilitate control over the direct forces of structural change. In the Greater Toronto Area population density and parcel size were not found to be related to the amount of vegetation cover (Conway and Hackworth, 2007), suggesting that other factors, such as land use policy, are influencing conditions on the ground.

Various socio-economic influences on urban forest structure are also recognized. A direct correlation between neighbourhood wealth and the extent and diversity of urban vegetation cover has been observed (Iverson and Cook, 2000; Martin *et al.*, 2004; Heynen and Lindsay, 2003; Hope *et al.*, 2003). Education (Heynen and Lindsay, 2003), household age composition (Fung and Sui, 2000), occupancy rates (Heynen *et al.*, 2006), and the distribution of long- versus short-term residency in neighbourhoods (Perkins *et al*., 2004) have also been identified as determinants of the structure of urban vegetation. Fraser and Kenney (2000) found that the landscape traditions unique to various cultural groups in the City of Toronto directly affected preferences for urban forest structure. For example, the Mediterranean community, having developed in a small-scale agrarian culture, demonstrated a preference for fruit trees and vegetable gardens. Chinese-Canadians expressed the greatest desire for treeless landscapes, while people of British descent responded the most positively to shade trees and naturalized parks. These cultural differences are largely consistent with the traditional use of trees in British, Mediterranean and Chinese landscaping, and appear to be maintained among North American immigrant populations (Fraser and Kenney, 2000).

Compositional differences in forest structure will directly influence the environmental services provided. For example, Beckett *et al.* (2000a) found that conifer species captured more particulate matter than deciduous species when location and placement were controlled. The greater particulate capture was attributed to the finer, more complex structure of conifer species.

[14] No such determinations have been made for Canadian cities.

Furthermore, structural properties of leaf and bark surfaces have been found to affect the capacity for particulate capture (Beckett *et al.*, 2000b). Rough, hairy leaf surfaces more effectively captured particles than smooth, waxy leaf surfaces. An understanding of the various attributes of different species can enhance the management capacity to direct urban forest structure to provide certain desired functions, such as particulate removal or stormwater interception.

Urban Forest Function

The urban forest provides numerous valuable ecosystem services. A general discussion of the relevant services is offered here.

Air Quality

Urban air pollution negatively impacts human health. Exposure to common transport-related air pollutants, such as particulate matter ($PM_{2.5}$ and PM_{10}), ozone (O_3), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), and carbon monoxide (CO), has been linked to various health problems, including: inflammation of the respiratory tract; exacerbated allergic reactions in asthmatics; adverse outcomes in pregnancy; and increased mortality risk due to heart attack, cardiopulmonary and respiratory complications (Kuna-Dibbert and Krzyzanowski, 2005). These risks are not equally distributed across the population. Rather, children and elderly persons with pre-existing chronic disease have shown increased susceptibility to the adverse effects of exposure to air pollutants.

By significantly reducing the amount of airborne pollutants, trees can mitigate the potential health problems associated with poor air quality. Trees reduce the amount of airborne particulate matter by intercepting and storing large airborne particulate matter on outer leaf, branch, and bark surfaces (Nowak et al., 2006). In addition, trees improve air quality by binding or dissolving water-soluble pollutants onto moist leaf surfaces. Other gaseous air pollutants, such as carbon monoxide and sulphur dioxide, are removed primarily by gas exchange through the leaf stomata (Smith, 1990).

Ground level ozone (O_3) is not emitted directly but is created by chemical reactions between oxides of nitrogen and volatile organic compounds (VOCs) in sunlight. Although trees are a source of VOC emissions, the net effect of tree cover on the landscape is usually positive with respect to O_3 formation, resulting in reductions in ground level ozone (Cardelino and Chameides, 1990; Taha, 1996). Because VOC emissions are temperature-dependent and trees have been found to lower air temperatures, increased tree cover can lower overall VOC emissions and, subsequently reduce ozone levels in urban areas (Nowak and Dwyer, 2007). Furthermore, increasing tree cover over parking lots can reduce VOC emissions by shading parked cars and thereby reducing evaporative emissions (Scott et al., 1999). Thus, urban trees, particularly species that emit low levels of VOCs, can contribute to the reduction of urban O_3 levels (Nowak et al., 2000). It should be noted that VOC emissions do vary by species, air temperature and other environmental factors (Guenther et al., 1994).

Carbon Dioxide Reduction and Energy Conservation

Urban forests also play a role in climate change mitigation by reducing atmospheric carbon dioxide (CO_2) concentrations. This is achieved by sequestering and storing carbon as woody biomass, reducing GHG emissions by conserving energy used for space heating and cooling, or displacing GHG emissions by using urban tree residue as bio-energy fuel.

Trees reduce atmospheric CO_2 levels through photosynthesis and subsequent carbon sequestration in woody tissue. During photosynthesis, atmospheric CO_2 enters the leaf through surface pores, combines with water, and is converted into cellulose, sugars, and other materials in a chemical reaction catalyzed by sunlight. Most of these materials then become fixed as wood, while a small portion are respired back as CO_2 or are utilized in the production of leaves that are eventually shed by the tree (Larcher 1980). Nowak (1994) found that the net annual carbon sequestration by trees in Chicago equaled the amount of carbon emitted from transportation in one week in the Chicago area. This trend is similar to the national rate of carbon sequestration in urban trees (Nowak and Crane, 2002). Furthermore, the amount of carbon emitted by the U.S. population over a 5.5 month period was equal to the estimated amount of carbon stored by urban trees in the United States (Nowak and Crane, 2002).

Trees that are adjacent to buildings can reduce the demand for heating and air conditioning through their moderating influence on solar insolation and wind speed. Additionally, trees moderate climate by transpiring water from their leaves, a process that has a cooling effect on the atmosphere, and by shading surfaces that would otherwise absorb and slowly re-emit heat. Thus, the effective placement of a tree or shrub can lower building temperatures. Simpson and McPherson (1999) report that by planting two large trees on the west side of a house, and one large tree on the east side of a house, homeowners can reduce their annual air conditioning costs by up to 30%. Potential greenhouse gas (GHG) emission reductions from urban forestry are likely to be greatest in regions with large numbers of air-conditioned buildings and long cooling seasons. However, in colder regions where energy demands are high during winter months, trees that are properly placed to create windbreaks can also substantially decrease heating requirements and can produce savings of up to 25% on winter heating costs (Heisler, 1986). This reduction in demand for heating and cooling in turn reduces the emissions associated with fossil fuel combustion (Simpson and McPherson, 2000).

Utilizing urban tree biomass as feedstock for bio-power plants eliminates GHGs that would have been emitted by combusting fossil fuels. The most common way to convert tree biomass to energy is by burning wood fuel to produce heat that powers turbines. However, the cost effectiveness of utilizing removed city trees as a bio-energy feedstock has not yet been well-researched. According to the California Climate Action Registry (2008) there can be costs associated with initial processing at the removal site, transporting to a transfer station, processing facility, or bio-energy facility, storing in open piles, and handling, usually through a combination of automatic conveyors and driver-operated front-end loaders. Research is also underway to develop more efficient processes for converting wood into fuels such as ethanol, bio-oil, and syngas (Zerbe 2006).

Stormwater Management

When stormwater hits impervious surfaces, the water is heated and various pollutants, including lawn fertilizers and oils on roadways, are picked up by the runoff. Water quality problems then arise when large volumes of polluted stormwater flow into receiving waters, posing threats to temperature sensitive species and providing suitable conditions for algal blooms and nutrient imbalances (Kollin, 2006). Leaves and branch surfaces intercept and store rainfall, thereby reducing runoff volumes and moderating the onset of peak flows. The urban canopy also filters pollutants that eventually flow to receiving waters. Once runoff is infiltrated into soils, plants and microbes can naturally filter and break down many common pollutants found in stormwater.

Tree roots also increase the rate at which rainfall infiltrates soil as well as the capacity of soil to store water, thereby reducing overland flow. Transpiration through tree leaves then reduces soil moisture, increasing the soil's capacity to store future rainfall. By increasing infiltration rates, urban vegetation also limits the frequency of sewer overflow events by reducing runoff volumes and by delaying stormwater discharges. It is worth noting that trees' ability to perform this work is hampered by heavily compacted soil, which may be too dense for large amounts of water to easily infiltrate and which may adversely affect tree health. Nevertheless, tree canopies can reduce soil erosion by diminishing the impact of rainfall on barren surfaces.

The trees and woody shrubs that comprise urban riparian buffers also improve water quality through filtration of sediment and contaminants, vegetative uptake of soluble nutrients, and infiltration of overland runoff from surrounding fields and hillslopes. Removal of over half the phosphorus, nitrogen and sediment inputs is typically achieved within the first 15 m of buffer width (Osborne and Kovacic, 1993; Castelle *et al*., 1994). Woody riparian vegetation also stabilizes banks and moderates stream temperature by providing shade, which provides favourable habitat for aquatic life.

Land use change associated with urbanization can negatively impact hydrologic processes. A summary of recent literature provided by Endreny (2005) concludes that conversion to urban cover results in the following: a reduction in stormwater interception as a consequence of the loss of tree and vegetative cover; a decrease in infiltration as a consequence of soil compaction and an increase in impervious cover; and, a decrease in evaporation due to reduced soil water volumes. The result is an increase in peak runoff magnitude from precipitation events, which can scour and destabilize many urban channels (Riley, 1998). Although many models have been created to examine the effects of land use change on urban hydrology, i-Tree Hydro, created by the USDA Forest Service, is the only model designed to explicitly examine tree effects on stormwater.

Social Benefits

Although more difficult to quantify, the urban forest provides a variety of important social benefits that bear on other important local issues, such as health care costs and economic productivity. For example, urban trees have been linked with reduced neighborhood crime levels. Kuo and Sullivan (2001) found that apartment buildings with high levels of greenery witnessed 52% fewer crimes than those without trees. This phenomenon is likely due to a combination of factors, including a positive effect by trees on neighbourhood property values, greater community involvement, and higher levels of pedestrian traffic. Some credit has also been given to the positive psychological effect of trees and natural features on human behaviours, and the general contributions of trees to overall community well-being (Jackson 2003).

Research has also shown that the urban forest has demonstrably positive effects on the physical and mental health of urban residents. Hospital patients were found to recover from major surgery more quickly and with fewer complications when provided with a view of trees (Ulrich, 1984). Trees and urban parks also improve mental health and over all well-being by conveying a sense of calm, relieving stress, and facilitating relaxation and outdoor activity. For example, Maas *et al*. (2009) found that residents reported better personal health and stronger social bonds in areas where there was access to green space within one kilometer of the home. Access to natural settings has also been linked to the improvement of children's mental health and academic performance (Roe and Aspinall, 2011), lower weight and BMI in children and teens (Wolch *et al*., 2011), and increased longevity in seniors (Takano *et al*., 2002). The presence of trees can contribute to a generally more attractive living environment and contribute to residents' quality of life (White *et al*., 2013). For example, trees effectively reduce noise levels by absorbing unwanted sound (Aylor, 1972; Cook, 1978).

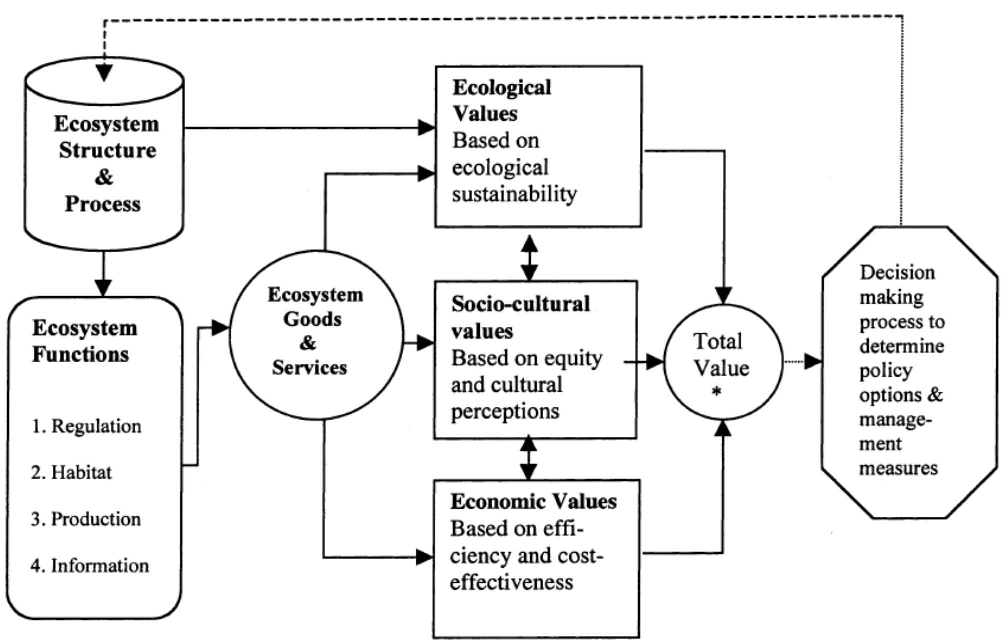
Traffic and Pedestrian Safety

Research suggests that trees may also improve driving safety. Drivers seeing natural roadside views demonstrated lower levels of stress and frustration compared to those viewing all-built settings (Parsons *et al*. 1998). A study conducted by Mok *et al*. (2006) found a 46% decrease in crash rates across urban arterial and highway sites after landscape improvements were installed. Similarily, research conducted by Naderi (2003) found that placing trees and planters in urban arterial roadsides reduced mid-block crashes by 5% to 20%.

Economic Benefits

A healthy urban forest is a municipal capital investment that will appreciate in value over time. As urban forests grow, their environmental, social and economic benefits increase. The process of valuation of the goods and services provided by the urban forest and surrounding natural system is currently receiving considerable attention across all fields of conservation. A comprehensive assessment of this area of research is beyond the scope of this review; therefore, only a few key examples of this research are offered here.

DeGroot *et al.* (2002) proposed a framework for the valuation of ecosystem functions, goods and services that is based on the synthesis of complex ecological structures and processes into a more limited number of ecosystem functions that provide ecosystem goods and services valued by humans. This framework can be used at various scales; for example, to calculate the natural capital assets within TRCA jurisdiction, a watershed, or an individual site.



*) The problem of aggregation and weighing of different values in the decision making process is an important issue, but is not the subject of this paper (see other papers in this issue for further discussion)

Figure 1: Framework for integrated assessment and valuation of ecosystem functions, goods and services (DeGroot *et al.*, 2002)

The Pembina Institute and Credit Valley Conservation (2009) estimated the value of ecosystem goods and services in the Credit River Watershed using a benefit transfer methodology that focused on the non-market value of ecosystem services; this non-market value was derived from a “willingness to pay” approach.[15] The report found that the value of the natural capital provided by the urban forest in the watershed was estimated at $18.7 million annually.[16] This estimate included the value of the following services: climate regulation; gas regulation; water supply; pollination; recreation; and amenity and cultural.

There are numerous challenges associated with ecological valuation. For example, many ecosystem services are difficult to measure directly (e.g. gas exchange) and therefore require the use of surrogates or indicators (Cuperus *et al.*, 1996; Bond and Pompe, 2003). Other services require a more qualitative approach to discern value, such as various social and cultural benefits. Furthermore, in the absence of local jurisdictional data, the best matching default values and parameters must be selected in order to calculate the value of ecosystem services. Consequently, values derived are often generalized for a large geographic area and are not site-specific. Thus, this field of research is still rapidly evolving in an effort to address these challenges.

A direct economic benefit of urban vegetation is observed in the relationship between tree cover and property value. Both residential tree cover and proximity to green space have been associated with higher property values in residential neighborhoods (Dombrow *et al*., 2000; Anderson and Cordell, 1988). The Center for Urban Forest Research (2005) estimates that properties with trees are valued five to fifteen per cent higher than comparable properties without trees. Sander *et al*. (2010) found that mere proximity to neighbourhood trees in Minnesota was linked to higher home sale values, with the highest value reported in local neighbourhoods with over 40% tree cover. Furthermore, research shows that shoppers in well-landscaped business districts were willing to pay more for both parking and goods and services (Wolf, 1999).

Urban tree cover can also increase the longevity of grey infrastructure, thereby reducing the frequency of costly repairs. McPherson and Muchnick (2005) have demonstrated that tree shade is correlated with reduced pavement fatigue, cracking, rutting, shoving, and other distress. Consequently, infrastructure maintenance costs can be reduced by increasing tree cover over asphalt. For example, repaving could be deferred ten years on a well-shaded street and potentially 25 years on a heavily shaded street.

An emerging valuation scheme in which urban forestry has begun to receive attention is the global carbon market. While carbon accounting through carbon offset programs has become a relatively well established protocol, in the past such programs generally operated outside the realm of urban forestry. In 2008 the California Climate Action Registry released the *Urban Forest Project Reporting Protocol Version 1.0*; this protocol was subsequently updated and rereleased as version 1.1 in March 2010. The Protocol provides guidance to account for and

[15] An individual’s willingness to pay for an ecosystem service can be used to assign a value to a particular ecological good or service. Please see Pembina Institute and CVC (2009) for a more detailed discussion of this approach.
[16] This value was considered the minimum lower bound of the natural capital value.

report greenhouse gas emission reductions associated with a planned set of tree planting and maintenance activities to permanently increase carbon storage in trees (Climate Action Reserve, 2010). This protocol is applicable to urban forest GHG projects undertaken by municipalities, educational campuses and Utilities. Only projects operating within the United States are eligible at the time of release of this report.

Wildlife Habitat

Urban zones have a somewhat complex relationship with wildlife. As rural ecosystems are replaced with urban and suburban development, wildlife diversity decreases, with urban-tolerant species dominating the landscape and sensitive species disappearing. Environmental factors such as noise and forest fragmentation disrupt the natural behaviour of many wildlife species, making urban areas unsuitable as habitat (Dowling *et al*., 2011; Tremblay and St. Clair, 2011). Construction activities destroy habitat and result in animals abandoning the area - eliminating these species both from the site and from adjacent areas (Schaefer 1996).

However, close proximity between urban development and natural habitat does not always translate into whole scale disappearances of wildlife. As human development at the margins of urban zones pushes further into intact forests, human-wildlife interactions increase, with potentially negative outcomes on both sides. As natural habitat shrinks and resources are more limited, wildlife may venture into urban areas seeking food, potentially causing conflicts and safety concerns, especially with large animals such as deer or bears (DeStefano and DeGraaf, 2003).

In York Region and southern Ontario as a whole, few large and connected woodlands remain to serve as habitat for native resident and migratory fauna species. Consequently, the urban forest now plays an increasingly important role in biodiversity conservation and habitat provision for these species. Preventing encroachment and maintaining connectivity of intact forest tracts are vital to the management of these remnant forests.

Sustainable Urban Forest Management

The structure and function of an urban forest will be influenced by a myriad of physical, biological, socioeconomic, cultural, and political factors; these factors are directly interconnected and cannot be viewed in isolation (Zipperer, 2008; Clark *et al.* 1997; Carreiro and Zipperer, 2008; Perkins *et al.*, 2004; Picket *et al.*, 1997). Moreover, these factors and the manner in which they interact with one another must be taken into account when making management decisions. A growing body of research suggests that in order to successfully incorporate these diverse factors into management plans a holistic *ecosystem-based approach* to urban forest management is required (Zipperer, 2008; Carreiro and Zipperer, 2008; Elmendorf and Luloff, 1999).

The ecosystem-based approach found formal acceptance at the Earth Summit in Rio (1992), where it became the primary framework for action under the Convention on Biological Diversity. It is based on the application of appropriate scientific methodologies focused on levels of biological organization, which encompass the essential structures, processes, functions and interactions among organisms and their environment. The following themes are central to this approach: ecological rather than jurisdictional boundaries; ecological integrity; interagency and intermunicipal cooperation; humanity in nature; and environmental justice (Elmendorf and Luloff, 1999). To achieve an ecosystem-based approach to urban forest management Zipperer (2008) argues that consideration must be given to the broader context in which a management site occurs, as the site will affect and be effected by adjacent land uses and surrounding ecological processes. Ames and Dewald (2003) state that assembling a diverse base of expertise with multiple viewpoints into partnerships to address the management of a city's urban forest is integral to an ecosystem-based approach, as these partnerships can inform the creation and implementation of plans at the outset, thereby avoiding costly problems during and after project completion. Unfortunately, as Ordóñez and Duinker (2013) discovered, many Canadian municipalities with strategic urban forest management plans had very limited public consultation and placed inadequate emphasis on elements crucial to an ecosystem-based approach, including climate change, community stewardship, and connectivity.

Urban forest managers typically alter the structure of the forest through single-tree management on public land only. However, this need not be a barrier to the use of a holistic ecosystem based management approach. Using the theory of vegetation dynamics developed by Pickett *et al*. (1987a,b), Zipperer (2008) demonstrates how managers may take a holistic approach through single-tree management. Three major drivers and explanatory categories for successional change are presented: site availability; species availability; and species performance (Figure 1). A non-exhaustive list of the factors that affect each these three variables is provided. By considering this hierarchy of factors in the management decisions made at the single-tree level, managers can better understand and direct urban forest change at a landscape level.

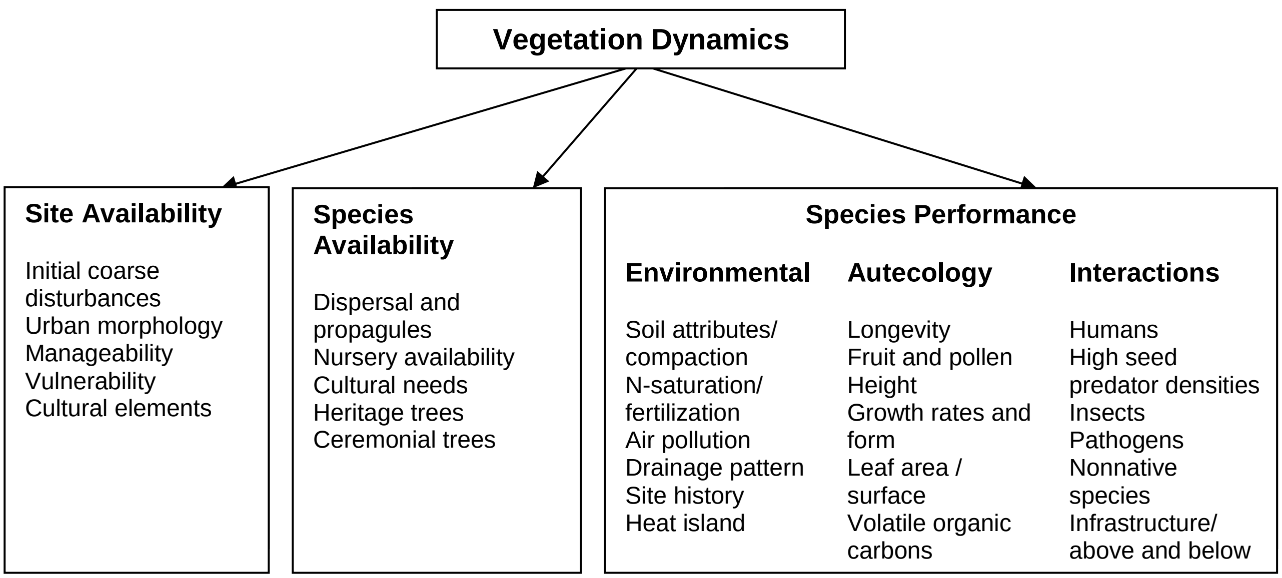


Figure 2: Theory of vegetation dynamics modified for application of ecosystem management in urban landscapes by incorporating elements of the urban ecosystem in the management-decision process (Zipperer, 2008).

In light of two observations, 1) urban environments are extremely heterogeneous in space and dynamic in time, and 2) areas containing urban trees and forest patches are often geographically fragmented, Wu (2008) argues that an urban forest may be most appropriately treated as a landscape that consists of a variety of changing and interacting patches of different shape, size, and history. Essentially, an urban forest is a dynamic patch mosaic system. The *urban landscape ecology approach* has been proposed by Wu (2008) in response to a growing awareness of the importance of considering spatial heterogeneity and its ecological consequences for understanding system processes. This approach emphasizes not only the diversity and interactions of the biological and socioeconomic components of a city, but also the spatial pattern of these elements and their ecological consequences from the scale of small patches to that of the entire urban landscape, and to the regional context in which the city resides (Pickett *et al.*, 1997; Zipperer *et al.*, 2000; Luck and Wu, 2002; Wu and David, 2002; Wu, 2008).

When pursuing an urban landscape ecology approach, urban forest managers should ideally consider a planning schematic that can modify tree planting projects according to the requirements of a variety of planting contexts rather than relying on a stock list of approved tree species. This will enable managers to properly assess and characterize different urban zones, thus enhancing the ability of planting projects to be contextually appropriate and to realize specific socio-cultural, economic, or environmental goals (Pickett *et al*., 2011). For example, while the selection of native species may be preferable in some scenarios, there may be instances in which non-native species are more suited to harsher growing environments and thus capable of delivering greater benefits. However, the use of non-native species must also account for their potential invasiveness and any detrimental influence they may exert on the urban landscape and its surroundings.

Progress must be assessed relative to defined standards if sustainability is the ultimate landscape management goal. Recognizing this need, Clark *et al.* (1997) have developed a model of sustainability that provides a list of criteria and associated indicators for the evaluation of the following critical elements of urban forest management: the vegetation resource; community framework; and resource management approaches. Kenney *et al.* (2011) revised this model further to produce a more detailed set of criteria and measurable indicators. This revised model has been used in the Urban Forest Strategic Management Plan for the Town of Oakville to assess the Town's progress towards sustainability. Carreiro and Zipperer (2008) argue that the construction of urban sustainability indices and the valuation of ecosystem services will be critical, particularly in the short-term, for preventing undesirable trajectories and gauging the efficacy of collective actions aimed at creating more ecologically sound cities.

Threats to the Urban Forest

Climate Change

Human activities occurring in the industrialized era, such as fossil fuel combustion, agricultural practices, land use change and deforestation, have released large quantities of heat trapping greenhouse gases into the atmosphere over a short period of time. As a consequence, the rising atmospheric greenhouse gas concentrations have been correlated with increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising sea levels (IPCC, 2007). Such climatic changes have had, and will continue to have, disastrous outcomes for the global biosphere.

Climate change is projected to impact the forests of Ontario by altering the frequency, intensity, duration, and timing of fire, drought, and insect and pathogen outbreaks (Dale *et al.*, 2001). In many areas, higher temperatures will alter moisture regimes and lead to increased drought stress for trees in urban settings; urban heat island effects are likely to magnify these stresses (Arnfield, 2003). Even a small rise in temperature during the growing season could increase evaporative demand, triggering drought stress (Dale *et al.*, 2001). In the Great Lakes basin soil moisture may decrease by as much as 30 per cent in the summer and fall (de Loë and Berg, 2006). In areas where drought is not observed, rising levels of carbon dioxide may lead to increased water-use efficiency in trees, and consequently increased tree growth. Higher temperatures may also increase rates of photosynthesis and extend the growing season (Zhou *et al.*, 2001).

Extreme precipitation events in Southern Ontario are projected to increase in both frequency and intensity under future climate change scenarios (Hengeveld and Whitewood, 2005). Consequently, increased branch failure caused by ice storms and high winds will lead to higher rates of tree mortality. Some degree of damage may be mitigated by proper routine maintenance and preferential selection of tree species that can withstand disturbance. Furthermore, erosion associated with flooding following heavy rain and rapid snow melt will expose roots to pathogenic fungi and will weaken tree stability.

Warmer annual temperatures will provide less control over many insect populations, many of which are kept at low levels by cold winter temperatures (Volney and Fleming, 2000). The seasonal development of many insects such as the spruce budworm (*Choristoneura spp*) or forest tent caterpillar (*Malacosoma disstria*) will likely be accelerated and extended as climate change continues (Fleming and Volney, 1995; Cerezke and Volney, 1995). Stress caused by drought, heat and air pollution will, in turn, increase the susceptibility of urban trees to such insect pest outbreaks.

Changes in species composition in the urban forest may also be observed as a consequence of altered climatic conditions. For example, certain generalist species that tolerate a wide range of conditions and have several means of reproduction, such as poplar species, may prevail over those species that have narrow ecological tolerances (Thompson *et al.*, 1998). Drought tolerant species will likely possess a greater adaptive capacity, while populations of structurally weak species that are susceptible to ice damage may decline. In addition, northward migration of species as a result of shifting population ranges will create opportunities for increased planting of Carolinian species, while a loss of species at the southern edge of their present natural range may also be observed. For example, research suggests that species found in the oak-hickory forests of the central United States may migrate into what is currently the Great Lakes-St. Lawrence forest (Colombo *et al.*, 1998). However, differing migration rates and the reactions of individual species to new environmental conditions (e.g. modified soil moisture levels) could result in new species mixes for which inadequate forest management experience exists.

Malcolm *et al.* (2008) modeled current and future tree species distribution in the Credit River Watershed under projected climate change scenarios. The results showed a clear north – south pattern in potential tree community change, understood as a temperature analog perspective. Thus, under a moderate warming scenario the habitat conditions observed in the south of the watershed could be expected to shift into the north of the watershed. More specifically, under an A2 emissions scenario tree communities in the watershed would likely approximate those of Kentucky or northern Georgia in 2095 (depending on the model used).[17] However, the authors state that it is unlikely that these tree species will achieve the rates of northward migration necessary to accompany the rapidly shifting habitat conditions. Rather, the more probable outcome for the Credit River Watershed will be decreased species diversity, lower forest biomass, and a “weedier” (early successional) set of taxa.

The uncertainty associated with climate change highlights the need for decisions that emphasize ecological processes, rather than those based solely on structure and composition (Harris *et al.*, 2006). Millar *et al.* (2007) note that attempts to use historical ecosystem

[17] The A2 emissions scenario projects an estimated 3.4ºC (range = 2.4 to 5.0ºC) temperature increase by the end of the 21st century, relative to average temperatures recorded at the end of the 20th century.

conditions as management targets may lead to the development of forests that are ill adapted to current conditions and more susceptible to undesirable changes. Thus, new management options must be considered.

Urbanization and Development Pressure

Population growth and the ensuing urbanization have transformed natural landscapes throughout the world and have contributed to the current crisis of biodiversity loss, habitat destruction, and deterioration of ecosystem services (Wu, 2008). The global urban population is growing three times faster than the rural population (Nilsson *et al.*, 1999). This trend is consistent with growth patterns in Canada. As of 2006, 80% of Canadian citizens lived in urban areas (Statistics Canada, 2008). The ecological footprints of growing Canadian cities are also increasing in size due to the demands for resources and the regional impacts of waste and emissions on soil, air, and water.

In southern Ontario, agriculture and urbanization have triggered the conversion of presettlement forest cover to isolated forest patches and prompted the loss of ecosystem services. Fragmentation and encroaching human development have been shown to cause alterations to plant communities, invasions of non-native flora and fauna, soil compaction or erosion, and damage from unauthorized recreational use (McWilliam *et al.*, 2010; Ranta *et al.*, 2013). Other types of encroachment, caused by light, sound, and other factors, are difficult to quantify and have yet to be studied in depth. A study by McWilliam *et al*. (2013) of several southern Ontario municipalities found that few had proper policy mechanisms to effectively deter or curb urban forest encroachment and that better cooperative planning strategies are needed.

If urban planning efforts fail to adequately include greenspace conservation, a community may see increased public costs for social and ecosystem services, increased public costs for disaster remediation, decreased community image and morale, lower property values, and increased public anxiety (Wilkinson, 1991). A failure to incorporate greenspace conservation and urban forest management into community development early on will only amplify the complexities and costs of later efforts as land values increase concurrently with competition for land purchase (Elmendorh and Luloff, 1999).

A study by Berland (2012) examined the long-term impacts of urbanization on tree canopy cover in the Twin Cities Area of Minnesota. The majority of land use change in the study entailed the conversion of agricultural land to urbanized land, with a significant decrease in tree canopy cover observed following the conversion. However, an overall increase in tree canopy cover was observed over time as trees planted during development reached maturity. Despite the improvement in overall tree canopy cover, this is not synonymous with an improvement in overall ecosystem services, as the canopy cover was still embedded in a highly urbanized matrix and the measurements cannot account for the nuanced outputs of ecosystem functions.

Air Pollution

Air pollution contributes directly to urban forest degradation by inducing changes in tree condition, tree physiology, and biogeochemical cycling and by lowering tree resistance to insects and disease (Percy, 2002). Matyssek *et al.* (1992) found premature leaf discoloration and abscission in European white birch (*Betula pendula)* that were exposed to relatively low concentrations of ozone during the growing season. In addition, susceptibility to drought may also be increased by ozone and other gaseous pollutants. Evidence also suggests that air pollution can predispose some tree species to low temperature injury by reducing frost hardiness (Chappelka and Freer-Smith, 1995).

Air pollutants can have a more subtle effect on tree health by inducing changes to the reproductive success of particular genotypes or species. For example, acidic precipitation was shown to negatively affect the germination of pollen of a variety of species (Van Ryn *et al.*, 1986). Similarly, Scholz *et al.* (1985) and O'Connor *et al.* (1987) found that pollen germination in some species could be inhibited by sulphur dioxide.

Urban Forest Pests and Disease

Exotic insect pests pose a serious threat to the health of urban forests as no natural controls have developed to regulate these non-native species. Consequently, infestations commonly result in a substantial loss of canopy cover and associated ecosystem services, an increase in municipal maintenance and removal costs, a loss of species diversity, and a shift to earlier age class distribution. Two exotic insect pests are of particular concern in this region: the emerald ash borer (*Agrilus planipennis*) and the Asian long-horned beetle (*Anoplophora glabripennis*).

The emerald ash borer (EAB) is an invasive beetle from Asia that attacks and kills all species of ash (genus: *Fraxinus*). The larvae tunnel beneath the bark and feed on the cambium, disrupting the flow of water and nutrients within the tree. The beetle was first identified in Michigan in 2002 and quickly became well established throughout much of Essex County and Chatham-Kent. The beetle is now established across TRCA's jurisdiction. Ash species are very common in many urban forests of southern Ontario as they are tolerant of harsh urban conditions. The loss of existing ash trees will therefore translate to a significant loss of total canopy cover and associated services, and significant costs to municipalities and homeowners when dead trees must be removed. Some evidence exists that ash trees have been regenerating in natural forests during the period of infestation but the dramatic losses of mature ash trees have resulted in a depleted seed bank (Kashian and Witter, 2011).

The Asian long-horned beetle (ALHB) is also an invasive beetle, native to eastern Asia. This exotic beetle attacks multiple hardwood species native to Canada. In particular, maple species (genus: *Acer*), which comprise significant portions of urban forests in Canada, are a preferred host tree. The beetle also attacks the following genera: horsechestnut (*Aesculus spp*), elm (*Ulmus spp*), birch (*Betula spp*), poplar (*Populus spp*), willow (*Salix spp*), mountain-ash (*Sorbus spp)* and common hackberry (*Celtic occidentalis*). The ALHB's presence in Canada was first detected in 2003 in an industrial area on the Toronto – Vaughan boundary, prompting the Canadian Food Inspection Agency to launch an aggressive effort to contain the infestation. The area has been regulated to prevent further spread and ALHB was declared to have been eradicated from the GTA. Despite this apparent success, an ALHB infestation was discovered in Mississauga in 2013 and is believed to be the result of a recent re-introduction of the pest – further proof that ongoing vigilance against urban forest pests is required.

Non-native Invasive Plant Species

Non-native invasive plants are aggressive and opportunistic species whose introduction or spread can dominate natural areas, potentially threatening the environment, economy, and society, including human health. Such species reproduce abundantly and subsequently displace native vegetation, impede the natural regeneration of forest tree species, modify habitat, sometimes hybridize with native species, and ultimately threaten biodiversity (Simberloff *et al.*, 1997). The agricultural and urban areas of temperate regions are among the most invaded biomes in the world (Lonsdale, 1999). Particularly persistent non-native invasive species in the Greater Toronto Area include common and glossy buckthorn (*Rhamnus cathartica, R. frangula*), dog-strangling vine / swallowwart (*Cynanchum louiseae [Vincetoxicum nigram], C. rossicum*), garlic mustard (*Alliara petiolata*), and Norway maple (*Acer platanoides*).

Non-native invasive plant species have few natural controls that prevent establishment. For example, Jogesh *et al.* (2008) found that several highly invasive non-native plants common in the Ottawa region were more resistant to generalist herbivores, suggesting that these plants possess resistance traits to which native North American herbivores are poorly pre-adapted. Similarly, Cappuccino and Carpenter (2005) determined that nine common invasive plants found in Ontario, New York and Massachusetts experienced, on average, 96 per cent less damage due to herbivory than non-invasive plant species.

In response to the serious threat to local biodiversity posed by non-native invasive plants, coordinated efforts for early detection and rapid response are now underway at the municipal, provincial, and federal scale. The prevention of new introductions will be vital to the success of these efforts, but some municipalities continue to plant Norway maple despite evidence of its invasiveness. Within the urban forest many invasive species are horticultural plants that have escaped from residential gardens into adjacent natural systems. Thus, a preference for planting non-invasive native species in urban gardens and yards will play an important role in invasive species management programs. Education of homeowners about plant invasiveness would also bolster efforts to control the establishment and spread of invasive plant species.

Additional Urban Forest Stressors

Urban forests are exposed to a host of additional biotic and abiotic stressors. Often multiple stressors combine to reduce a tree's vigour and increase vulnerability to additional problems. Moisture deficiency or excess are extremely common causes of urban tree decline. Soil saturation due to flooding or over-watering can decrease oxygen availability and lead to root suffocation (Iowa State University, 2008). Numerous factors may lead to soil-moisture-related drought stress, including restricted soil volumes, reduced rainfall infiltration, and soil compaction. Moisture stress can limit tree growth and reduce survival through direct and indirect effects on an array of physiological processes including photosynthesis (Cregg, 1995), respiration, protein synthesis, and secondary carbohydrate metabolism (Kramer, 1987). Furthermore, reduced tree vigour caused by moisture stress may predispose trees to additional health problems including insect infestation (Mattson and Haack, 1987), thereby creating favourable conditions for the spread of invasive pests such as Emerald Ash Borer. The urban heat island effect – whereby mean temperatures in urban cores are about 1-2 degrees Celsius higher or more than in nearby rural areas – can exacerbate tree stress and soil moisture loss. Soil temperatures can likewise be several degrees in higher in urban zones compared to rural soils (Pickett *et al.*, 2011). Chemical injury caused by exposure to herbicides, insecticides, fungicides, and de-icing salts is also a common cause of urban tree decline (Fluckiger and Braun, 1981).

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Appendix B: Glossary of Terms

Adaptive capacity: The ability of an ecosystem to withstand and adapt to changes in the environment. Adaptive capacity is higher in ecosystems with greater diversity of species and genetic variability among species, as these factors determine greater resiliency in the face of change or disturbance.

Canopy cover: The amount of land, typically represented as a per centage, covered by tree canopies as viewed from a two-dimensional, birds-eye perspective; does not account for detailed information such as tree height, species, or leaf area.

Carbon sequestration: The process of removing and capturing carbon, in the form of carbon dioxide (CO_2), from the atmosphere. During photosynthesis, trees and plants take carbon dioxide in through the stomata and synthesize it with water and light energy to produce carbohydrates. As carbon sequestration is performed mainly by leaves, large trees sequester greater amounts of carbon than small trees on a per tree basis.

Carbon storage: The long-term storage of carbon (C) following removal from the atmosphere. Trees store carbon in the form of woody tissue; therefore, large trees store greater amounts of carbon than small trees on a per tree basis.

Drip line: A line under a tree in the shape of the outermost contour of the tree's crown; so called because it receives most of the rain water dripped by the tree's leaves.

Ecosystem services: Services delivered by natural features as a result of their natural functioning that benefit human populations, including, but not limited to, air pollution removal, erosion control, and climate moderation.

Exotic species: [See **Non-native species**]

Extensive management: Large-scale tree management that occurs on the landscape level; e.g. woodlot management.

Forest: An ecosystem dominated by trees and usually defined by at least 30% tree canopy cover, but also including associated plants, shrubs, soils, and fungi, as well as microbes, insects, and wildlife for which the forest provides habitat and sources of food. A forest also performs vital functions such as soil nutrient cycling, water filtration, erosion control, and climate moderation.

Green infrastructure: Natural features that are managed by humans and often incorporated into conventionally built infrastructure to provide ecosystem services in urban zones. Examples include green roofs, living walls, and engineered wetlands.

Greenspace: Areas dominated by natural features, usually within developed zones and contrasting with adjacent areas dominated by built infrastructure, that provide ecosystem services and are often open to public access. Can include highly tended spaces (ex. Cemeteries) or natural ecosystems (ex. Urban woodlots or wetlands).

Intensive management: Small-scale tree management that focuses on individual tree maintenance; e.g. street and yard trees.

Invasive species: Species of flora and fauna that, when present in an ecosystem, are able to spread aggressively and may become dominant. Non-native invasive species (e.g. European buckthorn), which are introduced as a result of human activity, are present in an ecosystem outside of their natural range and therefore have few or no natural predators or controls to limit their spread. As a result, they often out-compete native species, reduce overall species diversity, and negatively affect ecosystem functioning. Native invasive species (e.g. goldenrod spp.) are often species that become established in disturbed environments and create an early successional stage that, over time, will change naturally into a climax ecosystem.

Leaf area density: An estimation of the surface area of the leaves growing on a given unit of land; calculated using data recorded during a sample tree inventory and extrapolated to represent the portion of land covered by the inventory. This measurement provides more information on forest structure and function than canopy cover.

Native species: Species of flora and fauna that are indigenous to a particular locality or region, regardless of political or jurisdictional boundaries.

Natural heritage: Natural features deemed significant for their common cultural, economic, historical, or ecological importance and therefore deserving of continuous preservation or conservation.

Natural system: Self-regulating features of the landscape that precede large scale human development and that exist with minimal intervention by humans; e.g. ravines, natural forests.

Non-native species: Species of flora and fauna growing in an area outside of their natural range. Non-native species may originate in foreign countries (also called **exotic species**), or they may originate from other areas of the same country or province. For example, horsechestnut, native to eastern Europe, is non-native in Canada; pitch pine (*Pinus rigida*) is native to eastern Ontario, but is non-native in the Greater Toronto Area.

Positive feedback loop: A cycle in which a discernible cause produces an increase within a system, which feeds into the initial cause, thereby increasing the magnitude of its effects.

Riparian zone: An area of land adjacent to a river, forming a buffer between land and water. Riparian zones play important ecological roles in river habitats, such as erosion control and sediment filtration, and usually contain unique types of vegetation adapted to wet conditions.

Root zone: The three-dimensional area under the ground surface occupied by a tree's roots and from which they derive nutrients and water. The majority of a tree's roots are in the upper 6 inches of soil where water and nutrients are most readily absorbed. A natural and uninhibited root zone typically extends well beyond the **drip line**. Soil compaction and constrained root zones have negative effects on tree growth and vitality.

Soil profile: The accumulated distinct horizontal layers of soil (called horizons) that have developed as a result of natural weathering and deposition of nutrients, water, air, and organic matter. Soil profiles vary according to a number of factors, but in southern Ontario, healthy soil profiles under most conditions typically consist of layers (horizons) of organic matter, topsoil, subsoil, and parent material. Additional layers may also exist.

Tree inventory: A systematic catalogue of trees typically created as a census and/or for forest management. Usually includes detailed information on tree species, size, condition, etc.

Urban forest: The totality of the trees, shrubs, grasses, and plants, along with their associated fungi, microbes, soils, insects, and wildlife, that exist in developed areas of settled human populations and their zones of influence. Includes intensively managed street and yard trees, and extensively managed woodlots.

Urban heat island: The effect of heat intensification in urban zones caused by the high proportion of impervious ground cover and building materials (e.g. asphalt, concrete, buildings) and the relatively low proportion of tree cover. Urban surface temperatures increase due to the high heat absorption and retention properties of impervious materials. Higher surface temperature can then lead to higher air temperatures as the heat retained in impervious materials is slowly emitted.

Urban nature: Natural features that exist within areas of settled human populations and their zone of influence, and which are valued for recreation, education, and natural ecosystem services.

Appendix C: Land Use Categories

MPAC Code	Description
	OPEN SPACE
103	Municipal park (excludes Provincial parks, Federal parks, Campgrounds)
490	Golf Course
702	Cemetery
491	Ski Resort
382	Mobile home park – more than one mobile home on a parcel of land, which is a mobile park operation.
486	Campground
109	Large land holdings, greater than 1000 acres
703	Cemetery with non-internment services
	RESIDENTIAL LOW
301	Single family detached (not on water)
302	More than one structure used for residential purposes with at least one of the structures occupied permanently
303	Residence with a commercial unit
304	Residence with a commercial/ industrial use building
305	Link home – are homes linked together at the footing or foundation by a wall above or below grade.
307	Community lifestyle (not a mobile home park) – Typically, a gated community under single ownership.
309	Freehold Townhouse/Row house – more than two units in a row with separate ownership
311	Semi-detached residential – two residential homes sharing a common center wall with separate ownership.
313	Single family detached on water – year round residence
314	Clergy Residence
322	Semi-detached residence with both units under one ownership – two residential homes sharing a common center wall.
332	Typically a Duplex – residential structure with two self-contained units.
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.
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.
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 unit and who, by reason of their emotional, mental, social or physical condition or legal status, require a group living arrangement for their well being.
366	Student housing (off campus) – residential property licensed for rental by students.
381	Mobile home – one or more mobile home on a parcel of land, which is not a mobile home park operation.
382	Mobile home park – more than one mobile home on a parcel of land, which is a mobile park operation.
383	Bed and breakfast establishment
	RESIDENTIAL MEDIUM
127	Townhouse block - freehold units

350	Row housing, with three to six units under single ownership
352	Row housing, with seven or more units under single ownership
333	Residential property with three self-contained units
334	Residential property with four self-contained units
335	Residential property with five self-contained units
336	Residential property with six self-contained units
360	Rooming or boarding house – rental by room/bedroom , tenant(s) share a kitchen, bathroom and living quarters.
361	Bachelorette, typically a converted house with 7 or more self-contained units
373	Cooperative housing – equity – Equity Co-op corporations are owned by shareholders. The owners of shares do not receive title to a unit in the building, but acquire the exclusive use of a unit and are able to participate in the building's management.
	RESIDENTIAL HIGH
340	Multi-residential, with 7 or more self-contained units (excludes row-housing)
370	Residential Condominium Unit
341	Multi-residential, with 7 or more self-contained residential units, with small commercial unit(s)
378	Residential Leasehold Condominium Corporation – single ownership of the development where the units are leased.
	COMMERCIAL AND INDUSTRIAL
400	Small Office building (generally single tenant or owner occupied under 7,500 s.f.)
401	Small Medical/dental building (generally single tenant or owner occupied under 7,500 s.f.)
402	Large office building (generally multi - tenanted, over 7,500 s.f.)
403	Large medical/dental building (generally multi - tenanted over 7,500 s.f.)
405	Office use converted from house
406	Retail use converted from house
407	Retail lumber yard
408	Freestanding Beer Store or LCBO - not associated with power or shopping centre
409	Retail - one storey, generally over 10,000 s.f.
410	Retail - one storey, generally under 10,000 s.f.
411	Restaurant - conventional
412	Restaurant - fast food
413	Restaurant - conventional, national chain
414	Restaurant - fast food, national chain
415	Cinema/movie house/drive-in
416	Concert hall/live theatre
417	Entertainment complex - with a large cinema as anchor tenant
419	Automotive service centre, highway - 400 series highways
420	Automotive fuel station with or without service facilities
421	Specialty automotive shop/auto repair/ collision service/car or truck wash
422	Auto dealership
423	Auto dealership - independent dealer or used vehicles
425	Neighbourhood shopping centre - with more than two stores attached, under one ownership, with anchor - generally less than 150,000 s.f.
426	Small box shopping centre less than 100,000 s.f. minimum 3 box stores with one anchor

	(large grocery or discount store)
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
428	Regional shopping centre
429	Community shopping centre
430	Neighbourhood shopping centre - with more than 2 stores attached, under one ownership, without anchor - generally less than 150,000 s.f.
431	Department store
432	Banks and similar financial institutions, including credit unions - typically single tenanted, generally less than 7,500 s.f.
433	Banks and similar financial institutions, including credit unions - typically multi tenanted, generally greater than 7,500 s.f.
434	Freestanding supermarket
435	Large retail building centre, generally greater than 30,000 s.f.
436	Freestanding large retail store, national chain - generally greater than 30,000 s.f.
438	Neighbourhood shopping centre with offices above
441	Tavern/public house/small hotel
444	Full service hotel
445	Limited service hotel
446	Apartment hotel
447	Condominium Hotel Unit
450	Motel
451	Seasonal motel
460	Resort hotel
461	Resort lodge
462	Country inns & small inns
463	Fishing/hunting lodges/resorts
465	Child and community oriented camp/resort
470	Multi-type complex - defined as a large multi-use complex consisting of retail/office and other uses (multi res/condominium/hotel)
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
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
473	Retail with more than one non-retail use
475	Commercial condominium
476	Commercial condominium (live/work)
477	Retail with office(s) - less than 10,000 s.f., GBA with offices above
478	Retail with office(s) - greater than 10,000 s.f., GBA with offices above
480	Surface parking lot - excludes parking facilities that are used in conjunction with another property
481	Parking garage - excludes parking facilities that are used in conjunction with another property
482	Surface parking lot - used in conjunction with another property
483	Parking garage - used in conjunction with another property

705	Funeral Home
711	Bowling alley
713	Casino
704	Crematorium
105	Vacant commercial land
106	Vacant industrial land
	UTILITIES AND TRANSPORTATION
496	Communication buildings
555	O.P.G. Hydraulic Generating Station
556	O.P.G. Nuclear Generating Station
557	O.P.G. Fossil Generating Station
558	Hydro One Transformer Station
559	MEU Generating Station
560	MEU Transformer Station
561	Hydro One Right-of-Way
562	Private Hydro Rights-of-Way
563	Private Hydraulic Generating Station
564	Private Nuclear Generating Station
565	Private Generating Station (Fossil Fuels and Cogen)
566	Private Transformer Station
567	Wind Turbine
741	Airport Authority
742	Public transportation - easements and rights
743	International bridge/tunnel
588	Pipelines - transmission, distribution, field & gathering and all other types including distribution connections
589	Compressor station - structures and turbines used in connection with transportation and distribution of gas
597	Railway right-of-way
598	Railway buildings and lands described as assessable in the Assessment Act
599	GO transit station/rail yard
737	Federal airport
738	Provincial airport
739	Local government airport
740	Airport leasehold
744	Private airport/hangar
745	Recreational airport
746	Subway station
748	Transit garage
749	Public transportation - other
755	Lighthouses
824	Government - wharves and harbours
826	Government - special educational facility
828	Government - canals and locks

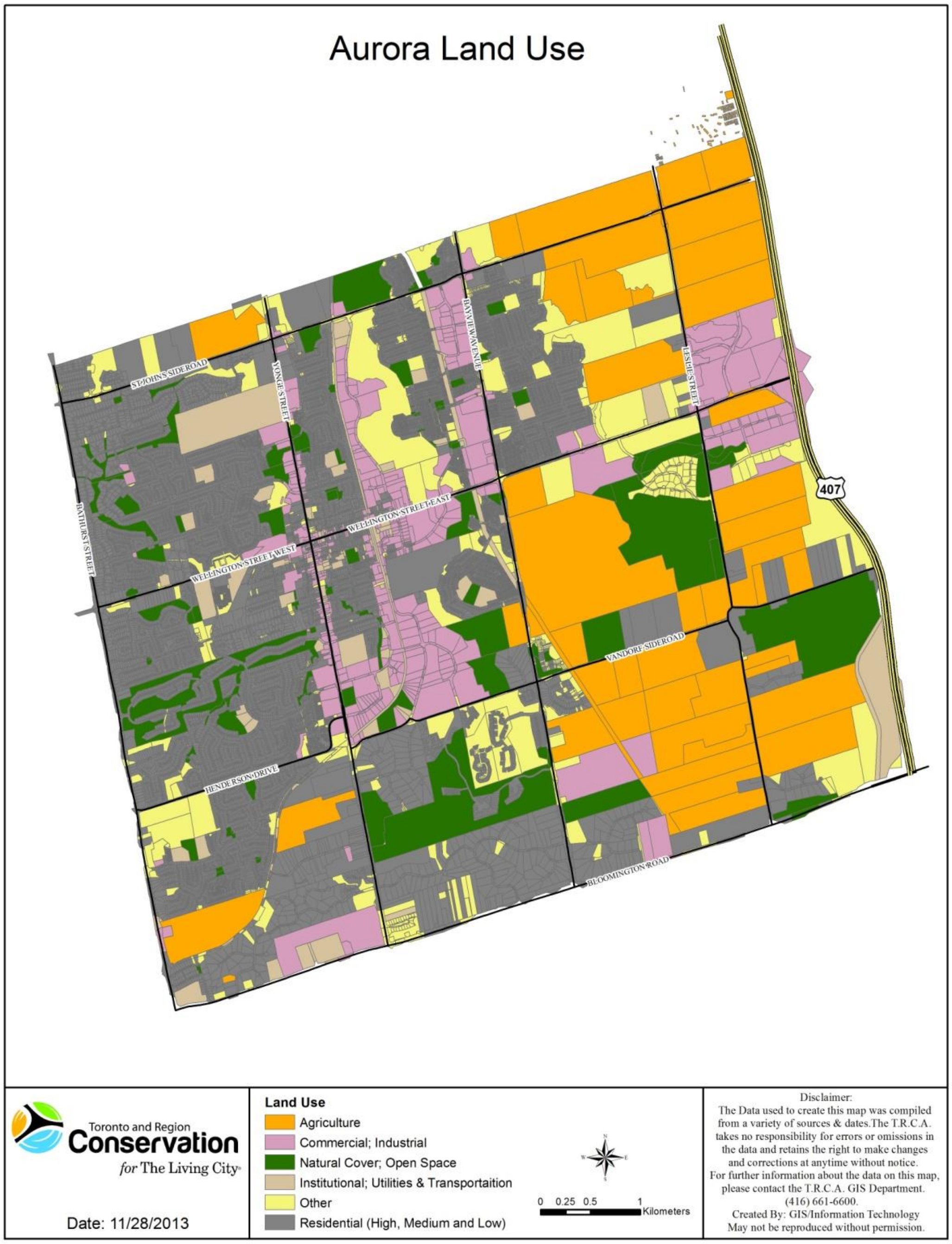
830	Government - navigational facilities
832	Government - historic site or monument
840	Port authority - port activities
842	Port authority - other activities
495	Communication towers - with or without secondary communication structures
155	Land associated with power dam
	INSTITUTIONAL
601	Post secondary education - university, community college, etc
602	Multiple occupancy educational institutional residence located on or off campus
605	School (elementary or secondary, including private)
608	Day Care
610	Other educational institution (e.g. schools for the blind, deaf, special education, training)
611	Other institutional residence
621	Hospital, private or public
623	Continuum of care seniors facility
624	Retirement/nursing home (combined)
625	Nursing home
626	Old age/retirement home
627	Other health care facility
630	Federal penitentiary or correctional facility
631	Provincial correctional facility
632	Other correctional facility
700	Place of worship - with a clergy residence
701	Place of Worship - without a clergy residence
730	Museum and/or art gallery
731	Library and/or literary institutions
733	Convention, conference, congress centre
734	Banquet hall
735	Assembly hall, community hall
736	Clubs - private, fraternal
750	Scientific, pharmaceutical, medical research facility (structures predominantly other than office)
760	Military base or camp (CFB)
761	Armoury
762	Military education facility
805	Post office or depot
806	Postal mechanical sorting facility
810	Fire Hall
812	Ambulance Station
815	Police Station
822	Government - agricultural research facility - predominantly non farm property (office building, laboratories)
	AGRICULTURE
200	Farm property without any buildings/structures

201	Farm with residence - with or without secondary structures; no farm outbuildings
210	Farm without residence - with secondary structures; with farm outbuildings
211	Farm with residence - with or without secondary structures; with farm outbuildings
220	Farm without residence - with commercial/industrial operation
221	Farm with residence - with commercial/industrial operation
222	Farm with a winery
223	Grain/seed and feed operation
224	Tobacco farm
225	Ginseng farm
226	Exotic farms i.e emu, ostrich, pheasant, bison, elk, deer
227	Nut Orchard
228	Farm with gravel pit
229	Farm with campground/mobile home park
230	Intensive farm operation - without residence
231	Intensive farm operation - with residence
232	Large scale greenhouse operation
233	Large scale swine operation
234	Large scale poultry operation
235	Government - agriculture research facility - predominately farm property
236	Farm with oil/gas well(s)
260	Vacant residential/commercial/ industrial land owned by a non-farmer with a portion being farmed
261	Land owned by a non-farmer improved with a non-farm residence with a portion being farmed
262	Land owned by a farmer improved with a non-farm residence with a portion being farmed
	NATURAL COVER
240	Managed forest property, vacant land not on water
241	Managed forest property, vacant land on water
242	Managed forest property, seasonal residence not on water
243	Managed forest property, seasonal residence on water
244	Managed forest property, residence not on water
245	Managed forest property, residence on water
107	Provincial park
108	Federal park
134	Land designated and zoned for open space
102	CA lands
	OTHER
120	Water lot (entirely under water)
492	Marina - located on waterfront - defined as a commercial facility for the maintenance, storage, service and/or sale of watercraft
493	Marina - not located on waterfront - defined as a commercial facility for the maintenance, storage, service and/or sale of watercraft
487	Billboard
111	Island under single ownership

385	Time-share, fee simple
386	Time share, right-to-use
391	Seasonal/recreational dwelling - first tier on water
392	Seasonal/recreational dwelling - second tier to water
395	Seasonal/recreational dwelling - not located on water
150	Mining lands - patented
151	Mining lands - unpatented
130	Non-buildable land (walkways, buffer/berm, storm water management pond,etc)
100	Vacant residential land not on water
101	Second tier vacant lot – refers to location not being directly on the water but one row back from the water
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 declaration.
306	Boathouse with residence above
110	Vacant residential/recreational land on water
140	Common land
375	Co-ownership – per centage interest/share in the co-operative housing.
371	Life Lease - No Redemption. Property where occupants have either no or limited redemption amounts. Typically Zero Balance or Declining Balance Life Lease Types.
372	Life Lease - Return on Invest. Property where occupants can receive either a guaranteed return or a market value based return on the investment. Typically, represented by Fixed Value, Indexed-Based, or Market Value Life Lease Types.
715	Race track, auto
716	Racetrack - horse, with slot facility
717	Racetrack - horse, without slot facility
718	Exhibition/fair grounds
720	Commercial sport complex
722	Professional sports complex
725	Amusement park
726	Amusement park - large/regional
710	Recreational sport club - non commercial (excludes golf clubs and ski resorts)
489	Driving range/golf centre - stand alone, not part of a regulation golf course
721	Non-commercial sports complex
112	Multi-residential vacant land
113	Condominium development land - residential (vacant lot)
114	Condominium development land - non residential (vacant lot)
115	Property in process of redevelopment utilizing existing structure(s)
125	Residential development land
379	Residential phased condominium corporation – condominium project is registered in phases.
369	Vacant land condominium (residential - improved) – condo plan registered against the land.
374	Cooperative housing - non-equity – Non-equity Co-op corporations are not owned by individual shareholders, the shares are often owned by groups such as unions or non-profit organizations which provide housing to the people they serve. The members who

	occupy the co-operative building do not hold equity in the corporation. Members are charged housing costs as a result of occupying a unit.
169	Vacant land condominium (residential)-defined land that's described by a condominium plan
377	Condominium parking space/unit – separately deeded.
376	Condominium locker unit – separately deeded.
380	Residential common elements condominium corporation – consists only of the common elements not units.

Appendix D: Generalized land use map based on Municipal Property Assessment Corporation (MPAC) codes.



The projections used in this study are based on MPAC designations from 2008. Some discrepancies in land use categories were observed in the field, and areas of some land use categories were undergoing changes as a result of development, primarily in the eastern half of Aurora. Most of the changes were observed in the lands categorized as "Agriculture", of which only 15% were observed to be currently used for agricultural purposes.

Appendix E: i-Tree Eco Model – Detailed Methodology

Adapted from: Nowak *et al.* 2008. A Ground-based Method of Assessing Urban Forest Structure and Ecosystem Services. Arboriculture and Urban Forestry. 34(6):347-358.

The i-Tree Eco model uses a sampling procedure to estimate various measured structural attributes about the forest (e.g., species composition, number of trees, diameter distribution) within a known sampling error. The model uses the measured structural information to estimate other structural attributes (e.g., leaf area, tree and leaf biomass) and incorporates local environmental data to estimate several functional attributes (e.g., air pollution removal, carbon sequestration, building energy effects). Economic data from the literature is used to estimate the value of some of the functions. The model has 5 modules:

1: Urban Forest Structure

Urban forest structure is the spatial arrangement and characteristics of vegetation in relation to other objects (e.g., buildings) within urban areas (e.g., Nowak 1994a). This module quantifies urban forest structure (e.g., species composition, tree density, tree health, leaf area, leaf and tree biomass), value, diversity, and potential risk to pests.

Sampling

i-Tree Eco assessments have used two basic types of sampling to quantify urban forest structure: randomized grid and stratified random sampling. With the randomized grid sampling the study area is divided into equal-area grid cells based on the desired number of plots and then one plot is randomly located within each grid cell. The study area can then be subdivided into smaller units of analysis (i.e., strata) after the plots are distributed (post-stratification). Plot distribution among the strata will be proportional to the strata area. This random sampling approach allows for relatively easy assessment of changes through future measurements (urban forest monitoring), but likely at the cost of increased variance (uncertainty) of the population estimates.

With stratified random sampling, the study area is stratified prior to distributing the plots and plots are randomly distributed within each stratum (e.g., land use). This process allows the user to distribute the plots among the strata to potentially decrease the overall variance of the population estimate. For example, since tree effects are often the primary focus of sampling, the user can distribute more plots into strata that have more trees. The disadvantage of this approach is that it makes long-term change assessments more difficult due to the potential for strata to change through time.

There is no significant difference in cost or time to establish plots regardless of sampling methods for a fixed number of plots. However, there are likely differences in estimate precision. Pre-stratification, if done properly, can reduce overall variance as it can focus more plots in areas of higher variability. Any plot size can be used in i-Tree ECO, but the typical plot size used is 0.04 ha (0.1 ac). The number and size of plots will affect total cost of the data collection as well as the variance of the estimates (Nowak *et al.* 2008).

Data Collection Variables

There are four general types of data collected on an i-Tree Eco plot: 1) general plot information (Table 1) – used to identify the plot and its general characteristics, 2) shrub information (Table 2) - used to estimate shrub leaf area/biomass, pollution removal and volatile organic compound (VOC) emissions by shrubs, 3) tree information (Table 3) – used to estimate forest structural attributes, pollution removal, VOC emissions, carbon storage and sequestration, energy conservation effects, and potential pest impacts of trees, and 4) ground cover data - used to estimate the amount and distribution of various ground cover types in the study area.

Typically, shrubs are defined as woody material with a diameter at breast height (dbh; diameter of stem at height of 1.3m from ground) less than 2.54 cm, while trees have a dbh greater than or equal to 2.54 cm (1 in). Trees and shrubs can also be differentiated by species (i.e., certain species are always a tree or always a shrub), or with a different dbh minimum threshold. For example, in densely forested areas, increasing the minimum dbh to 12.7 cm (5 in.) can substantially reduce the field work by decreasing the number of trees measured, but less information on trees will be attained. Woody plants that are not 30.5 cm (12 in) in height are considered herbaceous cover (e.g., seedlings). Shrub masses within each plot are divided into groups of same species and size, and for each group, appropriate data are collected (Table 2). Tree variables (Table 3) are collected on every measured tree.

Field data are collected during the summer leaf-on season in order to accurately assess crown parameters and tree condition. More detailed information on plot data collection methods and equipment can be found in the i-Tree User's Manual (i-Tree 2012).

Leaf area and leaf biomass

Leaf area and leaf biomass of individual open-grown trees (crown light exposure (CLE) of 4-5) are calculated using regression equations for deciduous urban species (Nowak 1996). If shading coefficients (per cent light intensity intercepted by foliated tree crowns) used in the regression did not exist for an individual species, genus or hardwood averages are used. For deciduous trees that are too large to be used directly in the regression equation, average leaf-area index (LAI: m^2 leaf area per m^2 projected ground area of canopy) is calculated by the regression equation for the maximum tree size based on the appropriate height-width ratio and shading coefficient class of the tree. This LAI is applied to the ground area (m^2) projected by the tree's crown to calculate leaf area (m^2). For deciduous trees with height-to-width ratios that are too large or too small to be used directly in the regression equations, tree height or width is scaled downward to allow the crown to the reach maximum (2) or minimum (0.5) height-to-width ratio. Leaf area is calculated using the regression equation with the maximum or minimum ratio; leaf area is then scaled back proportionally to reach the original crown volume.

For conifer trees (excluding pines), average LAI per height-to-width ratio class for deciduous trees with a shading coefficient of 0.91 is applied to the tree's ground area to calculate leaf area. The 0.91 shading coefficient class is believed to be the best class to represent conifers as conifer forests typically have about 1.5 times more LAI than deciduous forests (Barbour *et al.* 1980) and 1.5 times the average shading coefficient for deciduous trees (0.83, see Nowak 1996) is equivalent to LAI of the 0.91 shading coefficient. Because pines have lower LAI than other conifers and LAI that are comparable to hardwoods (e.g., Jarvis and Leverenz 1983; Leverenz and Hinckley 1990), the average shading coefficient (0.83) is used to estimate pine leaf area.

Leaf biomass is calculated by converting leaf-area estimates using species-specific measurements of g leaf dry weight/m^2 of leaf area. Shrub leaf biomass is calculated as the product of the crown volume occupied by leaves (m^3) and measured leaf biomass factors (g m^{-3}) for individual species (e.g., Winer *et al.* 1983; Nowak 1991). Shrub leaf area is calculated by converting leaf biomass to leaf area based on measured species conversion ratios (m^2 g^{-1}). Due to limitations in estimating shrub leaf area by the crown-volume approach, shrub leaf area is not allowed to exceed a LAI of 18. If there are no leaf-biomass-to-area or leaf-biomass-to-crown-volume conversion factors for an individual species, genus or hardwood/conifer averages are used.

For trees in more forest stand conditions (higher plant competition), leaf area index for more closed canopy positions (CLE = 0-1) is calculated using forest leaf area formula based on the Beer-Lambert Law:

$LAI = \ln(I/I_o)/-k$

where I = light intensity beneath canopy; I_o = light intensity above canopy; and k = light extinction coefficient (Smith *et al.* 1991). The light extinction coefficients are 0.52 for conifers and 0.65 for hardwoods (Jarvis and Leverenz, 1983). To estimate the tree leaf area (LA):

$$LA = [\ln((1-x_s)/-k\ ] \times \pi r^2$$

where x_s is average shading coefficient of the species and r is the crown radius. For CLE = 2-3: leaf area is calculated as the average of leaf area from the open-grown (CLE = 4-5) and closed canopy equations (CLE = 0-1).

Estimates of leaf area and leaf biomass are adjusted downward based on crown leaf dieback (tree condition). Trees are assigned to one of 7 condition classes: Excellent (< 1 dieback); Good (1-10 per cent dieback); Fair (11-25 per cent dieback); Poor (26-50 per cent dieback); Critical (51-75 per cent dieback); Dying (76-99); Dead (100 per cent dieback). Condition ratings range between 1 indicating no dieback and 0 indicating 100-per cent dieback (dead tree). Each class between excellent and dead is given a rating between 1 and 0 based on the mid-value of the class (e.g., fair = 11-25 per cent dieback is given a rating of 0.82 or 82-per cent healthy crown). Tree leaf area is multiplied by the tree condition factor to produce the final leaf area estimate.

Species Diversity

A species diversity index (Shannon-Wiener) and species richness (i.e., number of species) (e.g., Barbour 1980), are calculated for living trees for the entire city. The proportion of the tree population that originated from different parts of the country and world is calculated based on the native range of each species (e.g., Hough 1907; Grimm 1962; Platt 1968; Little 1971, 1976, 1977, 1978; Viereck and Little 1975; Preston 1976; Clark 1979; Burns and Honkala 1990a,b; Gleason and Cronquist 1991).

Structural Value

The structural value of the trees (Nowak *et al.*, 2002a) is based on methods from the Council of Tree and Landscape Appraisers (CTLA 1992). Compensatory value is based on four tree/site characteristics: trunk area (cross-sectional area at dbh), species, condition, and location. Trunk area and species are used to determine the basic value, which is then multiplied by condition and location ratings (0-1) to determine the final tree compensatory value. Local species factors, average replacement cost, and transplantable size and replacement prices are obtained from ISA publications. If no species data are available for the state, data from the nearest state are used. Condition factors are based on per cent crown dieback. Available data required using location factors based on land use type (Int. Soc. of Arboric. 1988): golf course = 0.8; commercial/industrial, cemetery and institutional = 0.75; parks and residential = 0.6; transportation and forest = 0.5; agriculture = 0.4; vacant = 0.2; wetland = 0.1.

Insect Effects

The proportion of leaf area and live tree population, and estimated compensatory value in various susceptibility classes to gypsy moth (Liebhold *et al.,* 1995; Onstad *et al.*, 1997), Asian longhorned beetle (e.g., Nowak *et al.*, 2001) and emerald ash borer (ash species) are calculated to reveal potential urban forest damage associated with these pests.

2: Biogenic Emissions

Volatile organic compounds (VOCs) can contribute to the formation of O_3 and CO (e.g., Brasseur and Chatfield 1991). The amount of VOC emissions depends on tree species, leaf biomass, air temperature, and other environmental factors. This module estimates the hourly emission of isoprene (C_5H_8), monoterpenes (C_{10} terpenoids), and other volatile organic compounds (OVOC) by species for each land use and for the entire city. Species leaf biomass (from the structure module) is multiplied by genus-specific emission factors (Nowak *et al.,* 2002b) to produce emission levels standardized to 30^oC (86^oF) and photosynthetically active radiation (PAR) flux of 1,000 µmol m^{-2} s^{-1}. If genus-specific information is not available, then median emission values for the family, order, or superorder are used. Standardized emissions are converted to actual emissions based on light and temperature correction factors (Geron *et al.,* 1994) and local meteorological data. As PAR strongly controls the isoprene emission rate, PAR is estimated at 30 canopy levels as a function of above-canopy PAR using the sunfleck canopy environment model (A. Guenther, Nat. Cent. for Atmos. Res. pers. comm. 1998) with the LAI from the structure calculations.

Hourly inputs of air temperature are from measured National Climatic Data Center (NCDC) meteorological data. Total solar radiation is calculated based on the National Renewable Energy Laboratory Meteorological/Statistical Solar Radiation Model (METSTAT) with inputs from the NCDC data set (Maxwell 1994). PAR is calculated as 46 per cent of total solar radiation input (Monteith and Unsworth 1990).

Because tree transpiration cools air and leaf temperatures and thus reduces biogenic VOC emissions, tree and shrub VOC emissions are reduced in the model based on air quality modeling results (Nowak *et al.,* 2000). For the modeling scenario analyzed (July 13-15, 1995) increased tree cover reduced air temperatures by 0.3^o to 1.0^oC resulting in hourly reductions in biogenic VOC emissions of 3.3 to 11.4 per cent. These hourly reductions in VOC emissions are applied to the tree and shrub emissions during the in-leaf season to account for tree effects on air temperature and its consequent impact on VOC emissions.

3: Carbon Storage and Annual Sequestration

This module calculates total stored carbon, and gross and net carbon sequestered annually by the urban forest. Biomass for each measured tree is calculated using allometric equations from the literature (see Nowak 1994c; Nowak *et al.,* 2002b). Equations that predict above-ground biomass are converted to whole tree biomass based on root-to-shoot ratio of 0.26 (Cairns *et al.,* 1997). Equations that compute fresh-weight biomass are multiplied by species- or genus-specific-conversion factors to yield dry-weight biomass. These conversion factors, derived from average moisture contents of species given in the literature, averaged 0.48 for conifers and 0.56 for hardwoods (see Nowak *et al.,* 2002b).

Open-grown, maintained trees tend to have less above-ground biomass than predicted by forest-derived biomass equations for trees of the same dbh (Nowak 1994c). To adjust for this difference, biomass results for urban trees are multiplied by a factor 0.8 (Nowak 1994c). No adjustment is made for trees found in more natural stand conditions (e.g., on vacant lands or in forest preserves). Since deciduous trees drop their leaves annually, only carbon stored in wood biomass is calculated for these trees. Total tree dry-weight biomass is converted to total stored carbon by multiplying by 0.5 (Forest Products Lab 1952; Chow and Rolfe 1989).

The multiple equations used for individual species were combined together to produce one predictive equation for a wide range of diameters for individual species. The process of combining the individual formulas (with limited diameter ranges) into one, more general, species formula produced results that were typically within 2% of the original estimates for total carbon storage of the urban forest (i.e., the estimates using the multiple equations). Formulas were combined to prevent disjointed sequestration estimates that can occur when calculations switch between individual biomass equations.

If no allometric equation could be found for an individual species the average of results from equations of the same genus is used. If no genus equations are found, the average of results from all broadleaf or conifer equations is used.

To estimate monetary value associated with urban tree carbon storage and sequestration, carbon values are multiplied by $22.8/tonne of carbon ($20.7/ton of carbon) based on the estimated marginal social costs of carbon dioxide emissions for 2001-2010 (Fankhauser 1994).

Urban Tree Growth and Carbon Sequestration

To determine a base growth rate based on length of growing season, urban street tree (Frelich, 1992; Fleming 1988; and Nowak 1994c), park tree (DeVries 1987), and forest growth estimates (Smith and Shifley 1984) were standardized to growth rates for 153 frost free days based on: Standardized growth = measured growth x (153/ number of frost free days of measurement).

Average standardized growth rates for street (open-grown) trees were 0.83 cm/yr (0.33 in/yr). Growth rates of trees of the same species or genera were then compared to determine the average difference between standardized street tree growth and standardized park and forest growth rates. Park growth averaged 1.78 times less than street trees, and forest growth averaged 2.29 times less than street tree growth. Crown light exposure measurements of 0-1 were used to represent forest growth conditions; 2-3 for park conditions; and 4-5 for open-grown conditions. Thus, the standardized growth equations are:

Standardized growth (SG) = 0.83 cm/yr (0.33 in/yr) x number of frost free days / 153

and for: CLE 0-1: Base growth = SG / 2.26; CLE 2-3: Base growth = SG / 1.78; and
CLE 4-5: Base growth = SG.

Base growth rates are adjusted based on tree condition. For trees in fair to excellent condition, base growth rates are multiplied by 1 (no adjustment), poor trees' growth rates are multiplied by

0.76, critical trees by 0.42, dying trees by 0.15, and dead trees by 0. Adjustment factors are based on per cent crown dieback and the assumption that less than 25-per cent crown dieback had a limited effect on dbh growth rates. The difference in estimates of carbon storage between year *x* and year *x+1* is the gross amount of carbon sequestered annually.

4: Air Pollution Removal

This module quantifies the hourly amount of pollution removed by the urban forest, its value, and associated per cent improvement in air quality throughout a year. Pollution removal and per cent air quality improvement are calculated based on field, pollution concentration, and meteorological data.

This module is used to estimate dry deposition of air pollution (i.e., pollution removal during nonprecipitation periods) to trees and shrubs (Nowak *et al.,* 1998, 2000). This module calculates the hourly dry deposition of ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), and particulate matter less than 10 microns (PM10) to tree and shrub canopies throughout the year based on tree-cover data, hourly Ontario Ministry of the Environment weather data, and U.S. Environmental Protection Agency (EPA) pollution-concentration monitoring data.

The pollutant flux (F; in g m^{-2} s^{-1}) is calculated as the product of the deposition velocity (V_d; in m s^{-1}) and the pollutant concentration (C; in g m^{-3}):

$$F = V_d \times C$$

Deposition velocity is calculated as the inverse of the sum of the aerodynamic (R_a), quasi-laminar boundary layer (R_b) and canopy (R_c) resistances (Baldocchi *et al.,* 1987):

$$V_d = (R_a + R_b + R_c)^{-1}$$

Hourly meteorological data from the closest weather station (usually airport weather stations) are used in estimating R_a and R_b. In-leaf, hourly tree canopy resistances for O_3, SO_2, and NO_2 are calculated based on a modified hybrid of big-leaf and multilayer canopy deposition models (Baldocchi *et al.,* 1987; Baldocchi 1988).

As CO and removal of particulate matter by vegetation are not directly related to transpiration, R_c for CO is set to a constant for in-leaf season (50,000 s m^{-1} (15,240 s ft^{-1})) and leaf-off season (1,000,000 s m^{-1} (304,800 s ft^{-1})) based on data from Bidwell and Fraser (1972). For particles, the median deposition velocity from the literature (Lovett 1994) is 0.0128 m s^{-1} (0.042 ft s^{-1}) for the in-leaf season. Base particle V_d is set to 0.064 m s^{-1} (0.021 ft s^{-1}) based on a LAI of 6 and a 50-per cent resuspension rate of particles back to the atmosphere (Zinke 1967). The base V_d is adjusted according to actual LAI and in-leaf vs. leaf-off season parameters. Bounds of total tree removal of O_3, NO_2, SO_2, and PM10 are estimated using the typical range of published in-leaf dry deposition velocities (Lovett 1994). Per cent air quality improvement is estimated by incorporating local or regional boundary layer height data (height of the pollutant mixing layer). More detailed methods on module can be found in Nowak *et al.* 2006a.

The monetary value of pollution removal by trees is estimated using the median externality values for the United States for each pollutant. These values, in dollars per tonne (metric ton: mt) are: NO_2 = \$6,752 mt^{-1} (\$6,127 t^{-1}), PM10 = \$4,508 mt^{-1} (\$4,091 t^{-1}), SO_2 = \$1,653 mt^{-1}

($1,500 t^{-1}), and CO = $959 mt^{-1} ($870 t^{-1}) (Murray *et al.,* 1994). Recently, these values were adjusted to 2007 values based on the producer's price index (Capital District Planning Commission 2008) and are now (in dollars per metric ton (t)): NO_2 = $9,906 mt^{-1} ($8,989 t^{-1}), PM10 = $6,614 mt^{-1} ($6,002 t^{-1}), SO_2 = $2,425 mt^{-1} ($2,201 t^{-1}), and CO = $1,407 mt^{-1} ($1,277 t^{-1}). Externality values for O_3 are set to equal the value for NO_2.

5: Building Energy Effects

This module estimates the effects of trees on building energy use and consequent emissions of carbon from power plants. Methods for these estimates are based on a report by McPherson and Simpson (1999). Distance and direction to the building is recorded for each tree within 18.3 m (60 ft) of two or one-story residential buildings. Any tree that is smaller than 6.1 meters (20 ft) in height or farther than 18.3 meters (60 ft) from a building is considered to have no effect on building energy use.

Using the tree size, distance, direction to building, climate region, leaf type (deciduous or evergreen) and per cent cover of buildings and trees on the plot, the amount of carbon avoided from power plants due to the presence of trees is calculated. The amount of carbon avoided is categorized into the amount of MWh (cooling), and MBtus and MWh (heating) avoided due to tree energy effects. Default energy effects per tree are set for each climate region, vintage building types (period of construction), tree size class, distance from building, energy use (heating or cooling) and/or leaf type (deciduous or evergreen) depending upon the energy effect of the tree (tree shade, windbreak effects, and local climate effect) (McPherson and Simpson 1999). Default shading and climate effect values are applied to all trees; heating windbreak energy effects are assigned to each evergreen tree. As shading effect default values are given for only one vintage building type (post-1980), vintage adjustment factors (McPherson and Simpson 1999) are applied to obtain shading effect values for all other vintage types.

Tree Condition Adjustment

The default energy effect values (McPherson and Simpson 1999) are adjusted for the tree condition as follows:

$$\text{Energy adjustment} = 0.5 + (0.5 \times \text{tree condition})$$

where tree condition = 1 - % dieback. This adjustment factor is applied to all tree energy effects for cooling, but only evergreen trees for the heating energy use effects as deciduous trees are typically out-of-leaf during the heating season.

Local Climate Effects

The individual tree effect on climate diminishes as tree cover increases in an area, though the total effect of all trees can increase. Base climate effect values for a tree are given for plots of 10, 30 and 60 % cover (McPherson and Simpson 1999). Interpolation formulas (McPherson and Simpson 1999) are used to determine the actual tree value based on the specific plot per cent tree and building cover. For plots with less than 10% cover, the slope between the 10 and 30 % cover values are used for the interpolation. Plots with per cent cover greater than 60 % used the slope between 30 and 60 % cover with a minimum individual tree climate effect of one-third the effect at 60% cover. This minimum is set to prevent a tree from obtaining a negative effect at high cover.

The total shading, windbreak, and climate energy effects due to trees on a plot are calculated by summing the individual tree's energy effects for the particular energy use and housing vintage. These values are adjusted for the distribution of the different vintage types within the climate region (McPherson and Simpson 1999).

Since the default cooling energy effects are determined based on the climate regions' electricity emissions factors it is necessary to convert the cooling energy effects to the state specific equivalent. This conversion is accomplished by multiplying the plot cooling energy effects by the ratio of the state specific electricity emissions factor to the climate region's electricity emissions factor (McPherson & Simpson 1999).

Home heating source distribution (e.g., fuel oil, heat pump, electricity, and natural gas) for the region is used to partition the carbon emissions from heating to the appropriate energy source. Standard conversion factors (t CO_2 / MWh, t CO_2 / MBtu) are used to convert the energy effect from t CO_2 to units of energy saved (MBtus, MWh). Cooling and heating electricity use (MWh) had state specific conversion factors; non-electrical heating fuels (MBtus) used a standard conversion factor because this factor does not vary by region (McPherson and Simpson 1999). Total plot effects are combined to yield the total energy and associated carbon effect due to the urban forest.

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Appendix F: Criteria and Indicators for Strategic Urban Forest Planning and Management

Source: Kenney, W.A., van Wassenaer, P.J.E, and A.L. Satel. 2011. Criteria and Indicators for Strategic Urban Forest Planning and Management. Arboriculture & Urban Forestry 2011. 37(3): 108–117

Shaded cells indicate the current state of the vegetation resource, community framework and management practice in Aurora, as proposed by Town of Aurora urban forestry staff.

Vegetation Resource: Aurora					
Criteria	**Performance Indictors**				**Key Objective**
	Low	**Moderate**	**Good**	**Optimal**	
Relative Canopy Cover	The existing canopy cover equals 0 - 25% of the potential	The existing canopy cover equals 25-50% of the potential	The existing canopy cover equals 50-75% of the potential	The existing canopy cover equals 75-100% of the potential	Achieve climate-appropriate degree of tree cover, community wide
Age distribution of trees in the community	Any Relative DBH (RDBH) class (0-25% RDBH, 26-50% RDBH, etc.) represents more than 75% of the tree population.	Any RDBH class represents between 50% and 75% of the tree population.	No RDBH class represents more than 50% of the tree population	25% of the tree population is in each of four RDBH classes.	Provide for uneven-aged distribution city-wide as well as at the neighbourhood and/or street segment level.
Species suitability	Less than 50% of trees are of species considered suitable for the area.	50% to 75% of trees are of species considered suitable for the area.	More than 75% of trees are of species considered suitable for the area.	All trees are of species considered suitable for the area.	Establish a tree population suitable for the urban environment and adapted to the regional environment.
Species distribution	Fewer than 5 species dominate the entire tree population city-wide.	No species represents more than 10% of the entire tree population city-wide.	No species represents more than 5% of the entire tree population city-wide.	No species represents more than 5% of the entire tree population city-wide or at the neighbourhood /street segment level.	Establish a genetically diverse tree population city-wide as well as at the neighbourhood and/or street segment level.

Condition of Publicly-owned Trees (trees managed intensively)	No tree maintenance or risk assessment. Request based/reactive system. The condition of the urban forest is unknown	Sample-based inventory indicating tree condition and risk level is in place.	Complete tree inventory which includes detailed tree condition ratings.	Complete tree inventory which includes detailed tree condition and risk ratings.	Detailed understanding of the condition and risk potential of all publicly- owned trees
Publicly-owned natural areas (trees managed extensively, e.g. woodlands, ravine lands, etc.)	No information about publicly-owned natural areas.	Publicly-owned natural areas identified in a "natural areas survey" or similar document.	The level and type of public use in publicly-owned natural areas is documented	The ecological structure and function of all publicly-owned natural areas are documented and included in the city-wide GIS	Detailed understanding of the ecological structure and function of all publicly-owned natural areas.
Native vegetation	No program of integration	Voluntary use of native species on publicly and privately-owned lands.	The use of native species is *encouraged* on a project-appropriate basis in both intensively and extensively managed areas.	The use of native species is *required* on a project-appropriate basis in both intensively and extensively managed areas.	Preservation and enhancement of local natural biodiversity

Community Framework: Aurora					
Criteria	Performance Indictors				Key Objective
	Low	Moderate	Good	Optimal	
Public agency cooperation	Conflicting goals among departments and or agencies.	Common goals but no cooperation among departments and/or agencies.	Informal teams among departments and or agencies are functioning and implementing common goals on a project-specific basis.	Municipal policy implemented by formal interdepartmental/ interagency working teams on ALL municipal projects.	Insure all city departments cooperate with common goals and objectives
Involvement of large private and institutional land holders	Ignorance of issues	Educational materials and advice available to landholders.	Clear goals for tree resource by landholders. Incentives for preservation of private trees.	Landholders develop comprehensive tree management plans (including funding).	Large private landholders embrace city-wide goals and objectives through specific resource management plans.
Green industry cooperation	No cooperation among segments of the green industry (nurseries, tree care companies, etc.) No adherence to industry standards.	General cooperation among nurseries, tree care companies, etc.	Specific cooperative arrangements such as purchase certificates for “right tree in the right place”	Shared vision and goals including the use of professional standards.	The green industry operates with high professional standards and commits to city-wide goals and objectives.
Neighbourhood action	No action	Isolated or limited number of active groups.	City-wide coverage and interaction.	All neighbourhoods organized and cooperating.	At the neighbourhood level, citizens understand and cooperate in urban forest management.
Citizen-municipality-business interaction	Conflicting goals among constituencies	No interaction among constituencies.	Informal and/or general cooperation.	Formal interaction e.g. Tree board with staff coordination.	All constituencies in the community interact for the benefit of the urban forest.

General awareness of trees as a community resource	Trees seen as a problem, a drain on budgets.	Trees seen as important to the community.	Trees acknowledged as providing environmental, social and economic services.	Urban forest recognized as vital to the communities environmental, social and economic well-being.	The general public understanding the role of the urban forest.
Regional cooperation	Communities cooperate independently.	Communities share similar policy vehicles.	Regional planning is in effect	Regional planning, coordination and /or management plans	Provide for cooperation and interaction among neighbouring communities and regional groups.

Resource Management Approach: Aurora					
Criteria	**Performance Indictors**				**Key Objective**
	Low	**Moderate**	**Good**	**Optimal**	
Tree Inventory	No inventory	Complete or sample-based inventory of publicly-owned trees	Complete inventory of publicly-owned trees AND sample-based inventory of privately-owned trees.	Complete inventory of publicly-owned trees AND sample-based inventory of privately-owned trees included in city-wide GIS	Complete inventory of the tree resource to direct its management. This includes: age distribution, species mix, tree condition, risk assessment.
Canopy Cover Inventory	No inventory	Visual assessment	Sampling of tree cover using aerial photographs or satellite imagery.	Sampling of tree cover using aerial photographs or satellite imagery included in city-wide GIS	High resolution assessments of the existing and potential canopy cover for the entire community.
City-wide management plan	No plan	Existing plan limited in scope and implementation	Comprehensive plan for publicly-owned intensively and extensively managed forest resources accepted and implemented	Strategic multi-tiered plan for public and private intensively and extensively managed forest resources accepted and implemented with adaptive management mechanisms	Develop and implement a comprehensive urban forest management plan for private and public property.
Municipality-wide funding	Funding for reactive management	Funding to optimize *existing* urban forest.	Funding to provide for net increase in urban forest benefits.	Adequate private and public funding to sustain maximum urban forest benefits.	Develop and maintain adequate funding to implement a city-wide urban forest management plan
City staffing	No staff.	No training of existing staff.	Certified arborists and professional foresters on staff with regular professional development.	Multi-disciplinary team within the urban forestry unit.	Employ and train adequate staff to implement city-wide urban forestry plan

Tree establishment planning and implementation	Tree establishment is *ad hoc*	Tree establishment occurs on an annual basis	Tree establishment is directed by needs derived from a tree inventory	Tree establishment is directed by needs derived from a tree inventory and is sufficient to meet canopy cover objectives	Urban Forest renewal is ensured through a comprehensive tree establishment program driven by canopy cover, species diversity, and species distribution objectives
Tree habitat suitability	Trees planted without consideration of the site conditions.	Tree species are considered in planting site selection.	Community wide guidelines are in place for the improvement of planting sites and the selection of suitable species.	All trees planted with adequate soil quality and quantity, and growing space to achieve their genetic potential.	All publically owned trees are planted in habitats that will maximize current and future benefits provided to the site.
Maintenance of publicly-owned, intensively managed trees	No maintenance of publicly-owned trees	Publicly-owned trees are maintained on a request/reactive basis. No systematic (block) pruning.	All publicly-owned trees are systematically maintained on a cycle longer than five years.	All mature publicly-owned trees are maintained on a 5-year cycle. All immature trees are structurally pruned.	All publicly-owned trees are maintained to maximize current and future benefits. Tree health and condition ensure maximum longevity.
Tree Risk management	No tree risk assessment/ remediation program. Request based/reactive system. The condition of the urban forest is unknown	Sample-based tree inventory which includes general tree risk information; Request based/reactive risk abatement program system.	Complete tree inventory which includes detailed tree failure risk ratings; risk abatement program is in effect eliminating hazards within a maximum of one month from confirmation of hazard potential.	Complete tree inventory which includes detailed tree failure risk ratings; risk abatement program is in effect eliminating hazards within a maximum of one week from confirmation of hazard potential.	All publicly owned trees are safe.

Tree Protection Policy Development and Enforcement	No tree protection policy	Policies in place to protect public trees.	Policies in place to protect public and private trees with enforcement.	Integrated municipal wide policies that ensure the protection of trees on public and private land are consistently enforced and supported by significant deterrents	The benefits derived from large-stature trees are ensured by the enforcement of municipal wide policies.
Publicly-owned natural areas management planning and implementation	No stewardship plans or implementation in effect.	Reactionary stewardship in effect to facilitate public use (e.g. hazard abatement, trail maintenance, etc.)	Stewardship plan in effect for each publicly-owned natural area to facilitate public use (e.g. hazard abatement, trail maintenance, etc.)	Stewardship plan in effect for each publicly-owned natural area focused on sustaining the ecological structure and function of the feature.	The ecological structure and function of all publicly-owned natural areas are protected and, where appropriate, enhanced.

Appendix G: Total Estimates for Trees in Aurora by Land Use and Species

Land Use	Species	Number of Trees		Carbon (¹mt)		Gross Seq (¹mt/yr)		Leaf Area (km2)		Values (Can$)	
		Val	SE	Val	SE	Val	SE	Val	SE	Val	SE
Agriculture	Northern white cedar	110769	57659	4955.54	2685.04	99.31	50.85	4.313	2.552	25370211	14665086
	European buckthorn	101189	38446	1947.09	760.06	99.09	35.06	1.939	0.646	7270536	4414877
	Sugar maple	25148	16737	3934.83	2521.76	64.36	32.7	1.749	0.879	5104922	2735448
	White ash	54486	31284	3556.54	1963.27	87.64	52.58	1.542	1.054	4965417	3473976
	Eastern white pine	27543	16320	1661.44	1062.91	62.22	40.11	1.899	1.437	16574823	12928920
	Boxelder	13771	8671	1283.78	881.25	54.11	31.74	1.486	0.821	5000699	3789446
	Scotch pine	2395	2393	73.78	73.72	2.64	2.64	0.193	0.193	250629	250420
	Red pine	4191	4188	1221.82	1220.8	23.43	23.41	0.507	0.507	3356169	3353365
	American beech	13771	12594	1287.81	1199.45	19.78	16.44	0.66	0.521	390469	282488
	Eastern hemlock	1198	837	64.56	62.44	1.84	1.66	0.261	0.238	189370	179104
	White spruce	35326	25729	1589.73	1118.6	69.13	49.45	0.925	0.732	7948666	5902597
	Staghorn sumac	1198	1197	0.84	0.84	0.59	0.59	0.008	0.008	70997	70937
	Alternateleaf dogwood	34728	31701	107.87	80.64	11.79	8.91	0.573	0.473	445898	310981
	Norway maple	599	598	20.26	20.25	3.01	3	0.039	0.039	105043	104955
	Blue spruce	1796	1795	111.69	111.59	8.82	8.81	0.267	0.267	1185556	1184566
	Common chokecherry	7185	5092	11.2	8.26	2.03	1.38	0.045	0.027	69353	46600
	Quaking aspen	7185	6595	198.39	174.07	6.65	4.71	0.111	0.08	321462	271219
	Black ash	16166	11367	215.22	154.22	11.49	8.37	0.153	0.107	293365	205023
	Eastern hophornbeam	599	598	0.3	0.29	0.1	0.1	0.123	0.123	8532	8525
	American basswood	5988	3412	126.8	91.79	4.87	2.86	0.227	0.139	342857	281792
	Northern red oak	1796	1326	670.52	660.56	10.63	9.83	0.3	0.289	1382577	1367592
	American elm	10179	8986	170.6	137.32	7.47	5.67	0.176	0.143	269043	204932
	Black cherry	5389	2653	1028.87	853.97	25.26	18.45	0.446	0.328	1645474	1351166
	Balsam poplar	10778	7432	102.67	82.26	7.05	5.26	0.088	0.063	151299	122855
	Paper birch	2994	1537	1367.75	968.3	20.29	17.14	0.439	0.304	1418638	1257377
	Black locust	599	598	387.29	386.96	10.02	10.01	0.278	0.278	3127632	3125019
	European crabapple	2395	1438	536.94	310.29	12.73	7.24	0.479	0.299	836316	480980
	Crack willow	1198	1197	10.01	10	1.06	1.06	0.019	0.019	12286	12276
	Eastern cottonwood	1198	1197	35.16	35.13	1.98	1.97	0.13	0.13	61288	61237
	Black walnut	6586	5490	1196.58	1177.39	25.89	24.4	2.066	2	2046751	2019435
	Dotted hawthorn	4191	3626	323.22	281.2	8.47	6.81	0.069	0.048	277385	210042
	Yellow birch	2994	2454	30.32	28.91	2.18	1.92	0.04	0.036	37942	30414
	European mountain ash	599	598	1.25	1.25	0.24	0.24	0.004	0.004	8532	8525
	Balsam fir	3593	3590	16.27	16.26	1.84	1.84	0.035	0.035	41458	41423
	European alder	4191	4188	67.27	67.22	5.1	5.09	0.139	0.139	70661	70602

	Willow spp	3593	3037	79.46	55.54	6.21	4.51	0.092	0.075	340617	310037
	Red osier dogwood	3593	3590	27.93	27.91	0.61	0.61	0.018	0.018	10239	10230
	Smooth service berry	599	598	10.82	10.81	1.62	1.62	0.022	0.022	43044	43008
	Bitternut hickory	1198	837	527.31	526.51	9.15	9.02	0.066	0.063	936222	925327
	Serviceberry spp	599	598	8.27	8.27	0.71	0.71	0.013	0.013	11385	11375
	Fireberry hawthorn	599	598	2.29	2.29	0.34	0.34	0.005	0.005	6137	6132
	Narrowleaf willow	599	598	4.27	4.27	0.49	0.49	0.008	0.008	6467	6461
	Total	534686	149114	28974.56	7311.96	792.23	181.08	21.952	5.158	92006367	25794286
Commercial + Industrial	European buckthorn	80724	39629	375.08	200.45	64.17	30.6	0.814	0.487	5000966	2481317
	White ash	19328	13368	106.51	83.13	24.66	19.53	0.236	0.206	1175125	848785
	Boxelder	32972	25700	1889.31	1517.16	73.53	44.69	0.864	0.478	7149042	5141853
	Scotch pine	2842	2840	298.81	298.55	9.64	9.63	0.426	0.426	4997195	4992798
	Red pine	41499	41463	2330.53	2328.48	83.74	83.67	0.457	0.456	5282953	5278304
	White spruce	1137	1136	124.49	124.38	5.08	5.08	0.227	0.226	1567367	1565987
	Staghorn sumac	50026	49982	329.28	328.99	28.99	28.96	0.102	0.102	835576	834841
	Norway maple	5685	5120	172.11	134.08	17.29	12.37	0.451	0.337	1212671	917346
	Common chokecherry	1137	1136	2.45	2.45	0.74	0.74	0.009	0.009	54041	53994
	Quaking aspen	5116	5112	100.97	100.88	6.74	6.74	0.07	0.07	507016	506570
	Green ash	1137	786	39.68	36.62	1.97	1.73	0.016	0.011	465977	455828
	Austrian pine	2274	2272	403	402.64	14.96	14.95	0.655	0.654	8453181	8445743
	Black cherry	1705	1704	115.45	115.35	7.13	7.12	0.022	0.022	879881	879107
	Black locust	3979	3976	173.36	173.2	10.25	10.24	0.164	0.164	1448755	1447480
	Crack willow	568	568	483.11	482.68	14.87	14.86	0.205	0.204	2812837	2810362
	White willow	3411	3408	202	201.82	15.98	15.96	0.048	0.048	1111889	1110910
	European mountain ash	568	568	54.19	54.14	4.57	4.56	0.065	0.065	351751	351441
	Japanese tree lilac	568	568	1.58	1.58	0.59	0.59	0.007	0.007	23308	23287
	Silver maple	568	568	1713.89	1712.38	27.55	27.53	0.835	0.835	12664589	12653445
	Callery pear	1137	1136	10.46	10.45	2.79	2.78	0.01	0.01	77005	76937
	Apple spp	568	568	326.57	326.29	8.91	8.9	0.06	0.06	2282679	2280671
	Total	256954	128613	9252.84	3646.08	424.16	153.37	5.742	1.927	58353803	20971668
Institutional + Utilities and Ttransportation	Northern white cedar	43074	43046	115.62	115.54	24.97	24.96	0.459	0.459	2273836	2272358
	European buckthorn	1538	1537	12.69	12.69	1.91	1.91	0.009	0.009	109426	109355
	Boxelder	2308	2306	198.73	198.6	17.06	17.04	0.577	0.577	981717	981079
	White spruce	8461	8455	148	147.9	23.44	23.43	0.411	0.411	564221	563854
	Norway maple	2308	1600	57.3	44.76	9.88	7.32	0.197	0.157	217682	167705
	Green ash	1538	1537	28.91	28.89	3.81	3.81	0.155	0.155	184358	184238
	Japanese tree lilac	1538	1537	6.49	6.49	2	2	0.021	0.021	92301	92241
	Silver maple	769	769	3.91	3.91	0.67	0.67	0.012	0.012	43266	43238
	Eastern red cedar	769	769	2.61	2.61						
	Northern hackberry	769	769	8.91	8.9	2.16	2.16	0.023	0.023	48711	48679
	Total	63072	46815	583.17	338.17	85.91	46.96	1.864	1.065	4515518	3292751

Open Space + Natural Cover	Northern white cedar	24894	13584	1022.54	904.33	25.86	20.01	1.118	1.03	20107382	19491565
	European buckthorn	6679	4948	146.07	134.14	5.8	4.99	0.105	0.069	560568	522692
	Sugar maple	59503	25898	6019.45	3062.15	214.84	98.75	5.447	2.46	46569100	27205455
	White ash	7286	3800	129.9	104.65	4.82	2.67	0.089	0.042	412829	208857
	Boxelder	1822	1330	85.2	79.49	4.89	3.63	0.191	0.187	115003	94310
	Scotch pine	29752	29727	2798.4	2796.1	66.39	66.33	1.31	1.309	7936938	7930399
	American beech	32788	31513	933.89	913.9	31.86	29.23	1.102	1.025	1070221	980131
	Eastern hemlock	32180	29134	2284.25	2001.33	87.04	76.5	3.094	2.735	25652109	22246570
	White spruce	607	607	6.61	6.6	0.8	0.8	0.012	0.012	33023	32996
	Alternateleaf dogwood	1214	1213	2.48	2.48	0.47	0.47	0.036	0.036	20765	20748
	Norway maple	4857	3678	654.99	581.84	19.59	13.45	1.009	0.79	4548527	4161907
	Blue spruce	1822	1820	17.53	17.51	2.11	2.11	0.051	0.051	105126	105039
	Common chokecherry	2429	2427	7.87	7.86	1.85	1.85	0.041	0.041	89273	89200
	Eastern hophornbeam	7893	4361	215.64	191.79	14.98	11.39	0.478	0.312	2398448	2155938
	American basswood	9715	7409	679.19	673.16	30.26	28.95	1.385	1.328	7439743	7285893
	Green ash	2429	2427	744.81	744.2	15.82	15.8	0.738	0.737	7217272	7211326
	American elm	3643	2512	89.67	60.83	6.77	4.14	0.482	0.292	659237	529622
	Black cherry	1214	1213	144.2	144.08	5.77	5.76	0.013	0.013	699288	698712
	Balsam poplar	607	607	0.92	0.92	0.27	0.27	0.003	0.003	20189	20172
	Paper birch	3036	1950	829.97	571.65	31.97	22.34	0.491	0.334	6325004	4373507
	European crabapple	607	607	226.44	226.25	5.54	5.54	0.032	0.032	926176	925413
	Red maple	7286	7280	28.94	28.92	4.85	4.85	0.218	0.218	265253	265034
	Crack willow	3643	3640	15.13	15.12	3.08	3.08	0.038	0.038	153446	153319
	Eastern cottonwood	2429	2427	719.77	719.18	4.95	4.95	0.038	0.038	746362	745747
	White willow	1214	1213	6.44	6.43	1.25	1.25	0.019	0.019	49837	49796
	Yellow birch	1822	1820	318.83	318.56	13.57	13.56	0.289	0.289	2296969	2295077
	Balsam fir	607	607	10.71	10.7	1.67	1.67	0.022	0.022	37182	37151
	Common linden	607	607	165.63	165.49	4.98	4.97	0.228	0.228	2605079	2602933
	Northern hackberry	607	607	1.16	1.16	0.35	0.35	0.004	0.004	26139	26117
	Witch hazel	607	607	0.49	0.49	0.22	0.22	0.005	0.005	36478	36448
	Total	253800	84431	18307.11	5510.02	612.62	183.5	18.088	5.53	1.39E+08	47715953
Other	Northern white cedar	19347	17055	627.21	614.11	17.26	16.06	0.895	0.84	2555753	2420812
	European buckthorn	12312	10552	325.38	309.09	33.37	32.09	0.366	0.308	2309526	2291373
	Sugar maple	13484	9570	3906.46	2837.25	122.58	84.86	2.071	1.442	27241474	19693994
	White ash	4104	2163	101.53	58.68	11.23	6.11	0.291	0.155	263598	135200
	Eastern white pine	2345	2343	349.46	349.16	7.27	7.26	0.251	0.251	1585507	1584154
	Boxelder	6449	6444	298.58	298.33	24.92	24.9	0.175	0.175	1359748	1358587
	Scotch pine	586	586	41.13	41.09	1.11	1.11	0.132	0.132	66525	66468
	American beech	2345	2343	334.46	334.17	11.78	11.77	0.268	0.268	2034571	2032835
	Eastern hemlock	15829	12257	655.66	559.03	32.96	26.5	1.91	1.521	7041122	6242013
	Blue spruce	9380	6763	510.8	355.56	43.59	30.57	0.972	0.709	3523185	2407584

	Common chokecherry	586	586	18.28	18.27	3.15	3.15	0.001	0.001	52339	52294
	Quaking aspen	7622	7615	295.34	295.09	24.06	24.04	0.244	0.244	1877283	1875682
	Eastern hophornbeam	6449	6444	13.72	13.71	3.66	3.66	0.354	0.353	280972	280732
	American basswood	1173	1172	0.74	0.74	0.32	0.32	0.025	0.025	54018	53972
	Northern red oak	9380	6710	2384.84	2351.73	60.81	55.6	0.66	0.579	17867201	17527816
	Green ash	2931	1893	44.65	30.18	6.17	4.33	0.215	0.138	239433	153893
	Austrian pine	1173	1172	13.59	13.58	1.14	1.14	0.03	0.03	127357	127248
	Black cherry	1173	1172	1.48	1.48	0.6	0.59	0.012	0.012	45430	45392
	Honeylocust	1759	1757	10.9	10.89	2.87	2.87	0.016	0.016	78949	78882
	European crabapple	1173	1172	137.14	137.02	10.54	10.53	0.168	0.168	936976	936177
	Paradise apple	586	586	2.66	2.66	0.15	0.15	0.005	0.005	2820	2818
	Black walnut	586	586	1.26	1.26	0.53	0.53	0.009	0.009	27987	27963
	White willow	1759	1757	169.35	169.21	7.5	7.5	0.133	0.133	808315	807625
	Dotted hawthorn	586	586	34.9	34.87	1.62	1.62	0.082	0.082	33245	33217
	Willow spp	586	586	18.14	18.13	1.65	1.64	0.036	0.036	48112	48071
	Silver maple	586	586	22	21.98	2.8	2.79	0.081	0.081	49823	49780
	Freeman maple	1173	1172	17.7	17.69	3.85	3.85	0.061	0.061	86363	86290
	American hornbeam	586	586	1	1	0.32	0.32	0.015	0.015	30779	30753
	Bitternut hickory	586	586	0.56	0.56	0.23	0.23	0.014	0.014	29240	29215
	Yellowwood	1759	1757	2.26	2.26	0.63	0.63	0.012	0.012	42168	42132
	Hawthorn spp	1759	1757	58.54	58.49						
	Bigtooth aspen	1759	1757	71.21	71.15	8.13	8.12	0.185	0.185	503530	503100
	English oak	1173	1172	1.92	1.91	0.93	0.93	0.011	0.011	70353	70293
	Grey alder	586	586	16.79	16.77	1.06	1.06	0.1	0.099	7853	7846
	Scarlet hawthorn	586	586	8.92	8.91	0.3	0.3	0.004	0.004	3460	3457
	White poplar	586	586	15.4	15.39	0.58	0.57	0.011	0.011	16769	16755
	Swamp white oak	586	586	1.74	1.74	0.48	0.48	0.002	0.002	21809	21791
	American cranberrybush	586	586	19.86	19.84	1.17	1.17	0.026	0.026	21495	21477
	Total	136016	48494	10535.55	5284.92	451.32	189.04	9.844	4.016	71345089	39590369
Residential	Northern white cedar	244959	84936	1963.75	1086.04	208.18	68.27	5.062	3.663	34520491	19476131
	European buckthorn	13406	7247	122.01	74.13	16.26	7.63	0.257	0.15	575699	243534
	Sugar maple	68857	38007	6334.17	3759.35	228.45	123.39	5.583	3.133	33929248	20484650
	White ash	46920	29892	574.41	378.02	35.95	20.63	0.537	0.306	1838665	1080960
	Eastern white pine	57279	46658	1317.74	1040.25	69.66	54.15	1.663	1.237	24313017	20897930
	Boxelder	21327	9717	2003.58	903.65	103.91	42.47	2.588	1.139	7418737	3442453
	Scotch pine	37170	32974	745.13	434.24	32.31	18.75	1.476	0.995	5928070	3526770
	Red pine	13406	12793	210.27	184.5	12.86	10.46	0.228	0.215	757972	558781
	American beech	6094	3611	722.11	496.43	32.36	18.9	0.541	0.362	3655917	2502109
	Eastern hemlock	3656	2255	80.09	55.75	4.78	3.84	0.244	0.229	361275	311036
	White spruce	6703	3326	746.64	461.97	36.77	20.73	1.273	0.71	7467968	4705570
	Staghorn sumac	609	609	1.16	1.16	0.51	0.51	0.006	0.006	27456	27434

	Alternateleaf dogwood	1219	856	2.94	2.29	1.05	0.81	0.016	0.013	62519	43888
	Norway maple	17671	3892	3983.43	1110.4	183.75	45.11	6.391	1.631	29697328	8275784
	Blue spruce	14015	5064	1987.55	870.14	99.18	39.09	3.105	1.1	20576795	9476390
	Common chokecherry	12187	10415	41.75	34.3	5.61	3.85	0.093	0.078	141717	106639
	Quaking aspen	609	609	1.53	1.53	0.54	0.54	0.008	0.008	15995	15982
	Black ash	3656	3653	49.51	49.47	3.06	3.06	0.084	0.084	112201	112109
	Eastern hophornbeam	3656	3097	76.58	75.52	5.54	5.23	0.126	0.109	630791	596135
	American basswood	1219	856	20.08	19.57	1.19	1.01	0.052	0.042	75768	54737
	Northern red oak	6094	5506	62.55	55.04	9.53	7.8	0.229	0.201	617562	579852
	Green ash	9140	5276	433.23	254.02	19.04	9.24	0.688	0.368	2779626	1702688
	American elm	2437	1475	38.64	31.63	1.42	1.21	0.161	0.138	61794	44120
	Austrian pine	10968	6000	1039.99	699.38	44.69	29.72	1.109	0.578	15924254	11236198
	Black cherry	2437	1475	868.01	817.84	18.02	17.3	0.305	0.296	4843205	4811627
	Common lilac	9750	5298	60.41	26.99	15.06	7.39	0.094	0.041	591084	326179
	Paper birch	3656	2255	523.33	342.1	39.9	24.45	0.496	0.312	2937446	1846804
	Honeylocust	7922	2661	1328.09	635	75.68	29.42	1.093	0.405	8681421	4149547
	Black locust	4875	4871	583.48	583	18.1	18.08	0.416	0.415	1008720	1007892
	Norway spruce	9140	3133	2369.94	992.86	93.03	35.46	2.437	0.926	23755540	9976281
	European crabapple	4265	2324	387.79	349.44	25.69	19.6	0.336	0.266	2317900	2205333
	Red maple	609	609	1.43	1.43	0.63	0.63	0.009	0.009	29706	29682
	Crack willow	2437	2435	472.98	472.6	10.96	10.95	0.121	0.121	614697	614192
	Paradise apple	6703	2704	147.84	70.91	19.29	7.93	0.331	0.143	910400	493465
	Eastern cottonwood	3656	3653	1464.74	1463.53	25.08	25.06	0.949	0.948	1926452	1924871
	Littleleaf linden	6094	2652	157.71	94.47	14.04	6.62	0.611	0.303	1479854	1156168
	Dotted hawthorn	1219	1218	0.96	0.96	0.28	0.28	0.007	0.007	15234	15221
	Yellow birch	609	609	296.02	295.78						
	Katsura tree	4265	3696	43.09	30.34	10	7.53	0.086	0.061	294236	219897
	Tamarack	4265	4262	31.81	31.79	2.36	2.35	0.231	0.231	117282	117186
	European mountain ash	3047	1806	45.81	39.82	6.81	5.61	0.057	0.043	280916	228138
	Japanese tree lilac	1828	1041	61.95	45.76	7.65	4.98	0.083	0.057	517074	404507
	Chinese juniper	3047	2003	74.96	54.2	6.85	4.68	0.143	0.113	724371	523168
	Silver maple	609	609	347.3	347.02	9.64	9.63	0.416	0.415	2634264	2632101
	Amur maple	2437	2435	15.59	15.58	3.12	3.11	0.025	0.025	83816	83748
	White mulberry	2437	1194	17.96	10.51	4.5	2.43	0.022	0.011	126220	63168
	Common linden	1828	1827	69.45	69.4	7.25	7.25	0.435	0.434	691039	690471
	Smooth service berry	1828	1354	23.17	19.65	4.3	3.27	0.016	0.012	129000	91246
	Freeman maple	1219	856	158.61	154.71	8.53	7.55	0.293	0.272	1139721	1109976
	Japanese maple	1828	1041	31.18	24.97	4.94	3.26	0.043	0.033	210491	152883
	Pussy willow	1828	1827	438.37	438.01	7.84	7.84	0.245	0.245	580566	580090
	American hornbeam	1219	1218	19.98	19.96	3.67	3.67	0.05	0.05	107746	107658
	Eastern red cedar	609	609	1.07	1.06	0.34	0.33	0.001	0.001	25136	25115

	Siberian pea tree	1219	856	13.88	10.13	3.33	2.37	0.006	0.004	73025	52392
	Purpleleaf sand cherry	1219	1218	5.93	5.92	1.01	1.01	0.01	0.01	25531	25510
	Witch hazel	609	609	1.17	1.17	0.52	0.52	0.008	0.008	27456	27434
	Horsechestnut	609	609	2188.08	2186.28	44.1	44.06	0.403	0.403	9999898	9991690
	Eastern redbud	609	609	4.94	4.93	1.4	1.39	0.02	0.02	31991	31965
	Showy forsythia	609	609	0.52	0.52	0.34	0.34	0.009	0.009	27456	27434
	Tartarian honeysuckle	609	609	12.62	12.61	2.37	2.36	0.001	0.001	47537	47498
	Saucer magnolia	609	609	2.42	2.41	0.77	0.77	0.009	0.009	31534	31508
	Amur corktree	609	609	21.6	21.59	2.76	2.76	0.038	0.038	137019	136907
	Jack pine	609	609	12	11.99	0.45	0.45	0.014	0.014	51444	51402
	American sycamore	609	609	1.56	1.56	0.61	0.61	0.007	0.007	29957	29933
	Plum spp	609	609	17.93	17.91	3.17	3.16	0.009	0.009	49866	49825
	Pin cherry	609	609	85.69	85.62	6.51	6.5	0.06	0.06	526703	526271
	Common pear	609	609	15.92	15.91	2.7	2.7	0.008	0.008	71374	71315
	Corkscrew willow	609	609	1.08	1.07	0.5	0.5	0.009	0.009	24679	24658
	Mountain ash spp	609	609	338.25	337.97	12.38	12.37	0.152	0.152	2441136	2439132
	Crimean linden	609	609	2.26	2.26	0.29	0.29	0.012	0.012	10130	10122
	Total	710504	141527	35327.76	6267.81	1683.36	216.08	41.646	6.066	2.62E+08	45464326
TOWN TOTAL	**Total**	**1955031**	**265477**	**102981**	**12823.77**	**4049.6**	**417.87**	**99.136**	**10.722**	**6.27E+08**	**83828472**