Lake Simcoe Region conservation authority

Whitchurch-Stouffville Forest Study

Technical Report

January 8, 2025

Acknowledgements

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Appreciation and thanks are extended to the following members of the Technical Working Group:

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Roger da Cunha, Town of Whitchurch-Stouffville
Graham Ross, Town of Whitchurch-Stouffville
Tracy Timmins, Toronto and Region Conservation Authority

Thank you to the staff at the United States Department of Agriculture Forest Service, Northern Research Station as well as the University of Vermont, Spatial Analysis Laboratory for their technical services, guidance, and expertise.

Erika Teach, The Davey Tree Expert Company
Alexis Ellis, The Davey Tree Expert Company
Jarlath O'Neil-Dunne, University of Vermont
Nina Safavi, University of Vermont

Special thanks to Toronto and Region Conservation Authority staff Tracy Timmins and Jacqueline DeSantis for contributions to the development of field protocols and analysis methods, and support during training, and to Krish Selvakumar, Catherine Edwards, and Sharnya Jeyaratnam for ongoing guidance and assistance throughout.

Funding for this project has been generously provided by:

The Regional Municipality of York
The Town of Whitchurch-Stouffville

GIS data preparation and mapping was completed by Toshia Fleischaker and Darren Campbell of the Lake Simcoe Region Conservation Authority.

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Reference: Lake Simcoe Region Conservation Authority, 2024. Whitchurch-Stouffville Forest Study: Technical Report

Executive Summary

The Regional Municipality of York (York Region or the Region) along with the Town of Whitchurch-Stouffville (Whitchurch-Stouffville or the Town) are committed to assessing the distribution, structure, and function of Whitchurch-Stouffville's forest every 10 years through a Forest Study. A Forest Study employs a combination of remote sensing, GIS tools, and plot-based field surveys to characterize the forest across the entire Town and examines factors that may impact its health and function, such as invasive species and soil condition.

The Region, in partnership with Whitchurch-Stouffville, retained Lake Simcoe Region Conservation Authority to undertake the Whitchurch-Stouffville Forest Study. This technical report examines the distribution of canopy cover by Municipal Property Assessment Corporation (MPAC) land use type, available planting opportunities, tree size and species composition, the structural value and ecosystem services of the forest, condition of the forest, and soil properties. Additionally, the report explores the potential future state of the forest and its vulnerability to climate change. Data was collected in 2023, but this report refers to the publication year of 2024 for clarity.

Whitchurch-Stouffville's forest has an estimated 6.1 million trees with an estimated structural value of $1.87 billion. Trees in Whitchurch-Stouffville sequester approximately 17,710 tonnes of carbon per year, with an associated annual value of $18.8 million and store 682,000 tonnes of carbon, valued at $725.5 million. Whitchurch-Stouffville's forest removes 447 tonnes of air pollution annually; the benefit of this ecosystem service is valued at $1.22 million each year. In Whitchurch-Stouffville, the forest reduces the annual energy consumption of residential homes and low-rise apartments by approximately 113,148 MBtu and 1,997 MWh, with an associated annual financial savings of approximately $600,000.

Canopy cover in Whitchurch-Stouffville is 38.9%. A total of 57.6% (11,943 ha) of the Town's land area could theoretically support additional canopy. However, much of this area is contained within active agricultural areas which in practice cannot be planted.

Whitchurch-Stouffville's forest is young, and 77.7% of the trees are in excellent, good, and fair condition. Approximately 56% of all trees are less than 15.2 cm diameter at breast height (diameter) – these trees will grow in future years, increasing both canopy cover and benefit provision. The most abundant species, eastern white cedar, makes up 18.5% of the population and efforts to diversify tree species composition is recommended. Limited species diversity reduces the resilience of the forest to impacts of climate change, pests, and diseases.

Soil and climate change impact the health of the forest – soil in forested areas was found to have lower compaction and salinity than soil on unforested lands. Fourteen out of the top

twenty species in Whitchurch-Stouffville are expected to be highly to extremely vulnerable to climatic changes that would occur by the 2050s, according to the Intergovernmental Panel on Climate Change's Representative Concentration Pathway (RCP) 8.5 (business-as-usual scenario).

Summary of Results and Recommendations

Through regular monitoring, this information can be used to track progress towards established goals, measure the effectiveness of efforts to maintain a healthy forest, and guide future management decisions.

Tree Cover and Leaf Area

Whitchurch-Stouffville's 6.1 million trees (±655,195) provide the Town with 38.9% canopy cover. There is a need to continue tree planting requirements and restoration plans as Whitchurch-Stouffville continues to urbanize to ensure that canopy cover is maintained or grows despite construction and development.

Leaf area, the total surface area of one side of all tree leaves in Whitchurch-Stouffville, is approximately 61,820 hectares across a municipal area of 20,640 hectares. Average tree density in Whitchurch-Stouffville is 289 trees/ha, which is above the average of the Greater Toronto Area[1] at 205.5 trees/ha, considering municipalities with available data. In theory, 57.6% (11,943 ha) of the Town's land area could support additional canopy and when excluding agricultural lands, this drops to 29.5% (6,089 ha).

Twenty-one percent (±4.7%) of the tree population occurs on public lands (such as municipal parks, rights-of-ways (ROWs), and protected areas, including Conservation Authority lands), and 79% (±10.6%) of trees are privately owned. Therefore, working with private landowners is an essential component of maintaining and enhancing the forest.

Canopy Cover and Plantable Space by Land Use

Canopy cover was analyzed by land use type. Land use types were based on the Municipal Property Assessment Corporation's (MPAC) allocation of land use codes to properties for tax

[1] Tree densities (/ha) from recent i-Tree Eco studies in the Greater Toronto Area: Ajax (2023): 134; Aurora (2023:): 169; Bolton (2011): 185; Brampton (2011): 134; Caledon East (2011): 633; East Gwillimbury (2017): 136; Georgina (2017): 181; Markham (2022): 155; Richmond Hill (2022): 291; Mississauga (2011): 71; King (2023): 285; Newmarket (2016): 77; Pickering (2012): 354; Whitchurch-Stouffville (2017): 119; Toronto (2018): 162; Vaughan (2023): 202.

purposes (Figure i). The *Natural Cover* land use category supports the highest existing canopy cover percent, with 77% tree cover. However, due to the relatively small size of this category, canopy cover within the *Natural Cover* category (782 ha) contributes only 12.5% of the municipality's total canopy cover area. The greatest proportion of the existing canopy (2,439 ha) is found within the *Agriculture* category which contributes 30.1% of Whitchurch-Stouffville's total canopy cover area.

The greatest opportunity to expand canopy cover is by planting on surfaces currently occupied by herbaceous cover / low shrubs ("Potential Vegetated") and paved surfaces that are not roads or buildings ("Potential Impervious") that occur within agricultural areas, followed by residential areas at 5,854 hectares and 1,626 hectares, respectively.

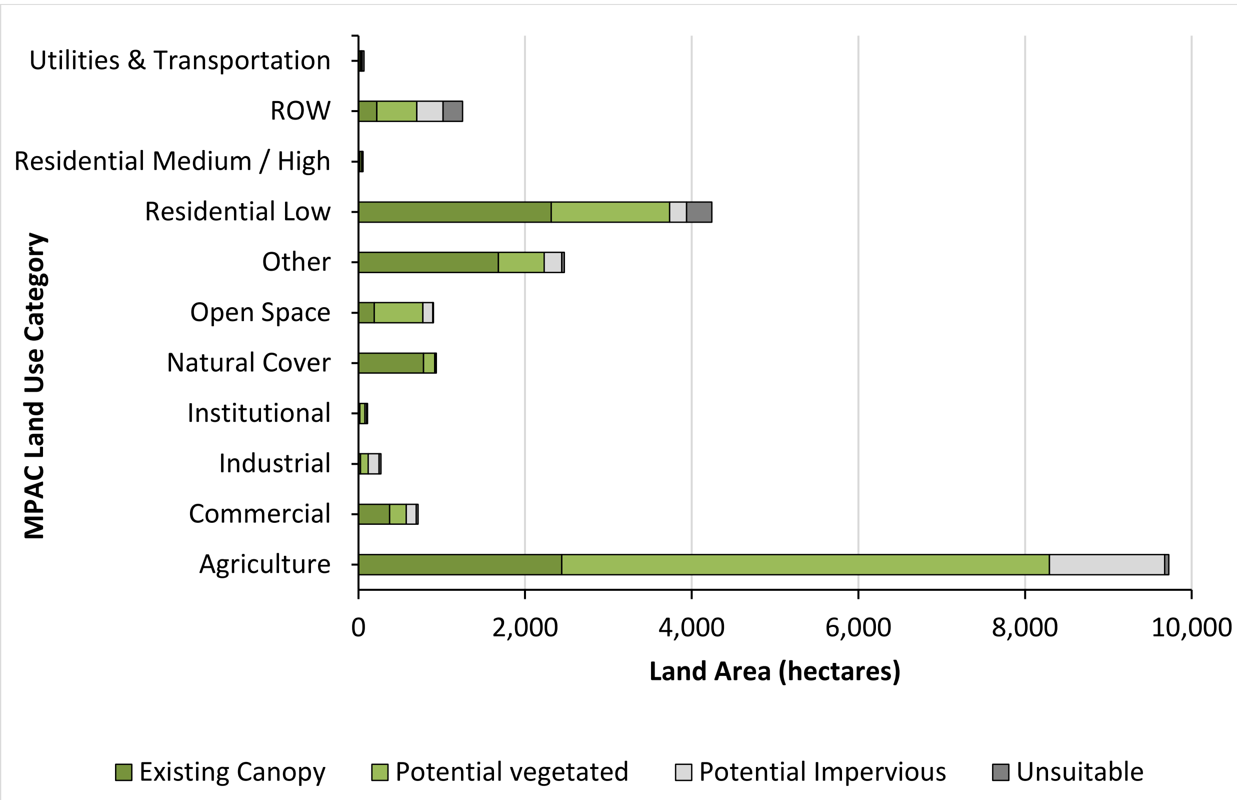

Figure i. The distribution of existing canopy cover and possible canopy cover[2] (ha) of MPAC land use land area in Whitchurch-Stouffville.

[2] Possible Vegetated: plantable space occurring on herbaceous/low shrub land cover; Possible Impervious: plantable space occurring on paved surfaces other than roads and buildings.

Species Composition

Species composition is a result of natural regeneration of forested areas with some influence from planting. The three most abundant tree species by population are eastern white cedar, sugar maple, and European buckthorn. These three species make up 32% of the total population. When considering leaf area, the top three species are sugar maple, eastern white cedar, and northern red oak. Leaf area is measured as the one-sided surface area of tree leaves.

Tree Size

Approximately 56% of all trees have a diameter at breast height (diameter) smaller than 15.2 cm and the proportion of larger trees is very low. Thirteen percent of the tree population has a diameter of 30.6 cm or greater. Across all MPAC land uses the trend is similar, with the smallest diameter classes containing the most trees, while very few trees (<5%) are found in the large (>45.7 cm) diameter classes. Since most of the trees in Whitchurch-Stouffville are young, they have the potential to significantly contribute to the canopy in the future. Although many of the young trees are under existing canopy, these will still play a large part in the future canopy as the overstory dies out with age. Active planting needs to continue, and trees of all sizes require protection to ensure that there are younger trees to replace older trees as they die. Older and larger trees provide significantly more ecosystem service benefits than smaller trees and take decades to replace with new plantings.

Condition and Tree Health

All trees measured in the field were assigned a condition rating based on the proportion of dieback in the canopy. Many trees are in good condition with approximately 48.6% of trees in Whitchurch-Stouffville estimated to be in either excellent or good condition. As shown in Figure ii below, *Natural Cover – Open Space* (17.2%) have the greatest proportion of dying and dead trees, followed by the *Other – Institutional* (15.5%) land use category. This partly reflects ash (*Fraxinus* spp.) on some of these sites, many of which have died, but also is indicative of different management strategies. In natural areas, it is beneficial to leave some dead and dying trees which provide additional habitat and resources, and do not pose a risk to public safety, whereas in residential areas and rights-of-ways (ROWs), it is important to remove dead or dying trees which can fall and potentially cause damage to infrastructure and/or injure people.

Tree health was also assessed more holistically through an additional tree health assessment which considered trunk and root health, canopy structure, and canopy vigour. Based on the results of this more holistic survey, the average condition of trees in Whitchurch-Stouffville is good.

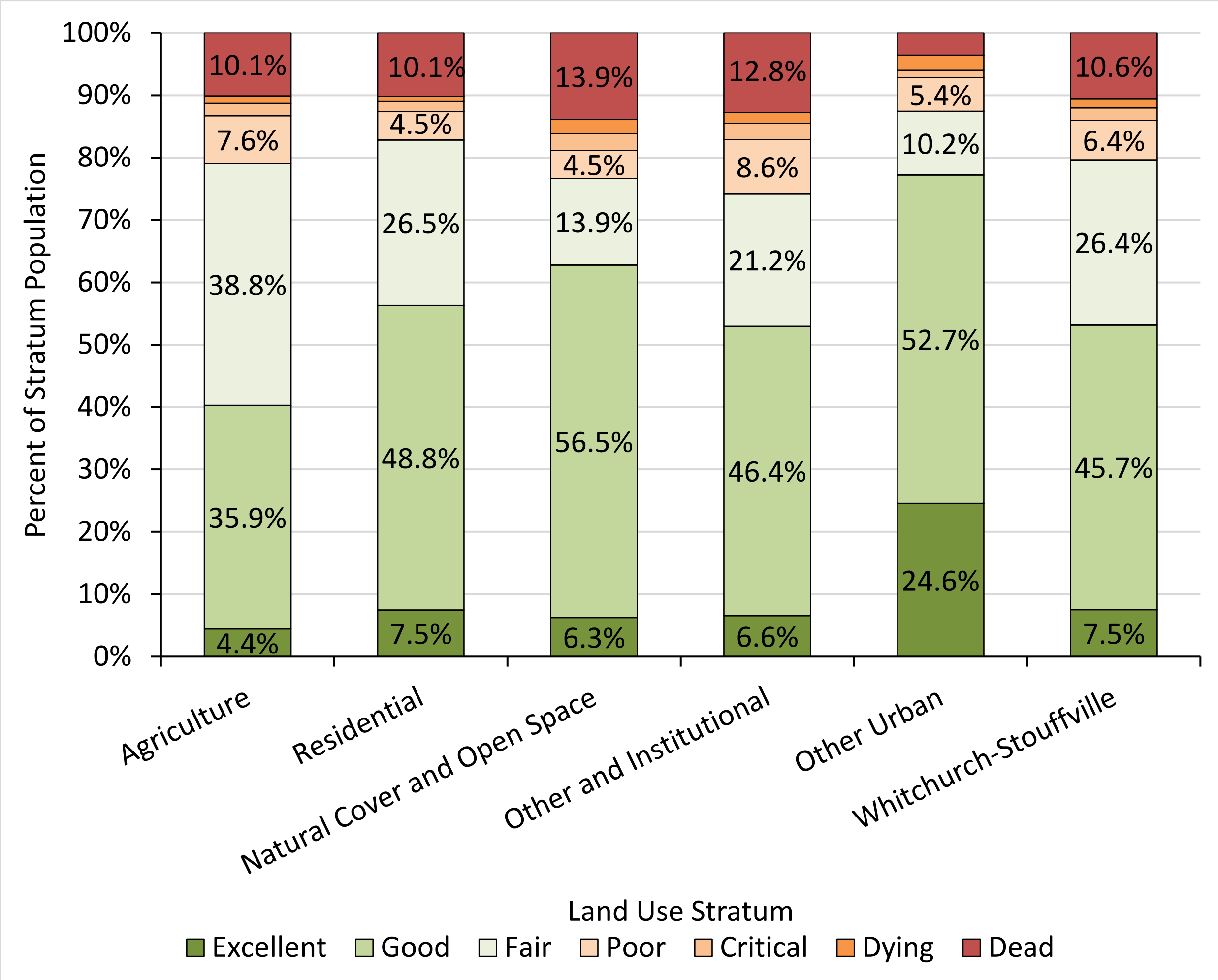

Figure ii. The proportion of trees in each condition category across Whitchurch-Stouffville MPAC land uses

Structural Value of Trees

The estimated structural value of all trees (both public and private) in Whitchurch-Stouffville in 2024 is approximately $1.87 billion. This value does not include the ecological or societal value of the forest, but rather it represents an estimate of tree replacement costs. This value is based on the Council of Tree and Landscape Appraisers Trunk Formula method (Nowak, 2020). This formula method considers species, diameter, condition, and location.

Ecosystem Service Benefits

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 released back to the atmosphere through decomposition. Trees in Whitchurch-Stouffville sequester approximately 17,710 tonnes of carbon per year, with an associated annual value of $18.8 million, and store 682,000 tonnes of carbon, valued at $725.5 million. Eastern white cedar stores the greatest volume of carbon and sequesters the largest amount of carbon annually.

Air Pollution Removal

The forest can improve local air quality by absorbing and intercepting airborne pollutants. Whitchurch-Stouffville's forest removes 447 tonnes of air pollution annually; the benefit of this ecosystem service is valued at $1.22 million annually.

- Ozone: 373 tonnes
- Particulate matter (2.5 microns): 19 tonnes
- Nitrogen dioxide: 41 tonnes
- Sulfur dioxide: 144 tonnes
- Carbon monoxide: 0.2 tonne

Residential Energy Savings

Trees reduce local air temperature due to shading effects, wind speed reductions, and the release of water vapor through evapotranspiration. In Whitchurch-Stouffville, the forest reduces the annual energy consumption of residential homes and low-rise apartments by approximately 113,148 MBTu and 1,997 MWh, with an associated annual financial savings of approximately $599,183.

Hydrological Benefits

The forest helps to prevent rainwater from entering the stormwater system, known as avoided runoff, by capturing rainwater, evapotranspiration, and facilitating the infiltration of water into the soil. Using 2019 rainfall data from Pearson International Airport, it was determined that 100,087 m^3 of precipitation were prevented from entering the stormwater system in 2024 with an associated value of $232,600 per year.

Soil

Soil quality has been widely recognized as a vital component and indicator of forest health. Forested areas were found to have lower soil compaction, salinity (as indicated by electroconductivity), and pH than on unforested areas (Table 1). Greater compaction and salinity are associated with decreased tree health. Research by the United States Department of Agriculture has shown that almost no roots can penetrate soil with a penetration resistance (psi) of 300 psi or more (Duiker, 2002). Tolerance to electroconductivity is species dependent and not well understood, however as electroconductivity increases there may be constraints to plant success. Lastly, optimal soil pH is typically between 5.5 and 7.5, where soil with pH levels that are too alkaline or acidic can hinder plant growth.

Table 1. Soil properties across Whitchurch-Stouffville

Soil Property	Forested	Unforested
Percent of uncompacted plots (PSI lower than 200)	84	61
Median salinity (µS/cm)	191	261
Median pH	7.01	7.26

The relationship between soil compaction, salinity, pH, and tree condition measured as percentage crown dieback was explored using correlation testing. Surprisingly, it was found that percent dieback decreased as soil compaction increased. However, this can be explained by noting that natural areas, which were the least compacted, had high proportions of dead trees, particularly ash trees. Crown dieback also decreased with increasing salinity. Again, this is likely attributed to the fact that more natural areas tended to have lower salinity values, but more dead or dying trees. Finally, crown dieback also decreased with increasing pH.

Invasive Species

Plants

Out of the 184 plots surveyed, 46% of plots had at least one invasive plant species present. Invasive plant species were most prevalent in the *Residential* land use stratum (43% of plots), followed by *Other Urban* (39%) and *Other – Institutional* (35%). The most common invasive species by proportion of plots affected were European buckthorn (*Rhamnus cathartica*; 34%), Manitoba maple (*Acer negundo*; 19%), garlic mustard (*Alliaria petiolata*; 10%), non-native honeysuckle (*Lonicera spp.*; 8%), and dog strangling vine (*Cynanchum rossicum*, 7%).

Pests and Diseases

The presence and/or symptoms of emerald ash borer (*Agrilus planipennis*) were observed at 13% of plots, while spongy moth (*Lymantria dispar dispar*) was observed at 10% of plots surveyed in Whitchurch-Stouffville. Six plots (3%) in Whitchurch-Stouffville had beech bark disease (*Neonectria faginata*), two plots (1%) had beech leaf disease (caused by *Liscotylenchus crenatae ssp. mccannii.*), and one plot (0.5%) had Dutch elm disease (*Ophiostoma ulmi*) present. No other pests or diseases were observed.

Climate Vulnerability

Fourteen of the 20 most abundant tree species in Whitchurch-Stouffville are highly or extremely vulnerable to climate change, including the top six species apart from sugar maple (eastern white cedar; European buckthorn; red pine, quaking aspen, and white spruce). These 14 species make up 70% of the total population of trees across the Whitchurch-Stouffville forest. Only three of the top 20 species were assigned a low vulnerability score, and two are not recommended for planting because they are invasive (Manitoba maple and Scots pine). The third species with a low vulnerability is eastern hophornbeam, or ironwood. Three species were given a moderate vulnerability score. It is essential to increase the diversity of resilient native and non-native non-invasive plant species – such as those projected to be low or moderately vulnerable to the impacts of climate change like eastern hophornbeam (*Ostrya virginiana*), black gum (*Nyssa sylvatica)*, honeylocust (*Gleditsia triacanthos*) – and carry out best management practices to support the forest in a changing climate.

Summary of Recommendations

The following recommendations were developed based on the results of the report, the current municipal context (i.e., existing programs, plans, policies, etc.), and the capacity and priorities of the Town of Whitchurch-Stouffville. The recommendations presented have been developed in alignment with Whitchurch-Stouffville's existing planning and management documents, including the Official Plan. Some recommendations are included in multiple sections as the recommended actions are cross-applicable. These are indicated with an asterisk (*).

Existing and Possible Forest Distribution

Recommendation 1*: Create an Urban Forest Management Plan for the Town of Whitchurch-Stouffville and include: a canopy cover target; species diversity; forest health, maintenance, and monitoring; invasive species management; soil conservation strategies; and climate change mitigation and adaptation approaches.

Recommendation 2: The next Town of Whitchurch-Stouffville Official Plan update should include a commitment to a 45% canopy cover target to align with the York Region Forest Management Plan. Additionally, the development of a woodland cover target should be further explored as a component of an overall canopy target by assessing the feasible restoration potential across the Town's natural areas.

Recommendation 3: Assess how land uses contribute to canopy and identify areas for increasing canopy.

Recommendation 4: Create a tree canopy development and maintenance strategy to reach and maintain the goal of 40% canopy cover by 2051.

Recommendation 5*: Work with York Region to customize and utilize the Region's tree planting prioritization tool for Whitchurch-Stouffville to improve equitable canopy cover distribution, the maximization of ecological benefits and ecosystem services, target areas impacted by invasive pests, and target high emissions zones. Use this to create a planting priority map to designate high priority areas for future plantings.

Recommendation 6: Continue to develop mechanisms to encourage and support private landowners (particularly commercial and industrial landowners, and property developers) to protect and enhance canopy and educate those landowners about maintenance best practices.

Recommendation 7: Continue to plant, prune, and replace trees on municipal properties. Evaluate planting and maintenance budgets regularly as the Town grows and assumes responsibility for new roads, parks, and facilities.

Recommendation 8: Consider the development of a Naturalization and Restoration plan to bolster planting inputs in naturalized areas.

Recommendation 9*: Continue assessing forest structure, function, and distribution every 10 years through the Forest Studies.

Improving Tree Diversity

See Recommendation 1.

Recommendation 10: In line with current practices, continue to establish a diverse tree population in intensively managed urban areas, in which no species represents more than 5% of the tree population, no genus represents more than 10% of the tree population, and no family represents more than 20% of the intensively managed tree population both municipal-wide and at the neighbourhood level.

- In 2017, the above recommendation was made to guide the establishment of a diverse tree population in Whitchurch-Stouffville. The current composition of the Town's forest does not yet reflect this ratio; however, it should be noted that planting and management changes since the last study require sufficient establishment time frames which may not yet be reflected in this iteration of the Forest Study. Additionally, much of the forest in Whitchurch-Stouffville regenerates naturally, so will follow a different structure. Each of the top three species represent more than 5% of the tree population (eastern white cedar (*Thuja occidentalis,* 18.6%), sugar maple (*Acer saccharum*, 16.1%) and European buckthorn (*Rhamnus cathartica*, 6.2%)). The two most common genera each represent more than 10% of the tree population (Cedars and junipers (*Cupressoideae* sub-family, 33.2%) and maples (*Acer spp.,* 13.4%)).

Recommendation 11*: Develop an invasive species management strategy. Apply targeted removal of high priority invasive plant species at high priority sites following best practices. Include the use of tools such as a Pest Vulnerability Matrix[3] to aid in species selection for planting trees and shrubs.

- This recommendation was made in the 2017 report and has been updated for the 2024 report. Given the anticipated increase in invasive pest outbreaks as a consequence of climate change, it is essential to enhance the diversity of the forest to ensure it is resilient to insect and disease outbreaks. The Pest Vulnerability Matrix is a model developed to visualize and assess the susceptibility of the forest to insects and diseases (Laćan & McBride, 2008). Using a model such as the Pest Vulnerability Matrix during tree species selection will help account for potential damage by future pest outbreaks, particularly by multi-host pests.

Recommendation 12: Utilize native and appropriate non-native, non-invasive planting stock in intensively managed areas. Increase genetic diversity of tree populations by using the guidance provided by the Ontario Tree Seed Transfer Policy. This policy is intended to help managers source seed based on the projected changes in climate to increase the likelihood of producing trees well-adapted to current and future conditions.

[3] For detailed methodology, please see Laćan and McBride (2008). The Pest Vulnerability Matrix tool can be obtained by contacting the author. Additionally, see research conducted Vander Vecht and Conway (2015) which applied the Pest Vulnerability Matrix to explore pest vulnerability of the species in Toronto’s urban forest.

- Given the sensitivity of native species to climate change, establishing a diverse forest composed of both native and suitable non-native non-invasive species will support the resiliency of the forest to stressors.

Increasing the Number of Large, Mature Trees

See Recommendation 1.

Recommendation 13: Develop a new street tree inventory and monitoring program that assesses diameter, condition and mortality for the purpose of informing maintenance, service requests, tree replacement, and species selection. Update every five years.

Recommendation 14: Evaluate and develop the strategic steps required to increase the number and proportion of large, mature trees across Whitchurch-Stouffville's forest including the Town's natural forests, street and park trees and trees on private lands.

- As urban trees increase in size, their environmental, social, and economic benefits increase as well. Large trees provide much greater energy savings, air, and water quality improvements, runoff reduction, visual impact, increase in property values, and carbon sequestration.

Recommendation 15: Continue to review and enhance tree preservation requirements in municipal guidelines and regulations for sustainable streetscape and subdivision design standards (and particularly soil volume) to support tree establishment and eliminate conflict between natural and grey infrastructure.

- Integrating green infrastructure, like trees, alongside grey infrastructure has many benefits for urban populations, however for trees to survive and establish, proper design is necessary to optimize their growing conditions.

Effect on Air Quality

See Recommendation 1.

Recommendation 16: Bolster evergreen tree population across the municipality to improve year-round pollution removal services.

- By planting evergreen species, with foliage all year round, such species can provide air pollution removal benefits during the dormant season (late fall to early spring) when deciduous trees do not provide air pollution associated benefits.

See Recommendation 5.

- Areas with dense pollution emissions should be targeted as high priority planting sites. Air pollution is a criterion considered in York Region's Tree Planting Prioritization tool and is determined through traffic volume. Planting adjacent to highways or high emission industrial sites would be beneficial to offsetting immediate emissions.

Effect on Stormwater Runoff

See Recommendation 1.

Recommendation 17: Continue applying soil enhancement techniques and enhanced rooting environments (i.e., silva cells, aeration, vertical mulching, etc.) on a project-by-project basis for street trees, particularly in constrained spaces such as intensification areas.

- Utilizing these technologies at selected sites in the short-term may provide a cost-effective means of integrating these systems into the municipal budget. Silva cells can function to improve stormwater runoff channels.

Recommendation 18: Explore the opportunity to utilize the Sustainable Technology Evaluation Program Low Impact Development Treatment Train Tool to evaluate and quantify the stormwater benefits of planting trees.

- The Low Impact Development Treatment Train Tool offers the ability to design and evaluate different urban tree planting scenarios at the site level to determine stormwater management benefits and can be a very effective way to demonstrate the benefits of urban tree planting.

Recommendation 19*: Following the Town of Whitchurch-Stouffville's Official Plan recommendation to encourage green roofs (Section 6), consider including the potential of trees to provide energy savings when developing planting guidelines or standards.

Recommendation 21: As outlined in the Whitchurch-Stouffville Official Plan (Section 1.2.2.2), the Town should support the advancement in stewardship of green infrastructure and invest in climate change mitigation and resilience.

- Green infrastructure should be incorporated into grey infrastructure planning and development as it can function to intercept precipitation, cool paved surfaces, directly remove air pollution, and improve soil content available for runoff capture in urbanized areas.

Effect on Residential Energy Bills

See Recommendation 1.

See Recommendation 19.

- Research has shown that trees planted adjacent to buildings can reduce the demand for heating and air conditioning through their moderating influence on solar insolation (i.e., providing shade) and wind speed. In addition, trees cool the climate by transpiring water from their leaves, a process that has a cooling effect on the atmosphere. Therefore, tree species selection and placement should be targeted to provide summer shade and reduce winter wind speeds around residential buildings.

Climate Change Mitigation and Adaptation

See Recommendation 1.

Recommendation 20: Consider including species' capacity for carbon storage and sequestration when developing planting lists or guidelines and future Urban Forest Management Plans.

- Trees are considered a natural climate solution. Trees can mitigate climate change by sequestering atmospheric carbon and then storing it long-term as woody biomass. Additionally, as climate change progresses, the impact of trees will become more important to adapt to heat stress especially in urban areas which are already warmer than surrounding regions due to the urban heat island effect.

Recommendation 21: As outlined in the Whitchurch-Stouffville Official Plan (Section 1.2.2.2), the Town should support the advancement in stewardship of green infrastructure and invest in climate change mitigation and resilience.

Recommendation 22: Under the context of a changing landscape and climate, consider monitoring stand level dynamics and growth trends for select key tree species.

Soil Health

See Recommendation 1.

Recommendation 23: Ensure best practices for healthy soils are implemented in Whitchurch-Stouffville's public and private urban areas in the planning of corporate or public planting programs, from site selection and assessment to species selection. Consider reference tools and programs such as the Sustainability Metrics program used by Markham, Richmond Hill, and Vaughan.

Recommendation 24: Manage compaction, salinity, and pH on public property through amendments and remedial measures like mulching and planting of herbaceous cover and shrubs on a case-by-case basis.

- The chemical and physical properties of soil influence its fertility and the capacity for tree growth (Pickett S. , et al., 2011). Urban soils are highly vulnerable to disturbances, and often become modified due to direct effects, such as construction activities, and indirect effects, such as pollution (Foldal, Leitgeb, & Michel, 2022; Lehmann & Stahr, 2007; Pouyat &

Trammell, 2019). The following recommendations are intended to support the mitigation of impacts to soil health to support tree health and survivorship.

Recommendation 25: Educate private homeowners and industrial and commercial landowners about soil best practices.

Invasive Plant Species, Pests and Diseases

See Recommendation 1.

See Recommendation 11.

Recommendation 31: Whitchurch-Stouffville should apply enhanced rooting environment techniques on a project-by-project basis for street trees, particularly in constrained spaces such as intensification areas.

Recommendation 26: Explore the development and implementation of municipal-led invasive plant, pest, and disease education and volunteer programs to enhance awareness of invasive plants, pests, and pathogens and proper removal practices.

Recommendation 27: The Town should consider the development of an invasive species density and priority map as part of the Urban Forest Management Plan to better understand the presence of common invasive plants and pests across the Town. Once developed, target high priority areas for monitoring and treatment.

Recommendation 28: The Town should consider working with York Region on a test study on the application of biological herbicides as means to treat invasive plants in high priority areas deemed unsuitable for traditional chemical herbicide treatments.

Historical Change

See Recommendation 1.

See Recommendation 9.

- The Forest Studies provide an opportunity to compare change through time, given they involve the reassessment of the same randomly distributed plots every 10 years. The capacity to assess change over time allows the chance to see the successes and opportunities in the Town’s forest maintenance, management, and monitoring.

Trajectory and Future Projections

See Recommendation 1.

Recommendation 31: Develop a post tree planting management and monitoring strategy to complement the tree maintenance program to ensure tree survivorship and mitigate common stressors in the urban environment.

- To sustain and enhance Whitchurch-Stouffville's forest, the Town should continue to engage in tree planting, and proactive monitoring and management.

Climate Vulnerability and Resilience

See Recommendation 1.

Recommendation 32: Assess the Town's current recommended planting list based on the climate vulnerability of each species. Shift recommendations to native and appropriate non-native, non-invasive species that have a higher tolerance and lower vulnerability to climate change impacts.

Recommendation 33: Educate and incentivize private landowners to plant a greater diversity of native, resilient species as part of the Town planting programs, to increase the functional diversity of species planted in Whitchurch-Stouffville. Encourage private landowners to plant alternatives to eastern white cedar, given its prominence and high vulnerability to climate change.

Recommendation 34: The Town should work with York Region to explore assisted range expansion, assisted migration, and increase proactive, long-term monitoring of species identified as highly and extremely vulnerable to climate change.

- Changes in climate conditions are expected to profoundly alter the environmental conditions across Southern Ontario, limiting the capacity of many tree species to cope as their optimal climatic ranges shift. The resilience of Whitchurch-Stouffville's forest to climate change can be improved via the Town's Urban Forest Management Plan.

Forestry and Asset Management

See Recommendation 1.

Recommendation 35: Begin integrating individual trees and forests into asset management planning, starting with the development of an inventory.

Recommendation 36: Continue to integrate green infrastructure into asset management planning, particularly municipal natural assets like woodlands and wetlands that have not yet been incorporated.

Recommendation 37: Continue to refine and update public and private tree bylaws while improving enforcement.

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1.0 Introduction

In the Town of Whitchurch-Stouffville (“Whitchurch-Stouffville” or “the Town”), the forest is fundamental to social, economic, public, and environmental health, and the resilience of the Town. All trees, shrubs, and woodlands located on public and private property make up the Town’s forest and provide vital services to the community. A healthy forest cleans the air, reduces stormwater run-off, moderates extreme heat, sequesters carbon, provides habitat for local wildlife, and makes a community more attractive and livable. The value of these services increases exponentially as healthy trees grow and thrive.

Trees and woodlands are adaptable to change, but in urban areas they often require special planning, management, and stewardship to ensure they are protected, maintained, replaced, and integrated properly into the built environment. Although Whitchurch-Stouffville does not have an urban forest management plan yet, it has recognized the importance of forests in its Natural Heritage Resources Study:

A robust natural heritage system with a strong associated policy framework sets the stage for the planning of healthy, resilient communities.

Climate change impacts, urban development pressures, difficult growing conditions, altered soils, and invasive species challenge the health of the forest and its ability to support a healthy and resilient community. If the forest is to continue to provide ecosystem services and benefits, evidence-based, coordinated, and cost-effective policies and management strategies are needed. This requires a comprehensive understanding of forest distribution, structure, and function.

1.1. Purpose

This Forest Study is a resource for use by Town and Regional staff to help track and evaluate progress towards established goals, adapt goals and strategies as needed, and make informed management decisions about the forest. The York Region Forest Management Plan (2016) has a target of achieving 40% canopy cover across York by 2051 and recommends a canopy cover range of 40% to 45% for Whitchurch-Stouffville.

The first townwide analysis of Whitchurch-Stouffville's forest was conducted through a collaboration between Whitchurch-Stouffville, York Region, Lake Simcoe Region Conservation Authority (the Conservation Authority), and Toronto and Region Conservation Authority. Data was collected in 2016, and the results were published in the *Upper York Region Urban Forest Study: Technical Report* (Lake Simcoe Region Conservation Authority, 2017). However, due to some data collection inconsistencies, the 2017 study will be omitted as the baseline against which change can be assessed. Refer to the *Town of Whitchurch-Stouffville Forest Study Change Assessment: Data Inaccuracies* internal report for some additional context. In lieu of a change assessment, the 2024 Forest Study will serve as a baseline against which future studies may assess change. This study will include more detailed information on tree health, invasive plant species, pest and disease presence, soil quality, and climate vulnerability for Whitchurch-Stouffville's forest.

To track progress, study partners committed to conducting sample-based field surveys every 10 years, and a GIS-based canopy cover assessment every five years. These timelines have been formally established in the York Region Forest Management Plan. A canopy cover assessment was completed in 2020 and the field data for this study was collected in 2023. Note that despite data being collected in 2023, this report refers to the publication year of 2024 for clarity.

1.2. Objectives

The objectives of the 2024 Forest Study are to:

- Assess canopy cover distribution and track progress towards Whitchurch-Stouffville's canopy cover targets;
- Quantify the existing distribution and structure of the forest, including species composition and condition;
- Quantify function of the forest, including carbon sequestration and air pollution removal;
- Assess vulnerability and climate change risks;
- Analyze key factors relating to the health of the Town's forest, specifically soil health, tree health, invasive plant cover, and presence of invasive pests and diseases;
- Provide communication based on the results of the Forest Study to gather support for strategic forest management planning;
- Conduct an i-Tree Forecast assessment to estimate tree planting needed to maintain existing canopy cover and to meet the recommended canopy cover goals.

2.0 Context

2.1. Demographic and Ecological Context

The Town of Whitchurch-Stouffville is a lower-tier municipality within the Regional Municipality of York. Whitchurch-Stouffville's population growth has increased, with a growth of 8.8% between 2016 and 2021 compared to 4.6 from 2011 to 2016, and 5.9 from 2006 to 2011 (Statistics Canada, 2021). This is higher than the provincial average of 5.8% and the national average of 5.2%. With the increasing speed of population growth, intensification and infill development has continued across the municipality. Based on the 2021 census, the total population in Whitchurch-Stouffville is 49,864 and the population density is 241.6 people per square kilometre (Statistics Canada, 2021).

Whitchurch-Stouffville is bounded by Richmond Hill, Aurora, and Newmarket to the west, East Gwillimbury to the north, Uxbridge to the east, and Markham to the south. The Town is part of the Holland River watershed, the Black River watershed, and the Rouge River watershed, with parts of Duffins Creek and Pefferlaw watersheds as well. About 80% of the municipality is within the Oak Ridges Moraine. The Provincial Greenbelt also extends along the same boundary. The Moraine is an irregular ridge stretching west from Rice Lake to the Niagara Escarpment. This landform supports significant ecological and hydrological features, including post-glacial kettle lakes and aquifers. The abundance of wetland communities supports a rich diversity of flora and fauna, including a high density of species of regional concern.

Whitchurch-Stouffville is located mostly in Plant Hardiness Zone 5B, with some in Zone 6A. It has about 80% ecodistrict 6E-7, the Oak Ridges Moraine. It also has about 10% of each 7E-4 Toronto, and 6E-6 Barrie, with about 1% 6E-8 Peterborough. Ecodistrict 6E-7 corresponds to the Great Lakes – St. Lawrence Forest Region. This ecoregion is characterized by coniferous species like eastern white pine (*Pinus strobus*), eastern hemlock (*Tsuga canadensis*), and red pine (*Pinus resinosa*), and deciduous species, such as sugar maple (*Acer saccharum*) and red oak (*Quercus rubra*). Ecodistrict 7E-4 corresponds to the Carolinian Forest Region. This ecoregion includes many deciduous species commonly found in other parts of Ontario, such as sugar maple and American beech (*Fagus grandifolia*), as well as regionally rare species such as the Kentucky coffee tree (*Gymnocladus dioicus*), tulip tree (*Liriodendron tulipifera*), and sycamore (*Platanus occidentialis*). Ecodistrict 6E-6 corresponds to the Eastern Temperate Deciduous Forest Vegetation Zone and the Huron-Ontario Section of the Great Lakes – St. Lawrence Forest Region. This ecoregion includes forests with many different deciduous species such as sugar maple, American beech, northern red oak, and yellow birch (*Betula allenghaniensis*). Common coniferous species in this ecoregion include eastern hemlock, spruce species (*Picea spp.*), eastern white cedar (*Thuja occidentalis*), and balsam fir (*Abies balsamea*). The deciduous and coniferous species occur in different combinations depending on the local site conditions (Crins, Gray, Uhlig, & Wester, 2009).

Approximately 10,500 to 11,000 years ago, about 1,500 to 2,000 years after the retreat of the glaciers, Indigenous peoples were moving across the landscape in what is now York Region, which at the time was a relatively barren tundra dotted with areas of open boreal forest (York Region, 2019). These earliest Indigenous people were nomadic and hunted caribou, as well as mastodon, moose and elk, and likely fished the waters of the post-glacier lakes. Over the centuries, with warming climate, more permanent villages emerged as people began to grow crops. In Ontario, the Haudenosaunee were the largest community to develop this less nomadic lifestyle. They cultivated land cleared by fire and harvested forest plants for food, medicine and fibre. One nation, the Huron-Wendat, had a village with as many as 2,000 members on the land that is now the community of Stouffville in Whitchurch-Stouffville. At least 80 per cent of what is now York Region was likely covered with mature and diverse forests and wetlands at the time of European contact.

Agriculture, urbanization, and industrial activity have led to the loss of pre-European settlement natural cover in the region, as well as the degradation of the remaining natural systems due to changes to local hydrology and soil quality. Concurrent with the loss of natural cover has been the loss of valuable ecosystem services, including water management and climate regulation[4].

Today, the most pressing challenges facing the natural systems in Whitchurch-Stouffville are urban development and the effects of climate change. Urban intensification and infill development threaten the retention of trees and reduces the space available for future trees in urban areas. The effects of climate change are already being observed in Whitchurch-Stouffville and are expected to threaten the health and sustainability of the natural environment. These effects include more frequent severe storms, extreme heat, windstorms, flooding, heavy rainfall, drought, etc. (Fausto, et al., 2015). Recognizing these challenges, Whitchurch-Stouffville is taking proactive steps to protect and enhance the Town's natural systems and mitigate and adapt to climate change. Whitchurch-Stouffville selects species based on drought and heat tolerance and provides maintenance and aftercare for new tree plantings including water, fertilization, and structural pruning.

2.2. Policy, Planning, and Management Context

2.2.1 Provincial Legislation

The provincial planning policies that guide growth and development heavily influence the retention and enhancement of the forest. The following provincial legislation impacts the capacity for municipalities to protect and increase the forest.

Ontario *Planning Act*, 1990

- The province provides an overarching framework to guide land use planning and development through the *Planning Act*, passed in 1990. The legislation sets out rules for

[4] For a more detailed breakdown of the history, read *It's in Our Nature: Management plan for the York Regional Forest 2019-2038* (2019).

land use planning in Ontario, providing the basis for natural resource management, Provincial Policy Statements, the preparation of municipal Official Plans, and the control of land use through zoning by-laws.

Provincial Planning Statement, 2024

- Under Section 3 of the *Planning Act*, the province can issue directions for municipalities in the form of policy statements. The current Provincial Planning Statement came into effect in October 2024 and supports the provincial goals to increase housing options and protect the environment, public health and safety, and manage natural resources, while also reducing barriers and costs for development.

***Municipal Act*, 2001**

- The *Municipal Act* empowers municipalities to be accountable for their own jurisdiction and provides the power to pass and adopt by-laws.

***Oak Ridges Moraine Conservation Act*, 2001**

The *Oak Ridges Moraine Conservation Act* established the Oak Ridges Moraine Conservation Plan, which includes land use designations and protections for land within the area defined as the Oak Ridges Moraine. Whitchurch-Stouffville contains significant land in the Natural Core Area, which has the highest restrictions on land use, aimed to protect key natural heritage features.

***Lake Simcoe Protection Act*, 2008**

- The *Lake Simcoe Protection Act* establishes the Lake Simcoe Protection Plan, which aims to protect and restore the health of the Lake Simcoe watershed. The plan sets several targets and indicators and outlines specific policies to address issues threatening the health of the watershed.

***Ontario Invasive Species Act*, 2015**

- The *Ontario Invasive Species Act* prohibits and regulates species deemed invasive to control their spread and limit the damage caused by them. There are several invasives terrestrial plants restricted under the *Act*.

2.2.2 Municipal Policies, Programs, and Plans

The subsequent list provides an overview of the municipal policies, programs, and plans that are currently applied in the governance or management of the forest in Whitchurch-Stouffville.

Town of Whitchurch-Stouffville Official Plan (May 2024)

- The Official Plan guides the Town's long-term land use planning, development, and growth. The new Official Plan was adopted by council in May 2024. The plan recognizes the importance of the forest in providing ecological benefits for the Town and recognizes the importance of maintaining and expanding the trees in the municipality. It sets several targets including the creation of an urban forest management plan, a Private Tree Preservation By-Law, and increasing canopy cover. Section 3.3.6 is dedicated to Enhancing the Tree Canopy.

Private Tree Preservation and Protection Bylaw No. 2023-060-RE

- Bylaw to protect private, heritage, and mature trees and to require for compensation, relocation and/or removal/cutting of mature trees on private property in the Secondary Plan Areas of the Town of Whitchurch-Stouffville implemented through site plan agreements, subdivision agreements, or conditions of consent under Sections 41, 51, or 53, respectively of the *Planning Act*, 1990, as amended.

Whitchurch-Stouffville Bylaw 2020-086-RE

- Bylaw to authorize, prohibit and/or regulate the planting, destruction or injuring of trees on highways and other public lands.

York Region Forest Conservation Bylaw no. 2013-68

- A bylaw to prohibit or regulate the destruction or injuring of trees in The Regional Municipality of York.

York Region Official Plan 2022

- The most recent iteration of the Official Plan aims to provide clear direction with respect to long-term growth management balancing the protection and enhancement of its agricultural and natural systems within the Region. The plan outlines that local municipalities must develop an urban forest management plan with York Region. The plan includes a target of at least 25% woodland cover for York Region's total land area and to increase canopy cover to a minimum of 40%.

York Region Forest Management Plan (2016)

- The York Region Forest Management Plan was adopted by York Regional Council in 2016 and covers the time period from 2016 to 2026. The plan directs the municipality to undertake the Forest Studies and provides recommendations on the monitoring of canopy and woodland cover. Additionally, long-term canopy cover and woodland cover targets for the entire region and local municipalities, including Whitchurch-Stouffville, are recommended in the plan. Targets for Whitchurch-Stouffville include 30-32% woodland cover by 2031 and 40-45% total canopy cover by 2051. It also outlines strategic goals and actions for forest management in York Region.

York Region Green Infrastructure Asset Management Plan (2022)

- York Region's 2022 Green Infrastructure Asset Management Plan ensures the management of Regional green infrastructure assets in a way that effectively balances costs, risks, and benefits to ensure ongoing sustainable service delivery related to the Region's green infrastructure. The assets within the plan include the forest (street trees, landscape planting, supporting infrastructure on roadways), York Regional Forest (forest tracts that include trails), and the Bill Fisch Forest Stewardship and Education Centre in Whitchurch-Stouffville.

York Region's Greening Strategy (2022)

- Since its inception, York Region's Greening Strategy has helped to secure over 1,600 hectares of land for conservation purposes and plant over 2 million trees. While the Greening Strategy has a focus on enhancing natural areas, private land stewardship is also promoted through planting programs for residents or best practices to support farmers on agricultural lands.

York Region Grow Your Legacy Program

- This program helps landowners with at least 0.8 hectares of land plant and tend trees to grow new forests. Implemented in partnership with the two local Conservation Authorities (Lake Simcoe Region and Toronto and Region), the program connects landowners with knowledgeable staff and helps establish new forests, connect or enlarge existing forests, and establish windbreaks and hedgerows. Since 2004, the program has planted 763,000 trees on 452 hectares of land.

Residential Subsidized Tree Planting Program

- In partnership with Local Enhancement and Appreciation of Forests (LEAF) and York Region, Whitchurch-Stouffville has a subsidized backyard tree planting program, in which residents may apply for a tree to be planted on their property at a reduced cost to encourage residents to plant more trees on private property.

York Region Climate Change Action Plan (2022)

- Alignment of this Study and the York Region Climate Change Action Plan relates to community resilience actions such as conducting a vulnerability assessment on natural systems, integrating adaptive actions into watershed planning, and assessing the role natural systems play in mitigating and adapting to climate change.

York Regional Forest Climate Change Adaptation and Mitigation Plan (Internal, March 2023)

- This plan aims to help forest managers make decisions regarding adaptation and mitigation of climate change in the York Regional Forest. It gives specific actions for the York Regional Forest, which has tracts within the Town of Whitchurch-Stouffville.

2.2.3 National Programs and Plans

Currently, there are no federal policies or laws in place dedicated to Canada's urban forests, though some policies do relate to urban forests. There are also relevant national programs and plans which recognize the importance of urban forests, including:

A Healthy Environment and a Healthy Economy (2020)

- A Healthy Environment and a Healthy Economy is the updated federal climate change plan that includes nature-based climate solutions as one of five pillars of action. Nature-based solutions include: the 2 billion trees program; enhancing carbon sequestration by enhancing wetlands, peatlands, and agricultural lands; and establish a Natural Climate Solutions for Agriculture Fund.

Canadian Urban Forest Strategy (2019 – 2024)

- The Canadian Urban Forest Strategy was developed in partnership by the Canadian Urban Forest Network, Tree Canada, and municipal, provincial, and federal representatives. In recognition of increasing urbanization and resulting pressures on Canada's urban forest, the Strategy was developed to support the protection and enhancement of sustainable, diverse, and healthy urban forests across the country.

***Plant Protection Act*, 1990**

- The *Act* and regulations under the *Act* give the Canadian Food Inspection Agency power to regulate plants to prevent the introduction and spread of plant pests in Canada. There are several regulations specific to Ontario that define requirements for certain species.

2.3. Study Background

The first analysis of Whitchurch-Stouffville's forest was conducted in 2017. The Authority completed an i-Tree Eco (formerly known as UFORE) analysis using land use mapping in conjunction with data collected at sample plots across the Town of Whitchurch-Stouffville, to determine the species composition, condition, size class distribution, and measures of ecological services and value. This information informed the development of recommendations, many of which have been implemented by the Town. However, due to inaccuracies present in the data collected, this original assessment has been excluded from this iteration's change assessment. Instead, the current forest study will serve as a baseline from which future studies may compare results and track trends.

The 2024 Forest Study is intended to assess the change in the forest over the last decade by surveying a pool of the same plots as those considered in 2017, following the i-Tree Eco protocol. Since 2017, additional assessments have been incorporated to better understand biotic factors pertinent to forest change. Additional assessments included in this iteration of the Forest Studies evaluated the invasive plant, pest and disease species, advanced tree health, soil properties, and climate vulnerability. The analysis and recommendations presented in this report have been aligned with the guidance of Whitchurch-Stouffville's existing and new policies and frameworks.

3.0 Methodology

This study utilized several complementary approaches, datasets, and analysis tools:

1. Canopy cover mapping and spatial analysis
2. i-Tree Eco and Forecast
3. Assessment of forest structure, composition, and function
4. Quantitative analysis of soil, tree health, and invasive species data
5. Climate vulnerability assessment of dominant tree species

Each analysis tool is examined in more detail in the following sections. Taken together, these analyses provided a broad understanding of Whitchurch-Stouffville's urban forest. While the i-Tree Eco and the canopy cover analyses each represent stand-alone assessments capable of supporting a forest management plan, experience from the 2017 Upper York Region Forest Study demonstrated the value of combining both approaches. By incorporating data collected in the field, the i-Tree Eco analysis allowed the quantification of critical attributes such as tree species and tree height, as well as ecosystem services such as carbon storage and sequestration. In contrast, the canopy cover analysis relied on the mapping of land cover based on high-resolution satellite imagery and LiDAR data. This allowed a detailed and accurate assessment of the quantity and distribution of canopy cover and potential planting space across Whitchurch-Stouffville. i-Tree Forecast allowed an estimate of future canopy cover and ecosystem services given current planting plans, while additional data collected on soil, tree health, and invasive species, in combination with a climate vulnerability assessment, provided the basis for obtaining a more detailed understanding of the health and vulnerabilities of the urban forest in Whitchurch-Stouffville.

3.1. Canopy Cover Analysis

In 2020, the Spatial Analysis Laboratory at the Rubenstein School of the Environment and Natural Resources at University of Vermont (UVM) completed land cover and canopy cover assessments for the whole of York Region. Detailed methods and results can be found in the 2021 York Region Canopy Cover Assessment Technical Report (Timmins & Sawka, 2022). Advanced automated processing techniques utilizing high-resolution WorldView-2 imagery acquired in the summer of 2019, in combination with high-resolution LiDAR data, and ancillary datasets were used to map land cover for the entire Town of Whitchurch-Stouffville in such detail that single trees were detected. The following land cover classes were mapped: tree canopy, grass/shrub, bare soil, water, buildings, roads/railroads, and other paved/impervious surfaces. The overall accuracy of the land cover map was 97%.

Using the land cover data, several canopy cover metrics were computed for Whitchurch-Stouffville: existing canopy, potential vegetated canopy, potential impervious canopy, and not suitable (see Table 2 for a description of each metric). Canopy cover metrics were summarized as the total area in hectares, and as a percent of land area.

Table 2. Existing and potential canopy cover categories

Category	*Description*
Existing Tree Canopy	The amount of tree canopy present when viewed from above using imagery.
Potential Vegetated Tree Canopy	Grass or shrub area that is theoretically available for the establishment of tree canopy.
Potential Impervious Tree Canopy	Asphalt, concrete, or bare soil surfaces, excluding roads and buildings, that are theoretically available for establishment of tree canopy.
Not Suitable	Areas where it is highly unlikely that new tree canopy could be established (buildings and roads).

For this report, existing and possible canopy cover were also summarized for ten land use categories derived from the Municipal Property Assessment Corporation (MPAC) codes assigned to each property in Whitchurch-Stouffville. MPAC is an independent body established by the Ontario Property Assessment Corporation Act, 1997, which administers a uniform, province-wide property assessment system based on current value assessment. MPAC data were obtained for the canopy cover assessment in 2019 and was last updated in 2016. Thousands of parcels were of an unknown land use (6.1% of York Region’s land area) due to problems with joining the land use codes to the parcel boundaries via the roll or parcel ID number. This was corrected where possible by Toronto and Region Conservation Authority staff, however, there are likely to be errors in the land use codes.

Each original MPAC code or description was grouped into one of ten generalized categories based on similarities in ownership and management type (see Appendix A: MPAC Land Use Categories for the list of MPAC classes in each land use category). Road rights-of-ways (ROWs) were added to the land use layer by UVM by filling in the gaps between the MPAC parcel boundaries and constitute an eleventh land use category.

3.2. i-Tree Eco

i-Tree Eco, a software application, model, and protocol, was chosen as the primary tool for the York Region Forest Studies, including Whitchurch-Stouffville. i-Tree Eco is an adaptation of the Urban Forest Effects (UFORE) model, which was developed by the U.S. Forest Service Northern

Research Station (NRS), the USDA State and Private Forestry's Urban and Community Forestry Program and Northeastern Area, the Davey Tree Expert Company, and SUNY College of Environmental Science and Forestry. i-Tree was used for the 2017 Upper York Region Urban Forest Study. UFORE and i-Tree Eco have been used in many other municipalities in the Greater Toronto Area over the past 15 years. The built-in i-Tree Eco models are continually improved upon by its developers, so the versions are not the same across studies. Version 6.0.32 was used for this assessment.

3.2.1 Study Design

The study area boundary was defined by the municipal boundary of Whitchurch-Stouffville. Two hundred randomly generated plot centres created for the 2017 Whitchurch-Stouffville Forest Study were reused for the 2024 study. According to the USDA Forest Service (2021), 200 plots in a stratified random sample in a city will yield a standard error of approximately 10%. 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. In cases where 200 plots are not feasible to complete, a minimum of 180 plots gives a standard error of 13%, which is deemed acceptable (USDA Forest Service, 2021). Although increasing the number of plots would have led to lower variances and increased certainty in the results, it would have also 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 associated with additional field data collection. In accordance with standard i-Tree Eco protocols, plots were circular and had an area of 0.0404 hectares.

i-Tree Eco was used to statistically extrapolate data to estimate totals and standard errors for the entire study area for tree population, leaf area, species composition, size distribution, and condition, as well as carbon storage and sequestration, avoided runoff, air pollution removal, and building energy savings. i-Tree Eco was also used to provide a structural value for the forest using a simplified Council of Tree and Landscape Appraisers Trunk Formula method and a valuation for ecosystem service benefits (Nowak, 2020).

3.2.2 Study Area Stratification

The study area was stratified into smaller units according to land use types (e.g., residential, commercial and industrial, etc.) to better understand variations in the structure of the forest. The randomly distributed plots were post-stratified according to the MPAC land use category in which they fell (Figure 1). The post-stratification approach was selected for the 2017 Whitchurch-Stouffville Forest Study, and repeated in the 2023 study, to enable the monitoring and assessment of change over time at the same plots, as well as the ability to report on trends within land use categories. Using this approach, permanent sample plots are not dependent on a static land use distribution.

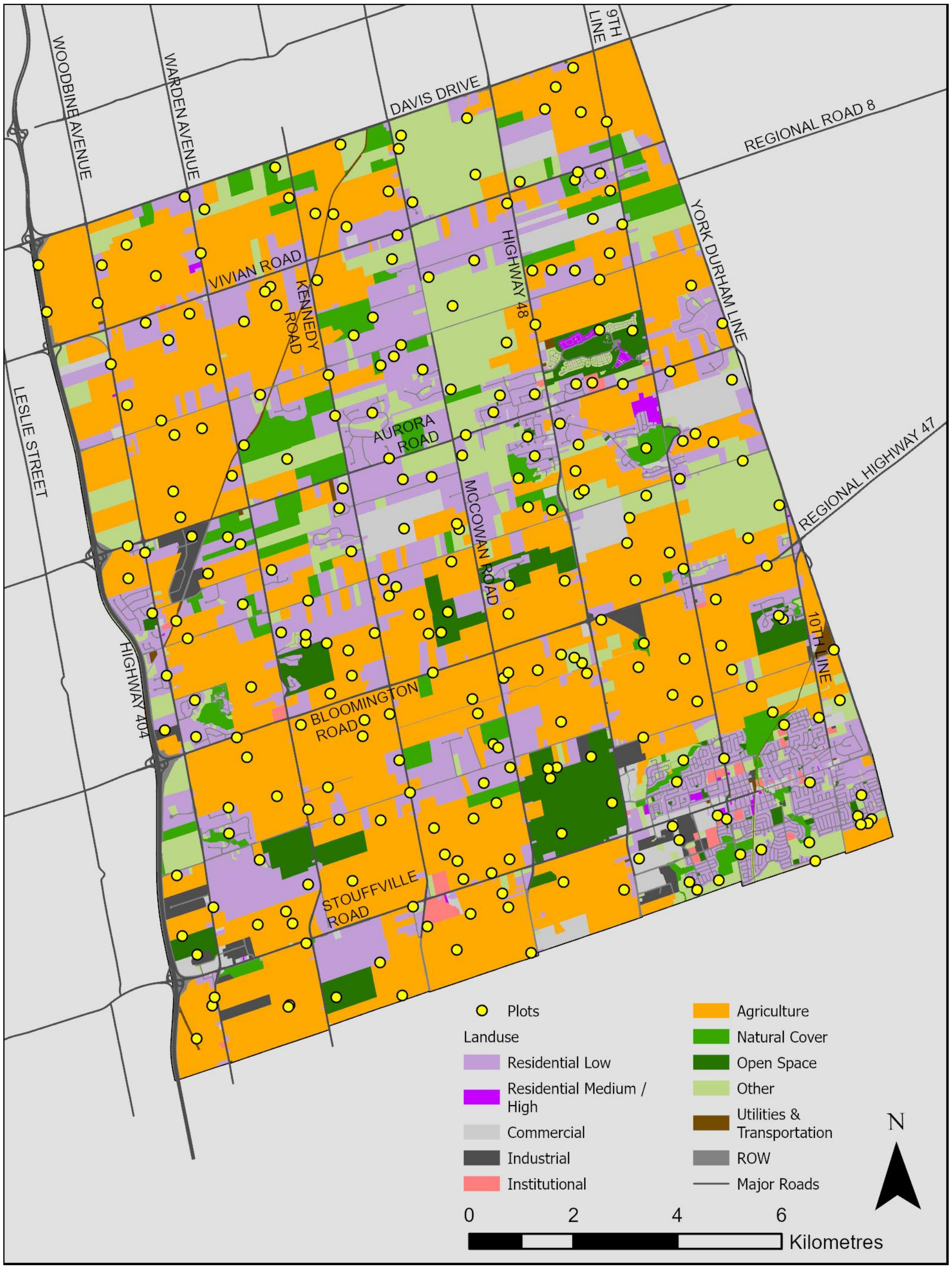


Figure 1. Distribution of MPAC land use types and plots across Whitchurch-Stouffville

For this study, plots were stratified into five land use categories based on 2016 MPAC land use data acquired for the canopy cover assessment. The MPAC land use categories were last updated in 2016 and the next iteration was scheduled for completion in 2020 but delayed due to the COVID-19 pandemic. It is likely that errors exist in the dataset.

To ensure acceptable accuracy, i-Tree Eco developers recommend that each stratum contains a minimum of 15 to 20 plots. Unfortunately, there were insufficient plots in the land use categories, *Commercial, Industrial, Institutional, Natural Cover, Open Space, Residential Medium / High, Utilities & Transportation,* and *ROW.* Consequently, the aforementioned categories were grouped into broader categories with other land use types based on similarities in vegetation cover and management needs to create a total of five land use categories or stratum as shown in Table 3. Appendix A: MPAC Land Use Categories contains a detailed description of the land use types. Figure 2 and Table 3 show the distribution of land use types and plots across Whitchurch-Stouffville. Utilities & Transportation includes plots that fall predominantly on rights-of-way (ROWs).

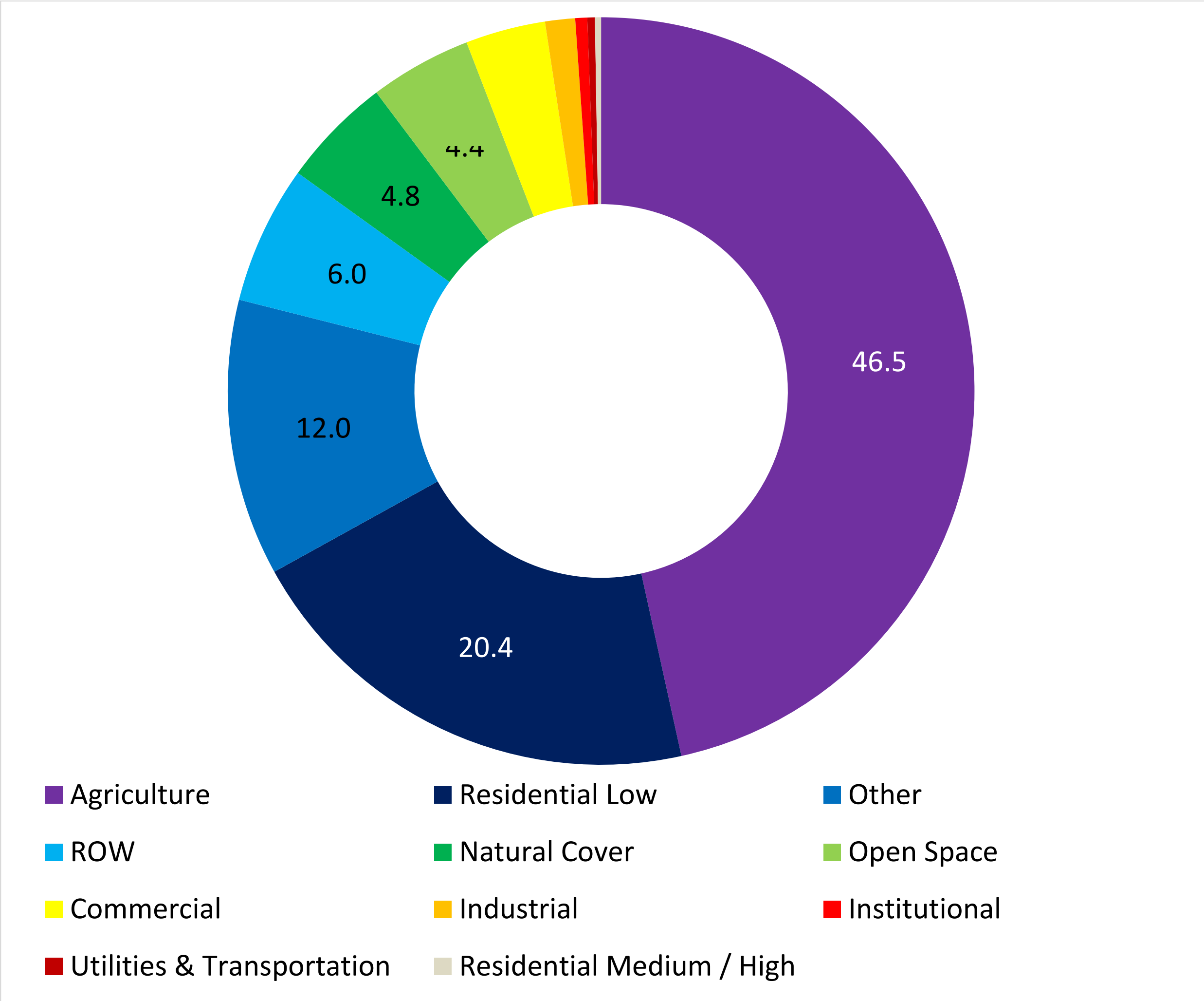


Figure 2. Current approximate MPAC land use distribution in Whitchurch-Stouffville

Table 3. Land use categories used for i-Tree Eco stratification

Stratum	Area (ha)	Number of Plots
Agriculture	9,829	108
Residential	4,367	65
Natural Cover + Open Space	1,946	22
Other Urban*	2,337	26
Other[5] + Institutional	2,636	34
TOTAL	**2,115**	**255**

*Commercial, Industrial, Utilities & Transportation, and ROW

3.2.3 Landowner Contact

Many plots were located on private property, so permission was required (Figure 3). Permission to access plots located on private property was obtained primarily through written communication. Prior to entry, all property owners received letter and request for access form outlining the scope and duration of the study. In the case of businesses, telephone numbers and email addresses found online were used to contact owners. If it was not possible to contact an owner or no response was received, field staff requested permission to access the property in person. When permission was not granted, access was not possible due to physical barriers, or the site was deemed unsafe, the plot was not assessed or was assessed from a distance.

[5] *Other* is comprised predominately of vacant residential land, but also includes non-buildable land such as stormwater management ponds and recreational sports complexes.

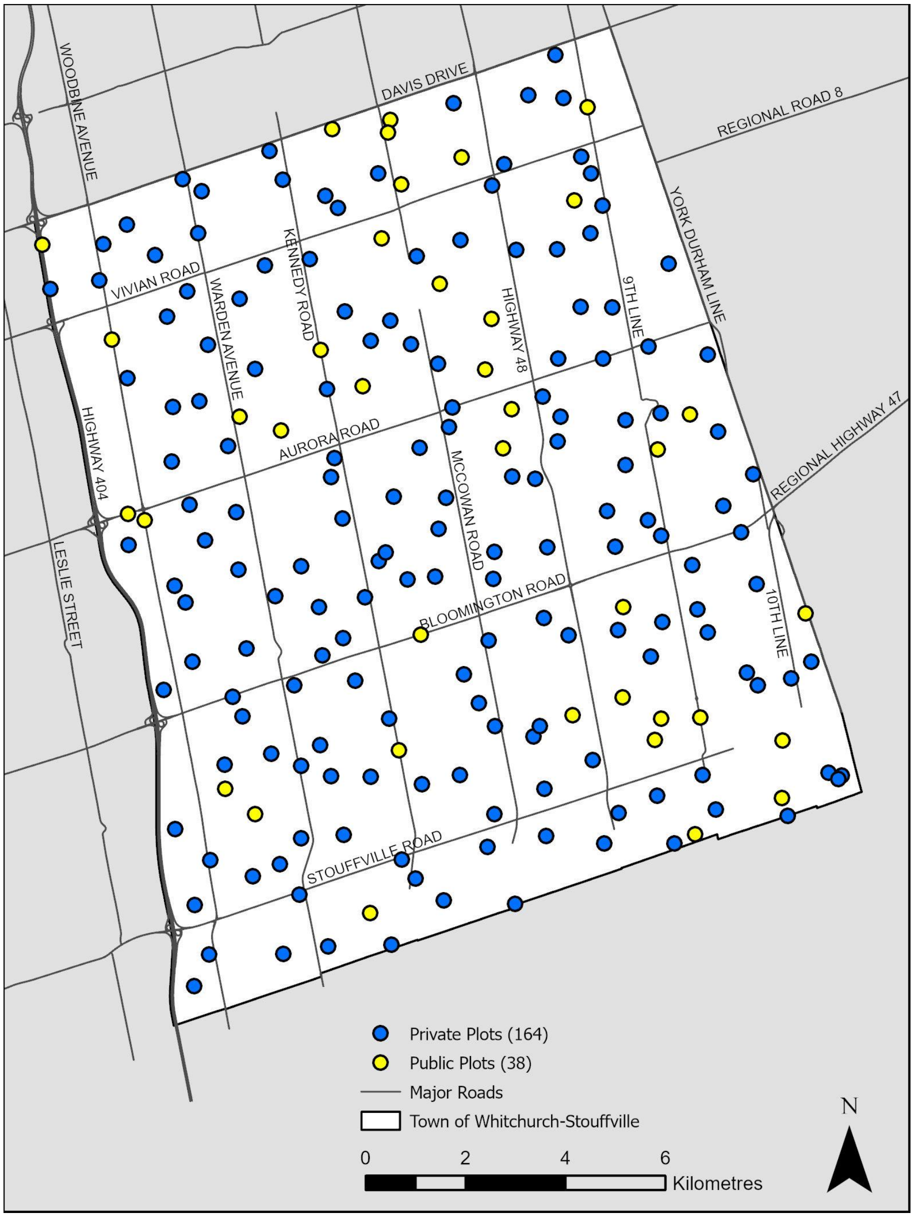


Figure 3. Distribution of public and private land across Whitchurch-Stouffville

3.2.4 Field Data Collection

Field data collection was conducted by three two-member field crews during the summer leaf-on season of 2023. Plot centres were found by using a combination of handheld GPS units, and high-resolution aerial orthoimagery on a mobile device that illustrated the centre and boundaries for each plot. Field staff recorded the distance and direction from plot centre to permanent reference objects so that plots could be found for future re-measurement. Where possible, (i.e., no risk of creating a tripping hazard), metal rebar stakes were also placed at plot centre to facilitate relocation. At each plot, detailed vegetation information was recorded in accordance with the i-Tree Eco field manual specifications. The following general plot data were recorded in the i-Tree Eco web interface via a mobile device:

- percent tree cover
- percent shrub cover
- land use
- percent of plot within the land use
- percent ground cover
- building
- cement
- tar – blacktop/asphalt
- soil
- rock
- duff/mulch
- herbaceous (exclusive of grass and shrubs)
- maintained grass
- wild/unmaintained grass
- water

In order for a tree to be included, the centre of its stem must be inside the plot and its diameter at breast height (diameter) must be a minimum of 2.54 cm. In forested areas[6], the minimum diameter was increased to 5 cm to increase sampling efficiency. The following information of each tree was recorded:

- species
- number of stems
- diameter at breast height
- tree height
- live tree height
- height to base of live crown

[6] Plots were defined as forested areas if 10% of the plot area was covered by natural canopy. Land was considered forested if it was not subject to use(s) preventing normal tree regeneration and succession, such as regular mowing, intensive grazing, or recreation activities. In some cases, plots with less than 10% canopy cover could qualify as a forested area if trees were harvested, died, or were otherwise removed but the land was expected to naturally regenerate to at least 10% cover.

- crown width in east-west direction
- crown width in north-south direction
- percent canopy missing[7]
- percent dieback[8]
- distance and direction (clockwise degrees from True North) from the building (for trees ≥6.1 m in height and located within 18.3 m of a residential building)

[7] Percent canopy missing is the percent of the crown volume that is missing foliage. It is assessed within the measured live crown width and height and requires imagining a typical crown outline that is full of live foliage.

[8] Percent dieback is the percent of the crown that is composed of dead branches.

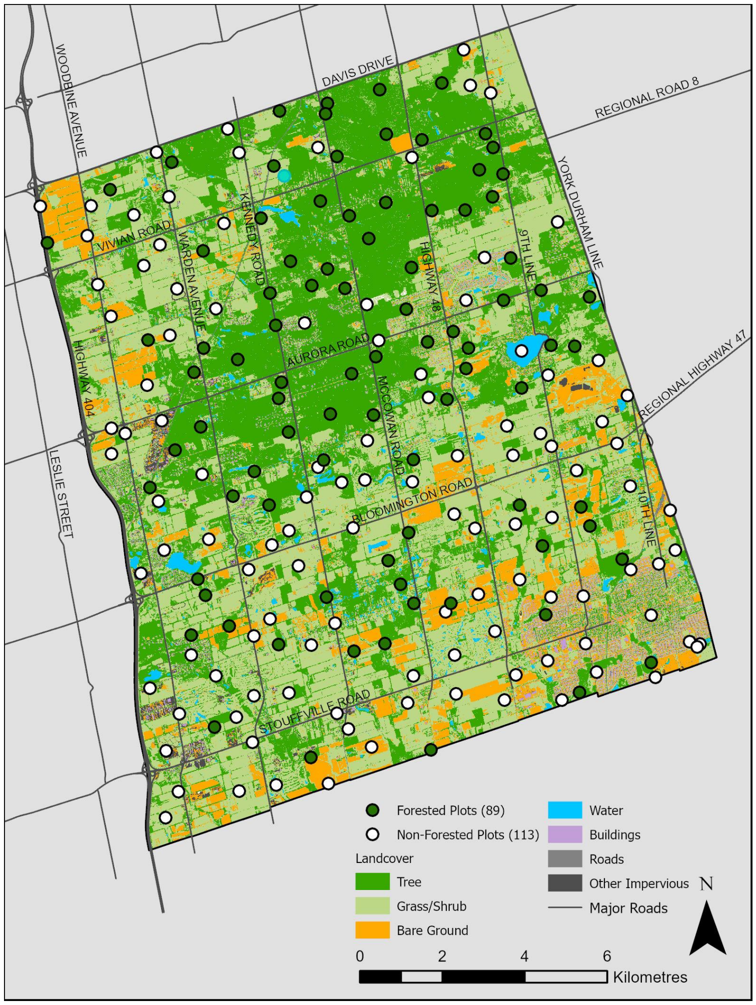


Figure 4. Distribution of forested and unforested plots and land cover across Whitchurch-Stouffville

Considering access constraints, it was possible to collect data at a total of 154 out of the original 202 plots. Partway through the field season, it was deemed necessary to add an additional 70 plots randomly across the study area. The original plots were created in a random grid, whereas the new plots were added completely randomly, which resulted in some areas having clusters of plots. Of these plots, 53 were kept as potential visits and 17 were not included since they did not have trees. This was decided because the original plots being replaced all had trees, and we did not want to underestimate the total number of trees. With the additional plots, a total of 184 plots were completed. Prior to the field assessment, plots were inspected using current orthoimagery and Google Street View. Plots which contained 98-100% impervious surfaces or agricultural fields without trees, were assessed using orthoimagery and Google Street View if recent 2022/2023 data was available. If uncertain about the presence of trees or invasives, the plots were visited. The remainder were visited in the field as summarized in Table 4. Table 5 summarizes the number of plots with complete i-Tree Eco data per land use stratum. Plots were also assessed as either forested or unforested, as another potential way to analyse the data (Figure 4).

Table 4. Data collected for plots

Description	Plots Completed
Field visits	142
Orthophoto/Google Street View	42
Total plots	184

Table 5. Number of plots completed per stratum

Stratum	No. of Plots with Complete i-Tree Eco data	Total Number of Plots
Agriculture	75	108
Residential	46	65
Natural Cover – Open Space	16	22
Other Urban*	24	26
Other – Institutional	23	34
Total	**184**	**255**

Research conducted by i-Tree Eco developers indicated that 200 plots (of 0.0404 ha each) in a stratified random sample will have a standard error of approximately 10% for the municipality and around 13% for 180 plots (USDA Forest Service, 2021). The relationship between the number of plots and standard error is non-linear, with the biggest gains in accuracy obtained in the first 80 to 90 plots. Therefore, the number of plots and plots per stratum that had complete data to run the i-Tree Eco model was deemed sufficient.

3.2.5 Quality Assessment and Quality Control

Quality assurance and quality control measures were taken to catch errors early in the season and correct them appropriately. Following best practices from the i-Tree Eco User Manual, the Conservation Authority incorporated ‘Hot’ and ‘Cold’ checks into the field season. Hot checks allow supervisors to visit teams in the field to monitor measurements and correct mistakes on the spot. Cold checks allow for a post-survey check by the supervisor without the field team present to re-take measurements and contrast results. These quality checks serve as an opportunity for the supervising team to monitor for errors in protocol implementation and address them via in-field demonstrations or follow-up training meetings. The Conservation

Authority has incorporated a data screening component where supervisors periodically reviewed i-Tree entries as an added degree of inspection. Inspections were followed by weekly check-ins to provide a consistent meeting time to review any issues as needed.

3.2.6 Data Analysis

The i-Tree Eco model used standardized field, air pollution-concentration, and meteorological data for Whitchurch-Stouffville to quantify 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, and leaf and tree biomass) based on field data.

2) Biogenic Emissions: quantifies 1) hourly urban forest volatile organic compound emissions (isoprene, monoterpenes, and other volatile organic compound emissions that contribute to ozone (O_3) formation) based on field and meteorological data, and 2) O_3 and carbon monoxide (CO) formation based on volatile organic compound emissions.

3) Carbon Storage and Annual Sequestration: calculates total stored carbon, and gross and net carbon sequestered annually by the urban forest based on field data.

4) Air Pollution Removal: quantifies the hourly dry deposition of ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), and particulate matter ($PM_{2.5}$) by the urban forest and associated percent improvement in air quality throughout a year. Pollution removal is calculated based on local pollution and meteorological data.

5) Building Energy Effects: estimates the effects of trees on building energy use due to heating and cooling.

3.2.7 Weather and Pollution Data, and i-Tree Eco Parameters

3.2.7.1. Weather and Pollution Data

Weather and pollution datasets are integrated into i-Tree Eco for use in modelling. It is not possible for the user to directly upload their own data into the application. Hourly precipitation data is utilized to calculate avoided runoff and improve the accuracy of estimating the removal of $PM_{2.5}$ by trees and shrubs. Weather data also impacts the calculation for emissions of volatile organic compounds. Toronto Pearson Airport meteorological station is the closest weather station to York Region and provides weather data from 2010 to 2020. It also provides hourly pollutant data for 2019, which was the most recent air pollution data available for the Region. The hourly 2019 pollution concentrations of sulphur dioxide (SO_2), and carbon monoxide (CO) were obtained from the Ontario Ministry of Environment, Conservation and Parks' Toronto

West station, and ozone (O_3), nitrogen dioxide (NO_2) and $PM_{2.5}$ data were obtained from their Newmarket station for the same year.

3.2.7.2. i-Tree Eco parameters

The i-Tree Eco model requires the user to select a variety of parameters to support model runs. Parameters used for the 2024 Whitchurch-Stouffville Forest Study are summarized in Table 6.

Table 6. i-Tree Eco parameters

Variable/Parameter / Dataset	Value/Source	Comments
Weather	2019 Pearson International Airport	Closest station and corresponds to date of air pollution data.
Air pollution	2019 Newmarket and Toronto West data / Ministry of Environment, Conservation and Parks, Ontario	Most recent and closest station data
Census Subdivision and Population Size	Study area type = rural Population (2021) = 49,864 Population Density = 241.6	From Statistics Canada (2021)

Variable/Parameter / Dataset	Value/Source	Comments
Electricity in Can$ (CAD)/kWh	$0.13 / Ontario Energy Board	This is used to calculate the cooling benefit of trees due to reduced air conditioner use. While air-conditioners may be used most in the day during peak hours, many people continue to use air-conditioners at night[9]. In addition, many people turn their air-conditioners off when they are not at home, which is more likely during the day. Therefore, an average electricity price was used as shown below. Ontario (oeb.ca – 2023-11-01) rates for electricity: Time of Use Costs: • Off-peak: 8.7 ¢/kWh • Mid-peak: 12.2 ¢/kWh • On-peak: 18.2 ¢/kWh • Average: 13.03 ¢/kWh

[9] According to archived research from Statistics Canada, 48% of people with an air-conditioner in Ontario kept their air-conditioner on when away from home in 2009. Only 29 of Canadian households with an air-conditioner turned it off while sleeping.

Variable/Parameter / Dataset	Value/Source	Comments

Heating in Can$ (CAD)/therm[10]	$0.30
	/ Ontario Energy Board
		Natural gas rates & prices in Ontario (oeb.ca – 2024-10-01)
		• Enbridge Gas Inc. - Union South Rate Zone: 12.3514 ¢/m^3
		• Enbridge Gas Inc.: 7.7012 ¢/m^3
		• EPCOR Natural Gas Ltd Partnership (South Bruce): 15.7983 ¢/m^3
		  ○ Average cost = 10.7365 ¢/m^3
		• Convert to a cents per cubic foot by dividing by 35.3147:
		  ○ Average: 0.3040 ¢/ft^3
		• Multiply the above by 100 to obtain a therm (100 cubic feet)
		  ○ Average: 30.4 ¢/therm

Carbon in Can$/metric ton	$1,066.0 /tC	The estimated social cost of carbon for 2023 (in $2021) is $261/t$CO_2$ (Government of Canada, 2023). The adjusted value of this amount (in $2023) is approximately $290.47/t$CO_2$ using the Bank of Canada inflation rate. To convert cost per tonne of carbon dioxide to tonne of carbon, it is necessary to multiply by 3.67.
Avoided Runoff in Can$ (CAD)/m3	$2.325 / Default i-Tree Eco value	Default value from i-Tree Eco. It uses the U.S. national average dollar value to estimate value of avoided runoff. This value is based on 16 research studies on costs of stormwater control and treatment (Nowak, 2020)

[10] One therm is an imperial unit of heat energy. It is the amount of energy in 100 cubic feet of gas.

3.2.7.3. Value of Air Pollution Removal

The default values of i-Tree Eco were used to estimate the value of air pollution removal services (there is no option to update these values in the modelling system). The associated economic value of the health benefits as a result of the removal of pollutants NO_2, SO_2, O_3, and $PM_{2.5}$ is based on U.S. median externality values from the U.S. EPA's Environmental Benefits Mapping and Analysis Program (BenMAP) model (Nowak, 2020). Based on BenMAP, various standardized health impacts and dollar values (value/person/pollutant) were calculated in i-Tree Eco. The standardized values were calculated using local pollution and population data. These values are multiplied by the corresponding local population total and pollution concentration change as a result of trees and other vegetation in the study area to determine health impacts and associated dollar values. For international estimates, regression equations based on population density are employed to estimate a dollar value per ton of pollution removal (Table 7) (Nowak, Hirabayashi, Bodine, & Greenfield, 2014).

Table 7. Value per tonne of air pollutant removed

Pollutant	Unit value
Carbon monoxide (CO)	$ 1,690 / tonne
Nitrogen dioxide (NO_2)	$ 170 / tonne
Sulphur dioxide (SO_2)	$ 60 / tonne
Ozone (O_3)	$ 1,170 / tonne
Particulate matter <2.5 microns ($PM_{2.5}$)	$ 40,800 / tonne

3.3. Additional Health Assessment

3.3.1 Background

Whitchurch-Stouffville has opted in for the additional tree health assessment. The purpose of the tree health assessment is to gain a holistic understanding of tree health issues including trunk and root issues that can take a long time to be reflected by crown health. Separate to the i-Tree Eco data, the field crews have rated the health indicators on a scale of very poor (1) to good (4) based on specified criteria for three tree health indicators: trunk integrity, canopy structure and canopy vigor.

3.3.2 Field Data Collection

The field data collection procedure and ratings are outlined in Appendix G: Overview of additional (optional) tree health assessment for each criterion below. However, certain species naturally show signs of structural indicators considered in the tree health assessment that do not represent a decline in health (i.e., self-pruning limbs in spruce, silver maples etc.). In such cases, relevant indicators were weighted less heavily as these are characteristic of the species.

The following categories were rated by staff for tree health:

- Trunk integrity indicator
- Canopy structure
- Canopy vigor

3.3.3 Data Analysis Methods

An average condition score was calculated by summing indicator scores for each criterion – trunk integrity, canopy structure and canopy vigor and divided by 3. The average condition score will range from 1 to 4, where a higher score indicates a better health rating, and a lower score is an indication of a worse health rating.

An average health score is calculated for each plot, i, in stratum *r.*

$$\bar{y}_{r_i} = \sum_{j=1}^{n_{r_i}} \frac{y_{r_{ij}}}{n_{r_i}}$$

Where y_{r_i} is the average health score for plot in stratum *r*. n_{r_i} is the number of trees in plot *i, and* $y_{r_{ij}}$ is the value of the variable *y* in subsample/tree, *j*, of sample/plot *i* in stratum *r*. In this case, $y_{r_{ij}}$ would be condition score for tree *j*.

The overall average health score is then calculated for each land use stratum.

$$\bar{y}_r = \sum_{i=1}^{n_r} \frac{\bar{y}_{r_i}}{n_r}$$

where y_r is the average health score for stratum *r*, n_r is the number of plots in stratum *r*, *i* is the *i*th plot in stratum *r* and $\bar{y}_{r_i}$ is the average health score for the *i*th plot in stratum *r*[11].

A health score is calculated for the municipality as a whole.
Calculate the mean of the stratum means, weighted by the stratum area.

$$\bar{y}. = \frac{\sum_{r=1}^{s} A_r \bar{y}_r}{A}$$

[11] Formula from i-Tree Eco sample_variance.pdf (itreetools.org)

Where $y_{.}$ is the average health score for the municipality, s is the total number of strata, A_r is the area of stratum r, y_r is the mean health score for stratum r and A is the total study area (sum of all area stratum).

We then test for significant differences in health between land use strata, forested and unforested land, and private and public land, using the Kruskal-Wallis test for ranked data.

Lastly, we calculate average health by species for the whole municipality.

3.4. i-Tree Forecast

3.4.1 Background

i-Tree Forecast is a computer model incorporated into the i-Tree Eco application. It was utilized in this study to estimate future canopy cover based on the current state of the forest and Whitchurch-Stouffville's tree planting plans, which were provided by Whitchurch-Stouffville. The objective of the i-Tree Forecast analysis was to determine if the Town's canopy cover would increase to the current recommended canopy cover range by 2051 (40-45%) under current planting, double planting, or no planting scenarios. If the canopy cover target range was not reached or maintained, the simulation could determine the quantity of additional trees required to meet the target.

i-Tree Forecast simulates future forest structure using current forest structure data from i-Tree Eco as an input. Forecast simulates the state of the forest each year within the simulation period using three components:

1) Tree growth: the projected growth of tree diameter, crown size, and leaf area for each tree recorded. Tree growth or annual increase in diameter is based on the number of frost-free days, crown light exposure, dieback, growth rate classification and median height at maturity.
2) Tree mortality: the projected annual mortality based on default or user-defined annual mortality rates for trees of various condition scores. Tree mortality rates are adjusted for tree size/maturity by i-Tree Eco.
3) Tree establishment: the projected number of trees added each year based on user inputs. Users must enter the stem diameter of newly established trees and annual planting rates.

i-Tree Forecast also allows the user to choose to simulate extreme events such as insect or disease outbreaks and storm events.

3.4.2 Simulation Scenarios

Simulations were run for a 30-year forecast period from 2023 to 2053. This corresponds to the time frame for meeting the canopy cover goals in the York Region Forest Management Plan. Simulations included the most common diseases and pests that are currently impacting the forest. Storm events were excluded due to uncertainty in mortality rates following different types of storms, the geographical extent of damage, and the frequency of storms. The effects of climate change were incorporated by increasing the growing season length which would impact the annual growth rate of trees.

Currently, the length of the frost-free season is 163 days (Climate Atlas, 2023). According to Historical and Future Climate Trends in York Region (Fausto, et al., 2015), the length of the growing season is expected to increase by approximately 30 days by the 2050s. Since only one value can be entered in into i-Tree Forecast, and because the length of the growing season will increase from 163 to 193 days, an average value of 178 days was used.

During the 2023 field season, the most commonly observed pests and diseases impacting Whitchurch-Stouffville were emerald ash borer (*Agrilus planipennis*), spongy moth (*Lymantria dispar dispar*), and beech bark disease (*Neonectria faginata*). Emerald ash borer arrived in Ontario in 2002 and has had devastating impacts on the ash population with near 100% mortality rates. Spongy moth has been a cyclical pest for decades and the most recent population outbreak peaked in the 2021 season with little damage observed in 2023. Beech bark disease has been in Canada since the 1890s, more recently moving into Ontario. It infects mature beech trees, causing severe dieback and often mortality. i-Tree Forecast only applies mortality rates to tree species impacted by the pest. Only pests that are known to occur in Whitchurch-Stouffville were considered in the i-Tree Eco model. Oak wilt (*Ceratocystis fagacearum*) crossed into Canada partway through the field season. Field staff were trained to identify signs and symptoms of oak wilt, but none were found. Asian long-horned beetle (*Anoplophora glabripennis*) was last found in Ontario in 2013 and is considered eradicated by the Canadian Food Inspection Agency (Natural Resources Canada, 2024). Hemlock woolly adelgid (*Adelges tsugae*), according to the Canadian Food Inspection Agency (2024), was found in the Niagara Peninsula but eradicated. However, it was recently observed in Hamilton, Haldimand County, Lincoln, and Port Colborne, Ontario, and is actively being managed. There is greater uncertainty as to when oak wilt, Asian long-horned beetle, and hemlock woolly adelgid may arrive and establish themselves, for how long and what impact they will have, hence, they were excluded. These pests and diseases should be considered in future iterations of the Forest Study.

Appendix C: Parameters Used for i-Tree Forecast summarizes the parameters used to set up i-Tree Forecast.

3.5. Soil

3.5.1 Background

Soil quality has been widely recognized in the literature and in strategic (urban) forest management guides and plans as a vital component and indicator of forest health. However, while regional forest management plans and assessments reference the need for high quality soil and sufficient soil quantity, they seldom provide guidelines beyond soil volume and the use of soil cells for street trees. To begin to address this gap, a baseline assessment of the physical and chemical soil properties across the study area was conducted as part of the Whitchurch-Stouffville Forest Study. The results can be used to inform future management decisions targeting forest enhancement and planting and provide an additional facet that can contribute to our understanding of the overall health of the forest.

Three soil properties indicative of soil health were measured for this study: compaction, salinity, and pH.

3.5.1.1. Compaction

Research by the United States Department of Agriculture (USDA) has shown that almost no roots can infiltrate soil with a penetration resistance (PSI) of 300 PSI or more (Duiker, 2002).

PSI values can be interpreted as follows:

- 0 – 200 PSI: uncompacted / good growing conditions,
- 201 – 300 PSI: moderately compacted / fair growing conditions, and
- > 300 PSI: highly compacted / poor growing conditions.

3.5.1.2. Salinity

Salts are chemical compounds which are made up of positively charged cations and negatively charged anions. Salts, in moderation, are good for plants as they provide key nutrients, and most fertilizers are salts. However, excessive salt can cause poor drainage, infiltration, structure, and toxicity to some plants (USDA, 2014). Salt concentrations in soil can vary greatly and are affected by several environmental factors including climate, local biota (plants and animals), bedrock and surficial geology, as well as human impacts on the land (e.g. road salt use in winter) (USDA, 2014).

3.5.1.3. pH

Like salinity, soil pH is affected by several environmental factors including climate, local biota (plants and animals), bedrock and surficial geology, as well as human impacts on the land. In general, pH readings between 1 and 6 are considered acidic, 7, neutral, and 8 to 14, basic. Soil pH directly impacts the growing abilities of plants, with most trees growing best in soils with a pH between 5.5 and 7.5 (Landscape Ontario, 2019).

3.5.2 Field Data Collection

The collection of soil data was an auxiliary assessment outside of the i-Tree Eco data collection. A protocol specific to soil collection was developed and an overview of the methodology is included as follows. Four measurements for compaction and salinity were taken in situ at each plot using a penetrometer and a probe, and pH measurements were attained by taking soil samples, which were submitted to ALS Environmental laboratory for analysis. The measurements were taken one metre around the centre of plots that had natural cover, were in parks or undeveloped. Staff avoided collecting samples near infrastructure, adjacent to trees or shrubs, or near development to reduce the risk of striking utility lines. Three soil samples for pH were obtained within the circle delineated by the in situ measurements. Samples were then mixed and sent to a lab as one average sample.

3.5.2.1. Compaction

Soil compaction was measured at four locations as described above using an analogue penetrometer. It was inserted into the soil to a depth of 6 to 10 inches. The field crew would record “uncompacted”, “moderately compacted”, or “highly compacted” according to the range of PSI values as mentioned above (subsection 3.5.1.1).

3.5.2.2. Salinity

Salinity was assessed indirectly by measuring electrical conductivity. Salt increases the ability of soil to conduct an electrical current, and therefore, electroconductivity can be used to infer salinity levels (Simons & Bennett, 2022; USDA, 2014). Electroconductivity is proportional to the total amount of salts present in a solution (it has been correlated to concentrations of nitrates, potassium, sodium, chloride, sulfate, and ammonia); however, it does not provide a direct measurement of specific ions or salt compounds. Generally, an electroconductivity of 1.0 mS/cm contains up to 1.0 gram of measured salts per 1 liter of water (Klaassen, 2012).

FieldScout electroconductivity meters and probes were used to measure electroconductivity in situ, and results were recorded on mobile devices using Survey123. Conductivity measurements are directly affected by temperature, however, the electroconductivity meter used for this study compensated for temperature. Conductivity is also impacted by moisture levels. To produce a consistent moisture level, distilled water was poured into the measurement location to reach a saturation point before inserting the electroconductivity probe approximately six inches into the ground. Trial experiments found it was difficult to consistently obtain depths of six inches or greater in compacted soils. Due to issues with one electroconductivity meter, some samples were collected and sent for lab analysis, to ensure enough salinity measurements were obtained for analysis.

3.5.2.3. pH

Three samples were taken by auger within the first 6 inches of the surface. They were mixed and sent for analysis at ALS Environmental. Permission to take soil samples was included in the permission letter given to private property owners.

3.5.3 Data Analysis Methods

Compaction, salinity, and pH were each analyzed separately and then compared with percentage dieback.

3.5.3.1. Compaction

Compaction levels were transformed to ranked values, 1, 2, and 3 corresponding with uncompacted, moderately compacted and highly compacted. These values were used to calculate an average compaction level per plot. Average compaction scores can be interpreted as follows:

- 1 – 1.75: Uncompacted
- 1.75 – 2.5: Moderately compacted
- >2.5: Highly compacted

The proportion of plots within each compaction category were calculated for the municipality, on public and private lands, forested and unforested plots, and across land use strata. Public lands included municipal, provincial, and conservation authority owned/managed lands. Land use strata were grouped into more general categories to ensure a sufficient sample size to lower uncertainty and perform statistical testing. Pearson's Chi-squared test was used to test if there were differences in the proportion of plots in each compaction category between groups, and the pairwise Wilcox test was used to identify which groups were different when there were more than two groups.

3.5.3.2. Salinity

Electroconductivity measurements per plot were screened for outliers. Outliers were removed before calculating an average electroconductivity score per plot. For the samples taken to ALS Environmental, a single measurement value was given per plot. Plot-level electroconductivity measures were used to calculate the mean, median, minimum, and maximum electroconductivity scores for the municipality, for public and private lands, and per stratum. Land use strata were grouped together to increase sample size when necessary.

The Wilcoxon rank sum test for non-normal data were used to test for statistically significant differences in electroconductivity between private and public lands, while the Kruskal-Wallis rank sum test for non-normal data was used to test for differences among land use strata.

3.5.3.3. pH

A single pH value was obtained for each plot from ALS Environmental. Eighty-one pH samples were obtained across Whitchurch-Stouffville and were used to calculate the average, median, minimum, and maximum pH for Whitchurch-Stouffville. A Wilcoxon rank sum test for non-normal data was used to test for a statistically significant difference in pH between public and privately owned plots, forested and unforested plots, and land use strata. Land use strata were grouped together to obtain a sufficient sample size to reduce uncertainty and allow for statistical testing.

3.5.3.4. Relationships between Soil Compaction, Salinity, pH, and Tree Condition

The relationship between soil compaction, electroconductivity, and pH and tree condition measured as percentage crown dieback were explored using correlation testing, scatter plots and linear regression. Where data were not bivariate normal Spearman's rho and Kendall's tau testing were used.

3.6. Invasive Species

3.6.1 Background

Collected separate to the i-Tree Eco data, the objective of the invasive species analysis was to evaluate degree and intensity of spread of invasive plants, pests, and diseases of concern across the municipality and different land use strata. To have a better understanding of the distribution and impact of invasive plant species and priority pests and diseases across Whitchurch-Stouffville, data about the presence or absence and extent of common invasive species was collected by the field crews as part of the Whitchurch-Stouffville Forest Study. The invasive species assessment was a supplementary survey outside of the i-Tree Eco data collection. Species of concern were identified based on the other York Region Forest Studies.

Potential future invasive insects and diseases such as oak wilt (*Ceratocystis fagacearum*), and spotted lanternfly (*Lycorma delicatula*) were not included in the priority list. At the beginning of the season, the above invasive insects and diseases had not been confirmed in Ontario and were not part of the formal field assessment protocol. By season's end, oak wilt had been confirmed three times and field staff were trained to identify its signs and symptoms, but no cases were found. Spotted lanternfly has not been confirmed in Canada, but it has the potential to harm the local forestry and agriculture industries. The insect prefers wineries and fruit orchards but also attacks a variety of other crops, landscape ornamentals and hardwood trees including black walnut, birch, and maple species. Table 8 below summarizes the invasive plants, pests, and diseases included in this study.

Table 8. List of invasive plants, pests, and diseases

Trees	Shrubs	Other Plants	Pests and Diseases
Norway maple *(Acer platanoides)*	European buckthorn (*Rhamnus cathartica*)	Goutweed (*Aegopodium podagaria*)	Asian long-horned beetle (*Anoplophora glabripennis*)
Manitoba maple *(Acer negundo)*	Morrow's honeysuckle (*Lonicera morrowii*)	Oriental bittersweet (*Celastrus orbiculatus*)	Spongy moth (*Lymantria dispar dispar*)
Callery pear (*Pyrus calleryana*)	Tartarian honeysuckle *(Lonicera tatarica)*	Wintercreeper euonymus (Euonymus fortunei)	Hemlock woolly adelgid (*Adelges tsugae*)
Ivory silk lilac (*Syringa reticulata*)	Shrub honeysuckle (*Lonicera x bella*)	Dog-strangling vine (*Cynanchum rossicum*)	Emerald Ash Borer (*Agrilus planipennis*)
Tree of heaven (*Ailanthus altissima*)	European fly honeysuckle (*Lonicera xylosteum*)	Lily of the valley (*Convallaria majalis*)	Beech bark disease (*Neonectria faginata*)
Black Locust (*Robinia pseudoacacia*)	Non-native honeysuckle spp.	Periwinkle (*Vinca minor*)	Beech leaf disease (caused by parasitic nematode *Litylenchus crenatae ssp. mccannii*.)
Black Alder (*Alnus glutinosa*)	European spindle-tree (*Euonymus europaeus*)	Himalayan Balsam (*Impatiens glandulifera*)	Dutch elm disease (*Ophiostoma ulmi*)
Winged spindle-tree (*Euonymus alatus*)		Garlic mustard (*Alliaria petiolate*)	
		Phragmites (*Phragmites australis*)	
		Wild parsnip (*Pastinaca sativa*)	
		Japanese knotweed (*Reynoutoria japonica*)	

3.6.2 Field Data Collection

At each plot, staff noted the presence of the invasive species listed in Table 9. If a species was present, a score was assigned based on the degree of spread in Survey123. Degree of spread was measured differently for plants, pests, and diseases and is further described below.

3.6.2.1. Scoring level of spread for plant species

Field crews recorded the degree of invasion for each plant using an ordinal or ranked system where 1 was the least amount of spread and 4 was the most. A definition for each is provided in Table 9. The scoring system was based on the one used for 2018 Toronto Canopy Study and is consistent with other York Region forest studies.

Table 9. Degree of spread scoring system for invasive plants

Score	Definition	Detailed Description
1	1 to 2 patches of the invasive plant	• Trees: 1 or more trees that are adjacent to each other, or 1 or 2 patches of adjacent seedlings/saplings • Shrubs: 1 or more shrubs that are adjacent to each other, or 1 or 2 patches of seedlings/saplings • Ground cover / Vine: 1 to 2 patches of adjacent plants 1 to 2 patches have maximum size: 0 – 25% of plot (or a circle with a max diameter of 11.35 m)
2	3 or more scattered pockets	There are 3 or more than patches and together they cover 0 – 49% of plot
3	A blanket effect	Pervasive spread: 50 – 100% plot cover
4	An extensive blanket effect within the plot and the surrounding area	50% - 100% within plot and continues into surrounding area.

Note: The area of invasive cover pertains only to the pervious area; For example, a plot could be 60% impervious while 100% of the pervious area is filled with an invasive plant. In that case it would be assigned to a level 3.

3.6.2.2. Scoring pest and disease spread

The field crew recorded the distribution of symptoms/damage caused by each of the listed pests/diseases, using a numbered ranking system:

- 1: presence of a pest symptom/damage on 1-3 trees
- 2: presence of a pest symptom/damage on 4-6 trees

- 3: presence of a pest symptom/damage on 7 or more trees

The field crew recorded the distribution of each of the pests (insects), using a numbered ranking system:

- 1: presence of a pest/larvae/egg/caterpillar on 1-3 trees
- 2: presence of a pest/larvae/egg/caterpillar on 4-6 trees
- 3: the presence of a pest/larvae/egg/caterpillar on 7 or more trees

3.6.3 Data Analysis Methods

Invasive species, pests and diseases were each analyzed separately by considering presence and degree of spread.

3.6.3.1. Presence

Invasive species presence was determined by calculating the percent of plots, on which data was collected, that have at least one invasive plant, pest or disease present across the municipality and each land use stratum. Each land use stratum has an attributed percentage for plots affected with an invasive plant, pest, or disease species. Each invasive species also had a percentage of presence by stratum. To assess co-invasion of invasive plants, an average number of invasive plant species was calculated for plots with at least one invasive plant species present. The results were tabulated by land use and utilized to develop figures and table statistics.

3.6.3.2. Degree of spread

Using the scores attributed to each category of spread, the average spread was calculated for each plant species, pest and disease across the municipality and each land use stratum for plots invaded.

3.6.3.3. Combined invasion score for plants

A combined invasive score which indicated the overall level of invasion was calculated by multiplying the average number of species by the average degree of spread for the municipality as a whole and each land use stratum.

3.7. Climate Vulnerability

The climate vulnerability of the top twenty most frequently occurring tree species was assessed. The approach for the climate vulnerability assessment follows the methods used to prepare the Peel Region Urban Forest Best Practice Guides, Guide 4: *Potential Street and Park Tree Species for Peel in a Climate Change Context* (Peel Climate Change Partnership (PCCP), 2021b) and is consistent with climate change adaptation frameworks developed by Gleeson, Gray, Douglas, Lemieux, & Nielsen (2011), Glick, Stein, & Edelson (2011), and Ordó?ez & Duinker (2015).

3.7.1 Background

One of the priority action's put forward to foster community resiliency as part of York Region Climate Change Action Plan (2022), is to conduct a vulnerability assessment on natural systems. Therefore, conducting a vulnerability assessment of York Region's forest can contribute to this action and help better understand the expected impacts of climate change on the forest and inform adaptation.

3.7.2 Emissions Scenario and Timing Window

The emissions scenario used for the Whitchurch-Stouffville climate vulnerability assessment was RCP 8.5 (AR5) – the "worst case" scenario based on "business as usual" – from the Intergovernmental Panel on Climate Change's fifth assessment report (IPCC, 2013). York Region's *Historical and Future Climate Trends* (Fausto, et al., 2015) and Peel Region Urban Forest Best Practice Guides, Guide 4: *Potential Street and Park Tree Species for Peel in a Climate Change Context* (Peel Climate Change Partnership (PCCP), 2021b) also use RCP 8.5 (AR5). Under this climate scenario, both York Region and Peel Region are projected to have similar climatic changes. It would be useful to use the more recent climate scenarios developed in the Intergovernmental Panel on Climate Change's sixth assessment report, the shared socioeconomic pathways, which account for different levels of policy intervention (Climate Data Canada, 2023). However, this was out of the scope for this project, so the methods from Peel Region using RCP 8.5 were used.

The time window for the assessment is 2041-2070, also known as the near future or 2050s. This time period is most suitable for forest planning in the next 30 years. It also aligns with the time frames used in York Region's *Climate Change Action Plan* (2022) and *Historical and Future Climate Trends* (Fausto, et al., 2015) and the Peel Best Practice Guide 4 ("the Guide") (Peel Climate Change Partnership (PCCP), 2021b).

3.7.3 Near Future Climate and General Impacts on Whitchurch-Stouffville's Forest

According to *Historical and Future Climate Trends in York Region* (Fausto, et al., 2015), under RCP 8.5 conditions (business as usual scenario), the following climatic changes are anticipated in the years 2041 to 2070, all of which will impact the development of the Whitchurch-Stouffville forest:

- Minimum and maximum temperatures are expected to increase significantly across all seasons and annually. This will increase the range of tree species northwards. Species that are already at their southerly extent are likely to shift northwards and become rare or extirpated. Species typically present further south are likely to establish themselves. Additionally, warmer temperatures will impact the population, survival rate, and distribution of invasive pests and diseases.
- Precipitation is expected to increase annually in all seasons except summer when it is expected to remain the same or possibly decrease. Similar or decreasing rainfall in combination with hotter temperatures is expected to result in drier conditions in the growing season. This will cause stress for many species which are less drought tolerant.
- Extreme precipitation events will become more frequent and severe, particularly in summer and will increase tree damage and mortality. For example, the windstorm event of May 21st, 2022, caused widespread, intense damage to trees and property across much of Southern Ontario.
- The quantity of extreme heat days will increase significantly, while extreme cold days will decrease. The increase in extreme heat days will increase stress on many species, particularly those on the southern end of their range.
- The length of the growing season will increase by over 30 days by the 2050s and the season will start earlier and end later. The growth of trees will accelerate, although this will be countered by less water availability.

3.7.4 Assigning a Vulnerability Score

A vulnerability score was assigned to the top twenty most abundant tree species in Whitchurch-Stouffville based on their exposure and sensitivity to climate change using the methods and values developed in the Guide[12] (Peel Climate Change Partnership (PCCP), 2021b). Exposure

[12] Note that there are other assessments for tree species vulnerability availability in Ontario. These may use different future climate scenarios and criteria or methods to assess exposure and sensitivity. For example, the NatureServe Climate Change Vulnerability Index is another tool used in the Greater Toronto Area and beyond. This tool assess sensitivity based on genetic variability, dependence on other species, sensitivity to pathogens/pests, and other factors. The choice of climate scenario and criteria can change how the vulnerability score assigned to different species. For this study, we opted to use the Guide because it aligned with the climate scenario used in York Region's *Draft Climate Change Action Plan* (2022) and *Historical and Future Climate Trends* (Fausto, et al., 2015), its application to a wide range of species, and the use of a climate dependent sensitivity criteria. For more information, Credit

refers to how much a species will be exposed to the impacts of climate change (such as high temperatures, extreme weather events, droughts), and sensitivity refers to the inherent characteristics or traits of species that make them more susceptible to climate change.

In the Guide, a combined vulnerability score was calculated for 88 tree species based on the likelihood of the species' exposure to climatic stress and the species' sensitivity to drought as follows:

3.7.4.1. Exposure to Climate Change

- Trees were considered exposed if climate change would result in them occurring outside of their ideal range as determined by their climate envelope. Species which occur in areas with low climate suitability in the near future will experience climatic stress.
- The Guide classified tree species as likely to have high, moderate, or low exposure to climatic stress as follows:
    - High: species for which climatic suitability declines within Peel; area of suitable habitat in Peel is less than 20%
    - Moderate: species with some loss in climatic suitability within Peel; area of suitable habitat in Peel does not fall below 20%
    - Low: species with no future loss or with a gain in climatic suitability within Peel Region; area of suitable habitat is more than 20%

3.7.4.2. Sensitivity to Drought

- The Guide classified species as having low, moderate, or high sensitivity to drought based on existing resources documenting drought tolerance.
- Niinemets and Valladares' (2006) five-level scale for assessing drought tolerance based on the geographical areas where species occur was used in the Guide to assign a drought sensitivity score. The Niinemets and Valladares numeric scale was converted to categorical values as follows:
    - High: 1 to 2.19
    - Moderate: 2.20 to 3.39
    - Low: values greater than 3.4

Valley Conservation's (2023), *Climate change vulnerability of treed habitats in the Credit River Watershed*, Appendix E, contrasts vulnerability scores of common climate vulnerability assessments.

3.7.4.3. Combined Vulnerability Score

- The Guide calculated a combined vulnerability score based on exposure and vulnerability as follows:
  - Extreme: high in climate exposure and drought sensitivity
  - High: high ranking of either climate exposure or drought sensitivity
  - Moderate vulnerability: two moderate rankings or one moderate and one low ranking of either climate exposure or drought sensitivity
  - Low vulnerability: low sensitivity to drought and low climatic exposure

The list of the top 20 most abundant species in Whitchurch-Stouffville was cross-referenced with the calculated vulnerability scores for the species list from the Guide. Vulnerability ratings from the Guide were used to assign vulnerability scores to each of the top species across Whitchurch-Stouffville (Table 26) in Section 4.8. Any tolerances, sensitivities, and risks identified for each species in the Guide were noted in Table 28 for the top five species.

The Guide used the Intergovernmental Panel on Climate Change scenario RCP8.5 as the climate model for future conditions to set the vulnerability levels for each species. This is the "worst case" scenario of the RCP scenarios created by the Intergovernmental Panel on Climate Change, but it is not most recent model available anymore. The Intergovernmental Panel on Climate Change has since come out with the "Shared Economic Pathways" scenarios that focus on the policy interventions that will influence the future climate (IPCC, 2023). It may be beneficial to invest in a report on the vulnerability of species based on these new scenarios, but this current report is limited to the Peel Region Guide.

3.7.5 Development of Impact Statements

Impact statements identifying how climate stressors are expected to affect the entire forest and the top five most abundant species growing across Whitchurch-Stouffville were developed using the "If-Then-So" method – a qualitative approach used in traditional risk-based assessments. The method requires the following questions to be answered:

- **If** expected changes in the future climate were to occur, including acute shocks (e.g., more extreme weather events) and chronic stresses (e.g., hotter, drier summers),
- **Then** what outcomes/impacts on the urban forest as a whole and individual species would be expected?
- **So,** what are the consequences of those outcomes/impacts (including strategic, financial, operational, environmental, public perception, and safety)?

3.8. Whitchurch-Stouffville Tree Planting Parameters

3.8.1 Planting programs

Most tree plantings completed by the Town will occur on boulevard or in parks and will be 40-60 mm caliper sized stock. Approximately 300-400 trees are expected to be planted each year, according to Town representatives (Table 10).

The above was used to extrapolate planting parameters per land use stratum.

Table 10. Tree planting simulation parameters for current annual rate of planting in Whitchurch-Stouffville

Stratum/Strata	Annual Planting Rate	Diameter at planting	Start	Duration (years)	Comments
Other Urban	200 / year	4 cm	2023	30	Planting completed by the Town of Whitchurch-Stouffville along boulevards.
Open Space – Natural Cover	200 / year	4 cm	2023	30	Plantings across park lands completed by the Town.

Note: These numbers were provided by the Town of Whitchurch-Stouffville.

4.0 Results

4.1. Canopy Distribution

The 2022 canopy cover analysis found that approximately 8,097 ha or 38.9% of Whitchurch-Stouffville's land area is covered by trees and tall shrubs[13] (termed existing canopy), while impervious surfaces, which include roads, buildings, and other paved surfaces, represent approximately 4.8% of the land area. The remaining 56% includes grass, smaller shrubs, and bare ground (Figure 5, Figure 7).

At 38.9% canopy cover, Whitchurch-Stouffville is just below the 40-45% canopy cover range recommended in the York Region Forest Management Plan (2016). Whitchurch-Stouffville's woodland cover is 30.9%, within the recommended 30-32% target (York Region, 2021).

Due to differences in methodology, a change assessment cannot be accurately completed to compare previous canopy cover with the current report (Timmins & Sawka, 2022). In the past assessment, i-Tree Canopy was used to estimate canopy cover. The overall canopy cover was estimated as 36.9% (±1.58) in the 2017 forest study report, suggesting an increase of about 2% between 2016 and 2020 (Lake Simcoe Region Conservation Authority, 2017). However, the change may be due to standard error and may not reflect a true change in canopy cover.

A total of 57.6% (11,943 ha) of the Town's land area could theoretically support future canopy (Figure 6). Within the possible canopy category, 56.3% (11,669 ha) of the municipality is possible vegetated canopy and another 1.3% (275 ha) is possible impervious canopy. It is worth noting that these quantities do not consider that some asphalt, concrete, or bare soil surfaces may already be approved for development. Detailed canopy cover and land cover metrics (areas and percentages) for Whitchurch-Stouffville can be found in Appendix B: Land Cover and Canopy Cover Metrics for Whitchurch-Stouffville and MPAC Land Uses.

[13] Tall shrubs are not distinguishable from trees due to their height. They are approximately 2 metres or taller.

Lake Simcoe Region conservation authority

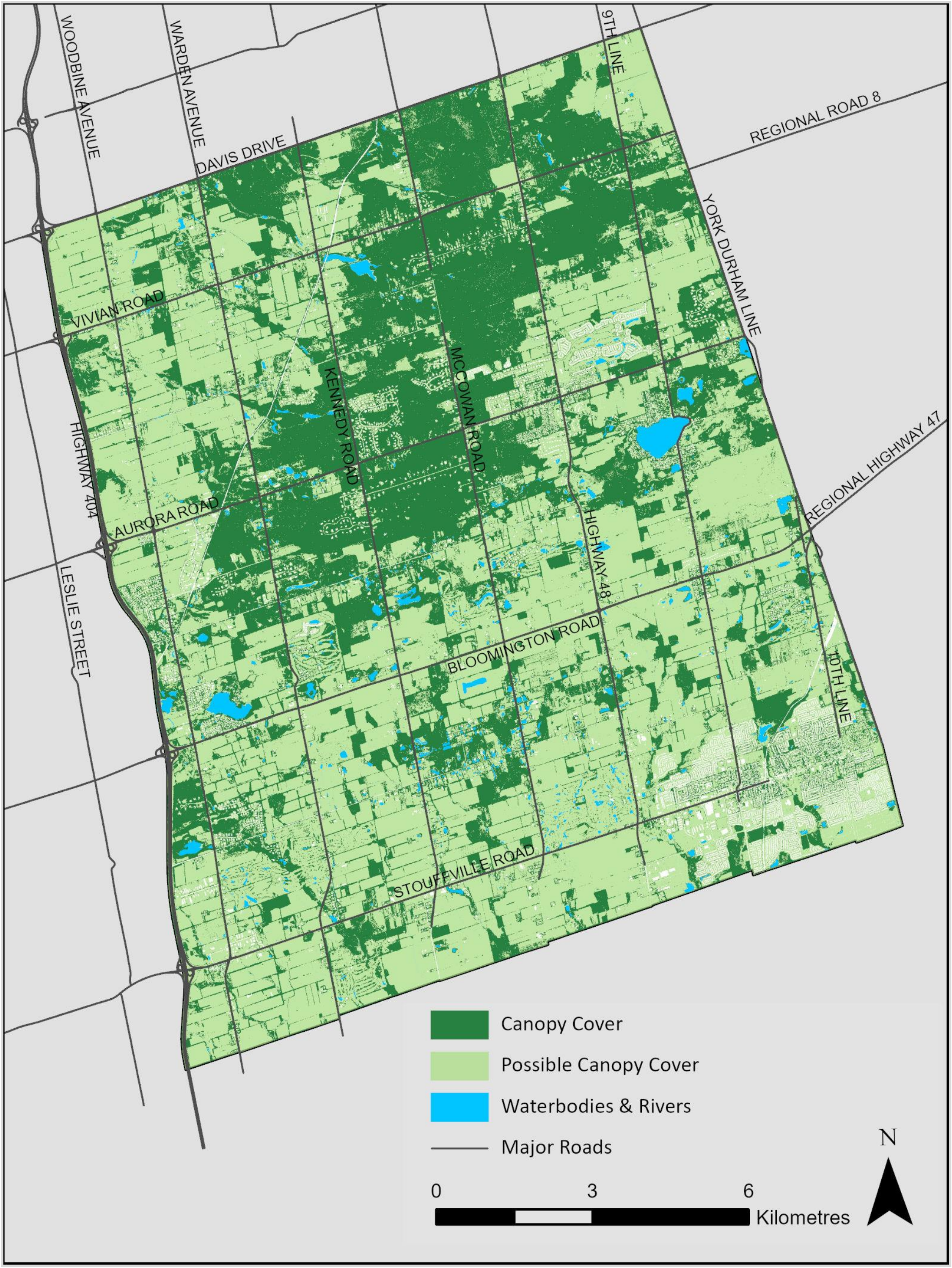


Figure 5. Distribution of existing and possible vegetated canopy cover across Whitchurch-Stouffville

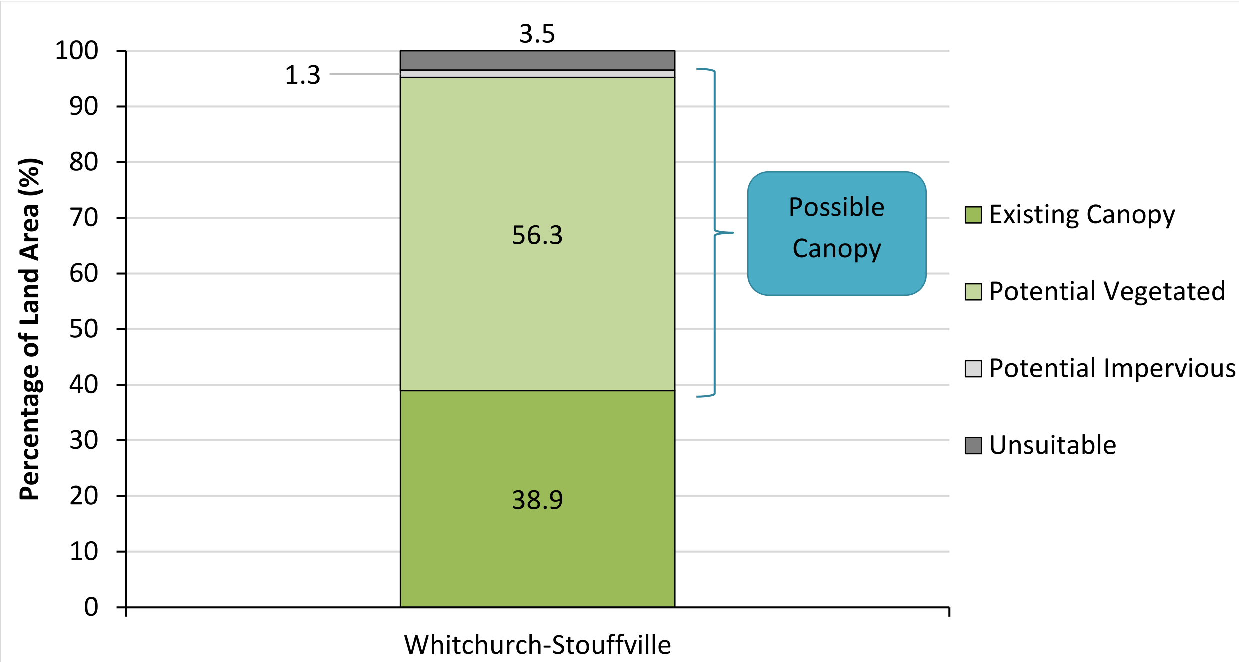


Figure 6. Canopy cover metrics for Whitchurch-Stouffville

4.1.1 Canopy Cover and Plantable Space by MPAC Land Use Type

Canopy cover metrics were also calculated for each MPAC land use type. As noted in Section 3.2.2, land use changes have occurred since 2016 (the date of land use designation by MPAC); results summarized by land use should be viewed as approximate totals. Figure 2 summarizes the proportion of each land use type within Whitchurch-Stouffville. The *Agriculture* category occupies the greatest proportion of area in Whitchurch-Stouffville at 46.5%, followed by *Residential Low* at 20.4%. Appendix B: Land Cover and Canopy Cover Metrics for Whitchurch-Stouffville and MPAC Land Uses provides a summary of land cover and canopy cover metrics for Whitchurch-Stouffville and per MPAC land use type.

The distribution of canopy cover varies across the MPAC land uses in Whitchurch-Stouffville. Table 11 provides a breakdown of how much each land use category contributes to overall canopy cover and the canopy cover percent within each land use type. These values are illustrated in Figure 7 and Figure 8. The greatest proportion of the existing canopy cover is found in *Agriculture* which contains 2,439 ha of tree canopy or 30.1% of Whitchurch-Stouffville's total canopy area. *Residential Low* is the second biggest contributor of canopy cover at 28.6%. The next largest is *Other* with 20.7%. The rest each have less than 5%, in decreasing order of *Natural Cover, Commercial, ROW, Open Space, Residential Medium / High, Industrial, Utilities & Transportation*[14], and *Institutional*.

Table 11. Canopy cover metrics by MPAC land use categories

MPAC Land Use	Contribution to Total Canopy Cover (%)	Canopy Cover (hectares)	Canopy Cover of Land Use (% of Land Area)
Agriculture	30.2	2,439	24.8
Residential Low	28.6	2,312	53.6
Other	20.8	1,680	66.4
Natural Cover	9.7	782	77.2
Commercial	4.6	373	51.0
ROW	2.7	219	17.3
Open Space	2.4	191	20.5
Residential Medium / High	0.2	38	50.0
Industrial	0.3	24	8.7
Utilities & Transportation	0.3	23	33.6
Institutional	0.2	16	14.7
Whitchurch-Stouffville	**100**	**8,097**	**38.9**

Understanding the distribution of canopy cover is important, but another key component is understanding the distribution within land uses to guide management decisions. Twenty-five percent of the *Agriculture* category land area is made up of canopy cover, whereas the *Natural Cover* category has a canopy cover of 77%. However, due to the relative size of the latter land use (4.8% of municipal area), canopy within the *Natural Cover* category represents only 12.5% of the municipality's total canopy cover area, contributing 782 hectares. The *Other* land use accounts for almost 21% of total canopy cover and 66% of its land area has canopy cover. *Other* consists largely of vacant lands, often slated for development, so its large contribution to canopy cover is important considering the lack of protection to these lands. Existing canopy cover percent is lowest in the *Industrial* land use category, with only 9%.

[14] *Utilities and Transportation* excludes ordinary rights-of-way and is comprised of large infrastructure projects such as power stations, airports, public transportation-easements, and railways.

4.1.2 Potential Canopy Cover

The greatest opportunity to increase municipal canopy is found in the *Agriculture* land use category. Twenty-eight percent of land use land area (approximately 5,854 ha) of the *Agriculture* category is classified as possible vegetated canopy cover, and an additional 1,381 ha (6.7%) is classified as possible canopy cover on impervious surfaces. However, possible canopy considers only the physical requirements of tree planting and not the social or economic expectations for each land use. It is unlikely that most of this area can be planted with trees, since it is being used for agriculture fields, although there are opportunities to plant windbreaks around fields.

The Residential Low land use category has the second highest possible canopy cover, with 1,626 ha available for canopy. The *Other* land use category also maintains a large proportion of land available for tree establishment; 762 hectares in *Other* are classified as possible canopy (Figure 7). It will be important to ensure that development guidelines allow for tree planting and maintaining of pervious surfaces, since the *Other* land use category includes vacant lands slated for development. Approximately 44% and 83% of *Commercial* and *Industrial* land use categories, respectively, were classified as possible canopy cover (both impervious and pervious), a cumulative total of 543 ha (Figure 7, Figure 8). Although establishing tree canopy on impervious surfaces is more challenging than on pervious cover, it would reduce the heat transfer from such surfaces and the volume of storm water runoff. Only impervious surfaces such as bare soil, concrete, and asphalt that could theoretically be planted in the future are included as possible impervious canopy cover.

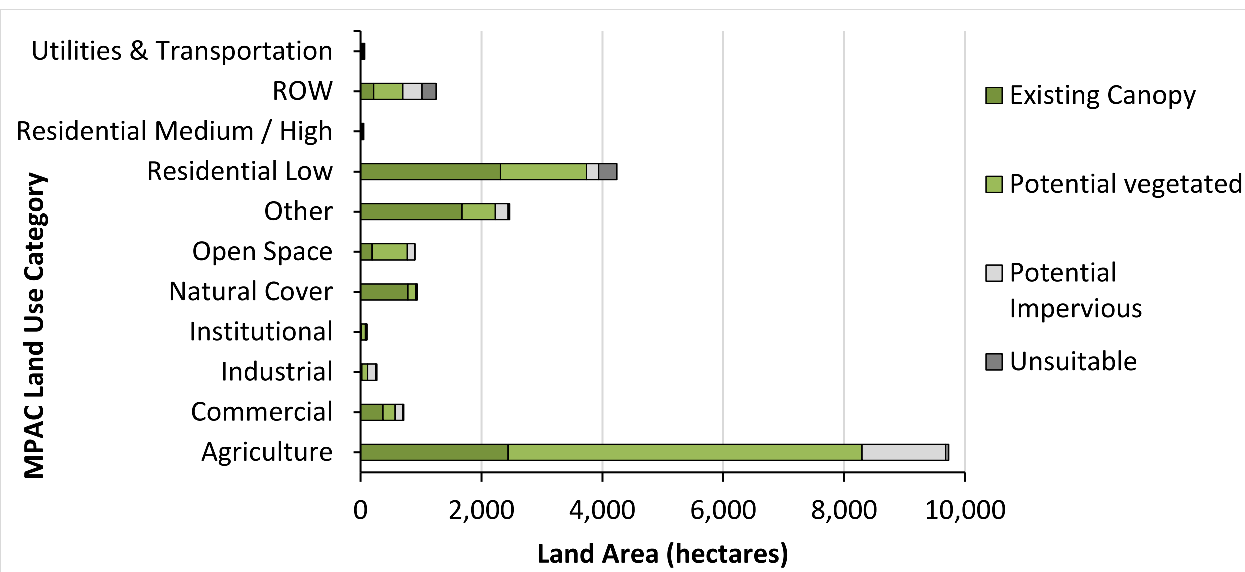


Figure 7. The distribution of existing canopy cover, possible vegetated cover, and possible impervious canopy cover measured in hectares within MPAC land use type

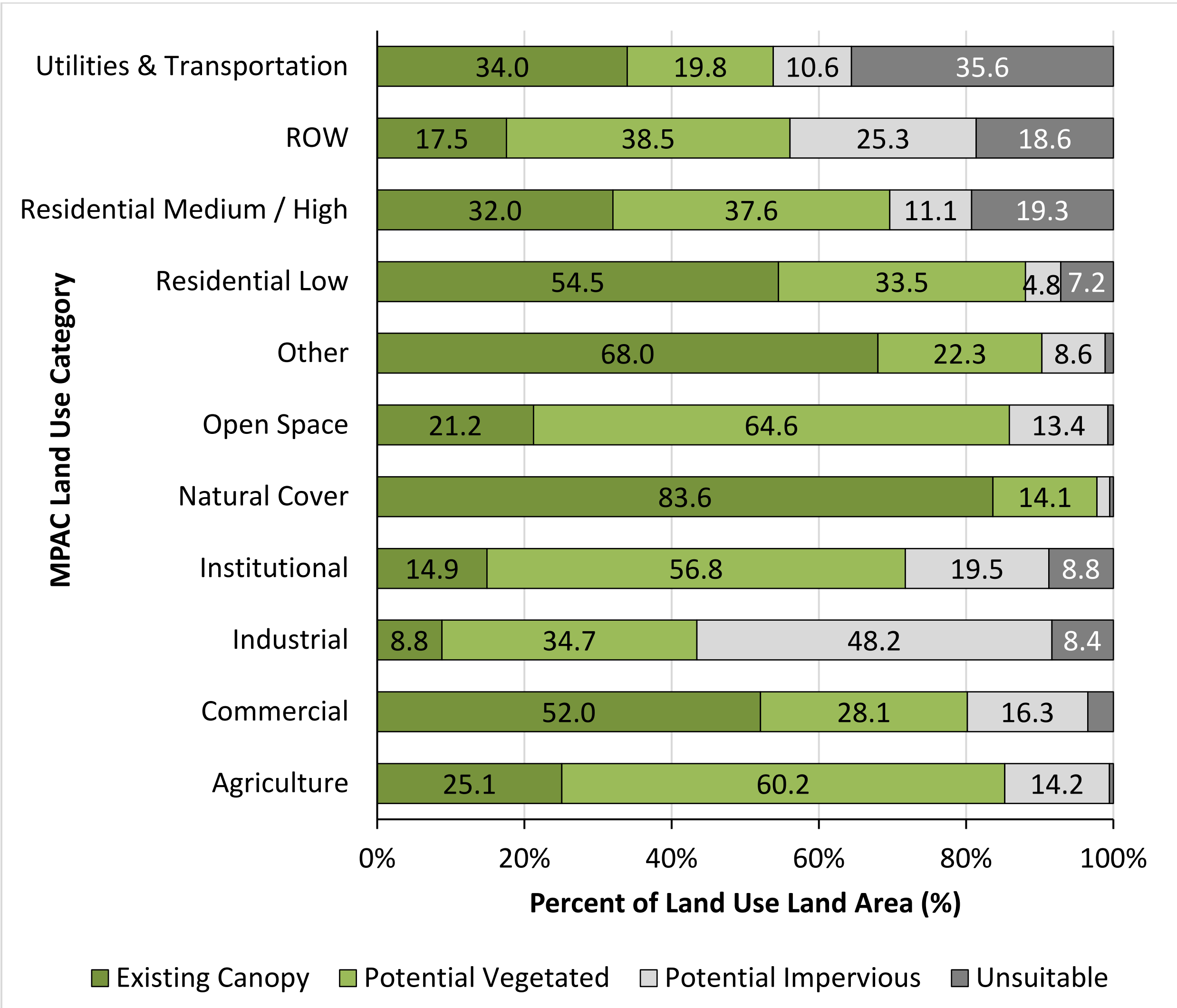


Figure 8. The distribution of existing canopy cover, possible vegetated cover, and possible impervious canopy cover as a percent of land use land area within MPAC land use type

4.2. Forest Structure

4.2.1 Structure

The i-Tree Eco model determined that there are approximately 6,100,000 (±655,195) trees in Whitchurch-Stouffville. The average tree density in Whitchurch-Stouffville is 289 trees/ha, which is significantly above average for the Greater Toronto Area[15] of 205.5 trees/ha, considering municipalities with available data. In terms of land use and tree density, Whitchurch-Stouffville is most similar to the Town of King. The *Other*[16] *– Institutional* land use stratum has the highest tree density at 533.9 trees/ha, followed by *Residential* (397 trees/ha) and *Natural Cover – Open Space* (322.8 trees/ha) (Figure 9).

[15] Tree densities (/ha) from recent i-Tree Eco studies in the Greater Toronto Area: Ajax (2023): 134; Aurora (2023:): 169; Bolton (2011): 185; Brampton (2011): 134; Caledon East (2011): 633; East Gwillimbury (2017): 136; Georgina (2017): 181; Markham (2022): 155; Richmond Hill (2022): 291; Mississauga (2011): 71; King (2023): 285; Newmarket (2016): 77; Pickering (2012): 354; Whitchurch-Stouffville (2017): 119; Toronto (2018): 162; Vaughan (2023): 202.

[16] The *Other* land use is a mixed category comprised largely of lands zoned as vacant residential land, recreational/non-commercial sports complexes, and common land (as of 2016 and therefore may be out of date).

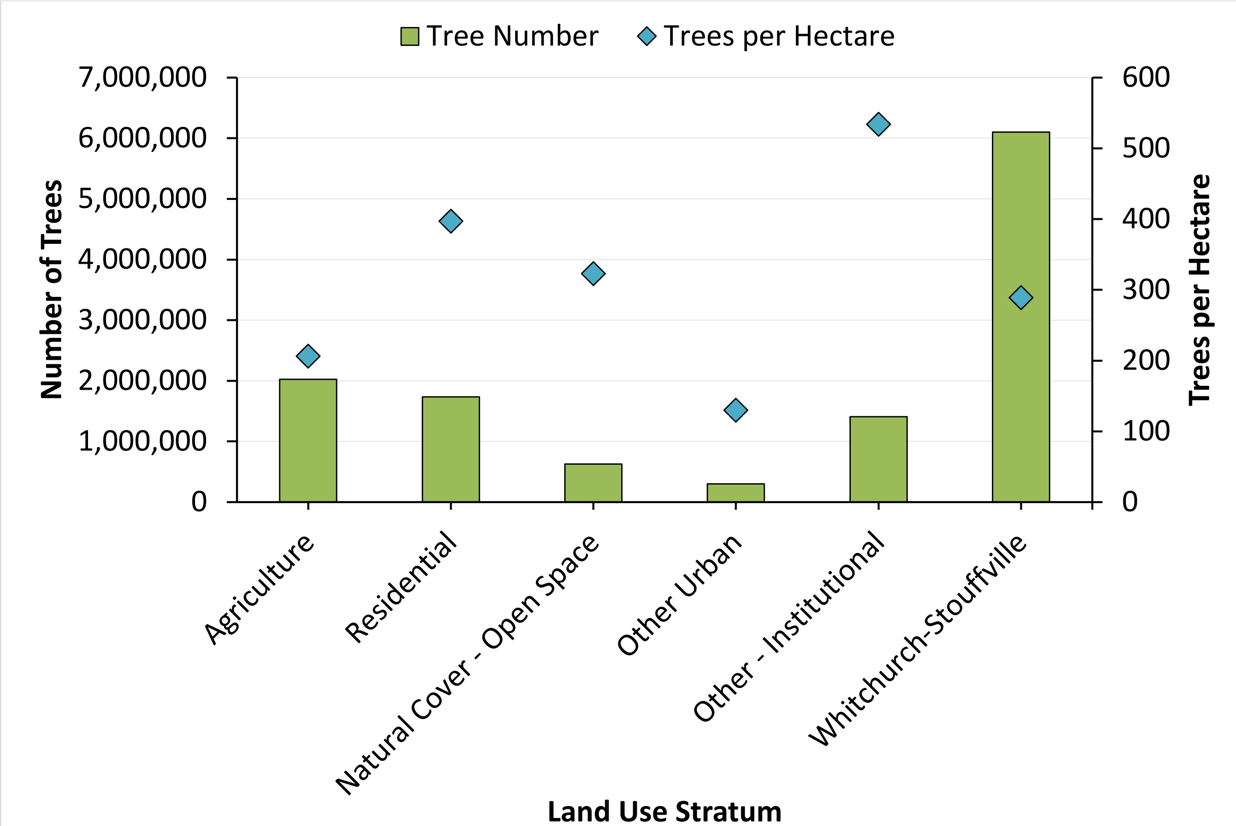


Figure 9. Total number of trees and tree density (trees per hectare) summarized by land use stratum in Whitchurch-Stouffville

Leaf area in Whitchurch-Stouffville is approximately 61,820 hectares (±6,959.4 ha) across a municipal area of 20,640 hectares. Therefore, the mean leaf area density (of trees) in Whitchurch-Stouffville is approximately 29,275 m^2/ha (±3,296 m^2/ha). This can also be expressed as 2.93 m^2 of leaf area for every 1.0 m^2 of land area (±0.33 m^2/m^2). This is slightly above the average for other municipalities in the Greater Toronto Area[17], which is 1.71 m^2/m^2. Leaf area density varies widely between land uses and is concentrated in the *Residential* and *Agriculture* strata (Figure 10, Table 12); these land uses represent 67% of the total area in Whitchurch-Stouffville. Leaf area density is lowest in the *Other Urban* land use stratum.

[17] Leaf area densities (m^2/m^2) from recent i-Tree Eco studies in the Greater Toronto Area: Aurora (2022), 1.53; King (2022), 2.52; Markham (2022), 1.12; Richmond Hill (2022), 1.77; Vaughan (2023), 1.63.

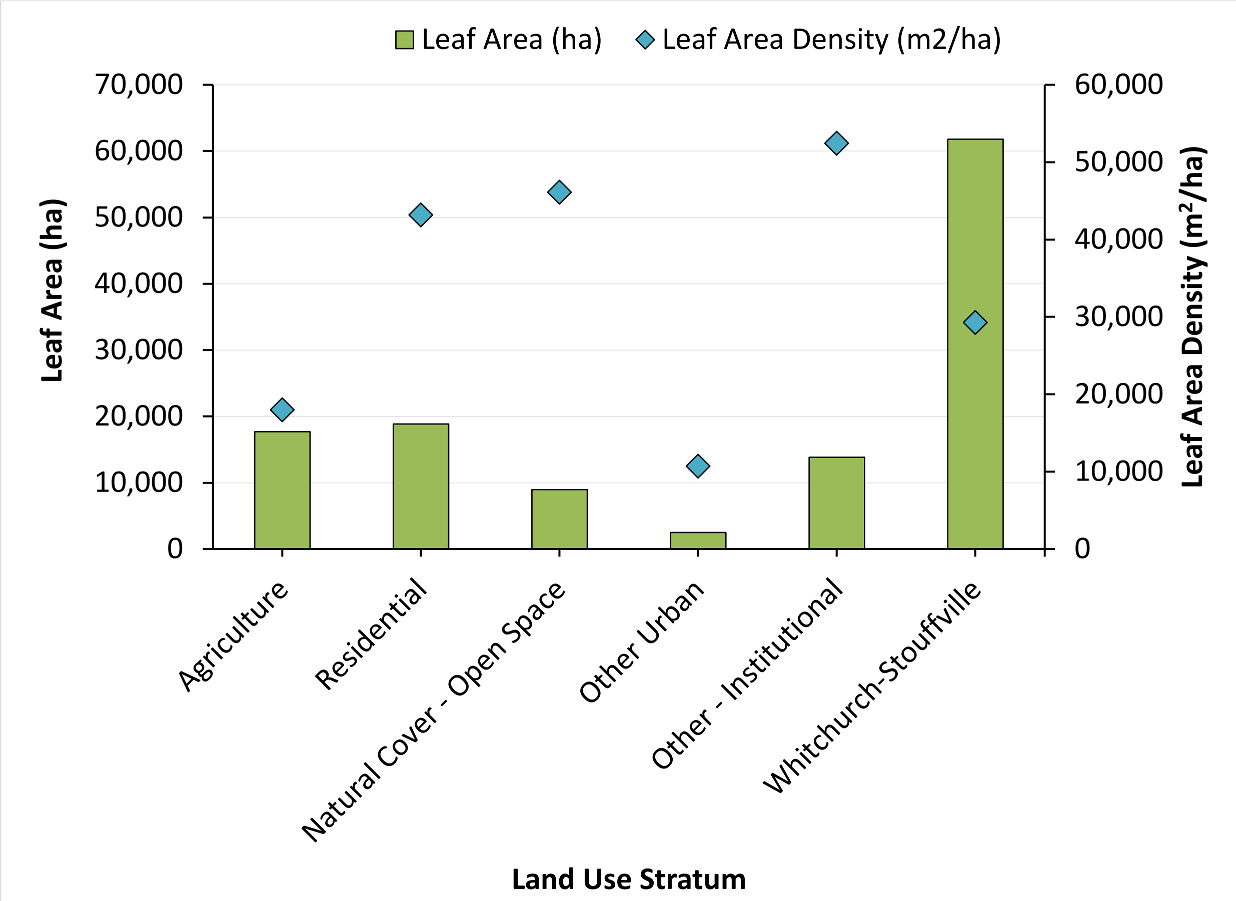


Figure 10. Leaf area (ha) and leaf area density (m^2/ha) by land use stratum in Whitchurch-Stouffville

Table 12. Summary of structural metrics per stratum

Stratum	Number of Trees	Trees per Hectare	Leaf Area (ha)	Leaf Area Density (m^2/ha)
Agriculture	2,027,153	206.2	17,673.59	17,981.25
Residential	1,733,562	397.0	18,851.00	43,167.24
Natural Cover – Open Space	628,183	322.8	8,972.42	46,101.80
Other Urban	303,203	129.7	2,501.91	10,704.44
Other – Institutional	1,407,522	533.9	13,816.44	52,412.82
Whitchurch-Stouffville	**6,099,623**	**288.9**	**61,815.36**	**29,274.97**

4.2.1.1. Public and Private Trees

Twenty-one percent (±4.7%) of the tree population occurs on public lands, such as municipal parks, rights-of-way (ROWs), protected areas, and conservation authority lands and 79% (±10.6%) of trees are privately owned. The *Other and Institutional* land use stratum has the greatest proportion of public trees at 55.9% of trees in that stratum and contains 60.4% of all public trees.

4.2.2 Composition

Species composition can be expressed either as a percent of total leaf area[18] or as a percent of the total number of trees. Composition expressed as a percent 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).

The relative abundance of species varies on whether species composition is expressed as percent of the total number of trees or percent of leaf area. When the leaf area is used, species that maintain a smaller growth form and that grow in high densities, such as European buckthorn (*Rhamnus cathartica*), tend to dominate total species composition. As shown in Figure 11, the top three most abundant species by number of trees is eastern white cedar (*Thuja occidentalis*, 18.5%), sugar maple (*Acer saccharum*, 16.1%), and European buckthorn (*Rhamnus cathartica*, 6.2%), while the most abundant species in terms of leaf area, as shown in

[18] Leaf area is defined as the total surface area (one-sided) of tree leaves. It is not equivalent to canopy cover which is the area of ground covered by canopy as viewed from directly above. Leaf area is much larger than canopy cover.

Figure 12, are sugar maple (*Acer saccharum*, 35.8%), eastern white cedar (*Thuja occidentalis*, 11.0%), and northern red oak (*Quercus rubra*, 4.3%).

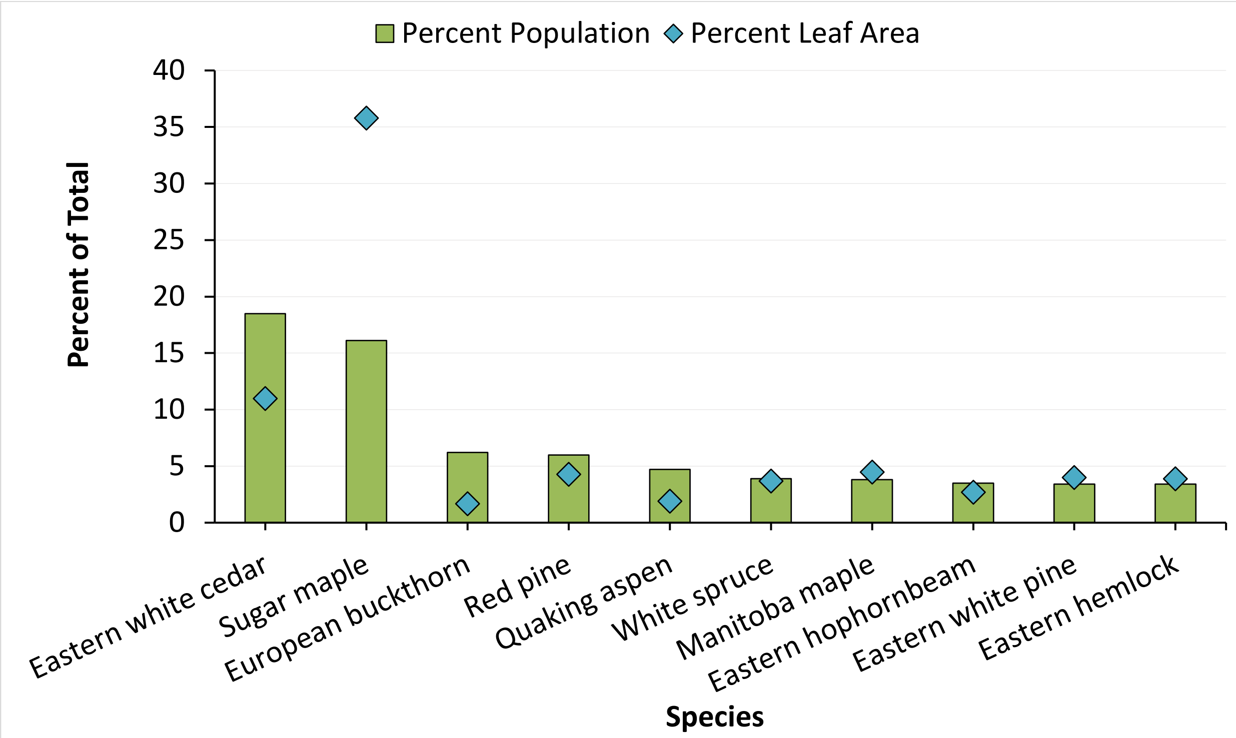


Figure 11. Ten most abundant tree species by percent of trees

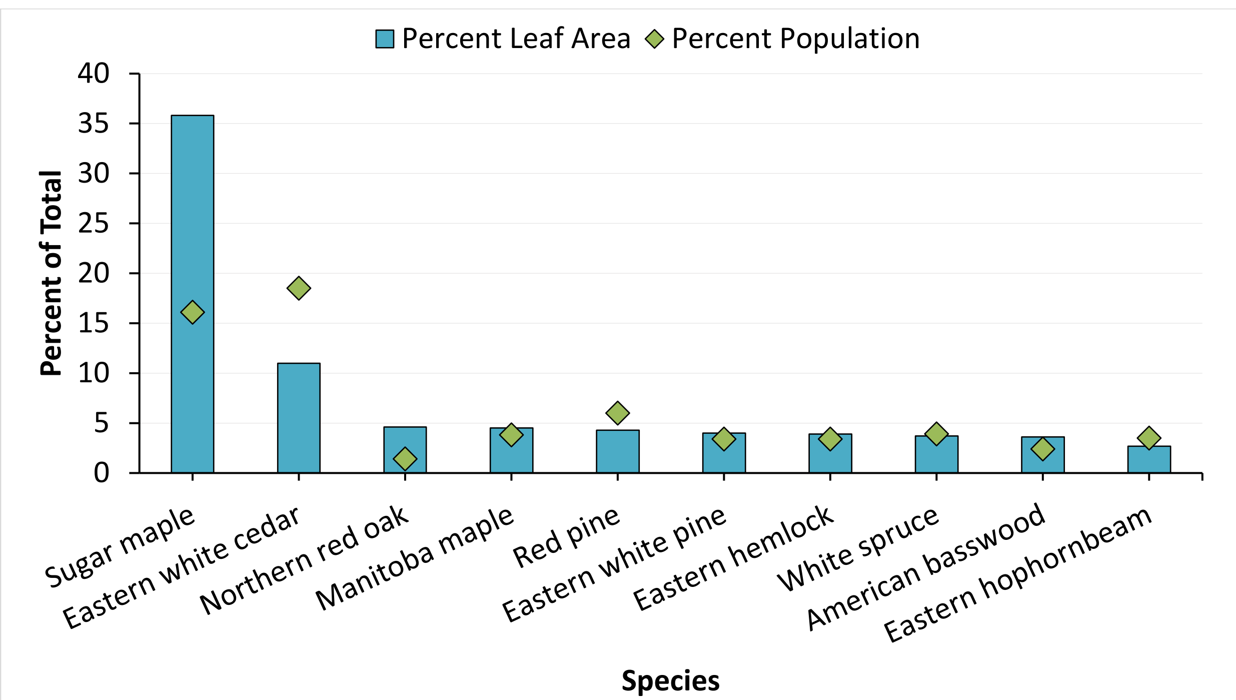


Figure 12. Top ten most abundant tree species by leaf area

In addition to species dominance, several genera and sub-families dominate Whitchurch-Stouffville's forest (Figure 13). Maples (*Acer spp.*, 21.9%), cedars and junipers (*Cupressoideae* sub-family, 18.7%, predominantly eastern white cedar), pines (*Pinus spp.*, 11.7%), European buckthorn (*Rhamnus spp.*, 6.2%, comprised only of European buckthorn), ash (*Fraxinus spp.*, 6.1%), and poplars (*Populus spp.*, 5.3%) were the most common subfamily and genera in the municipality in terms of tree population. Species dominance also varies by land use as summarized in Table 13. A total of 79 tree species were identified across all plots in Whitchurch-Stouffville.

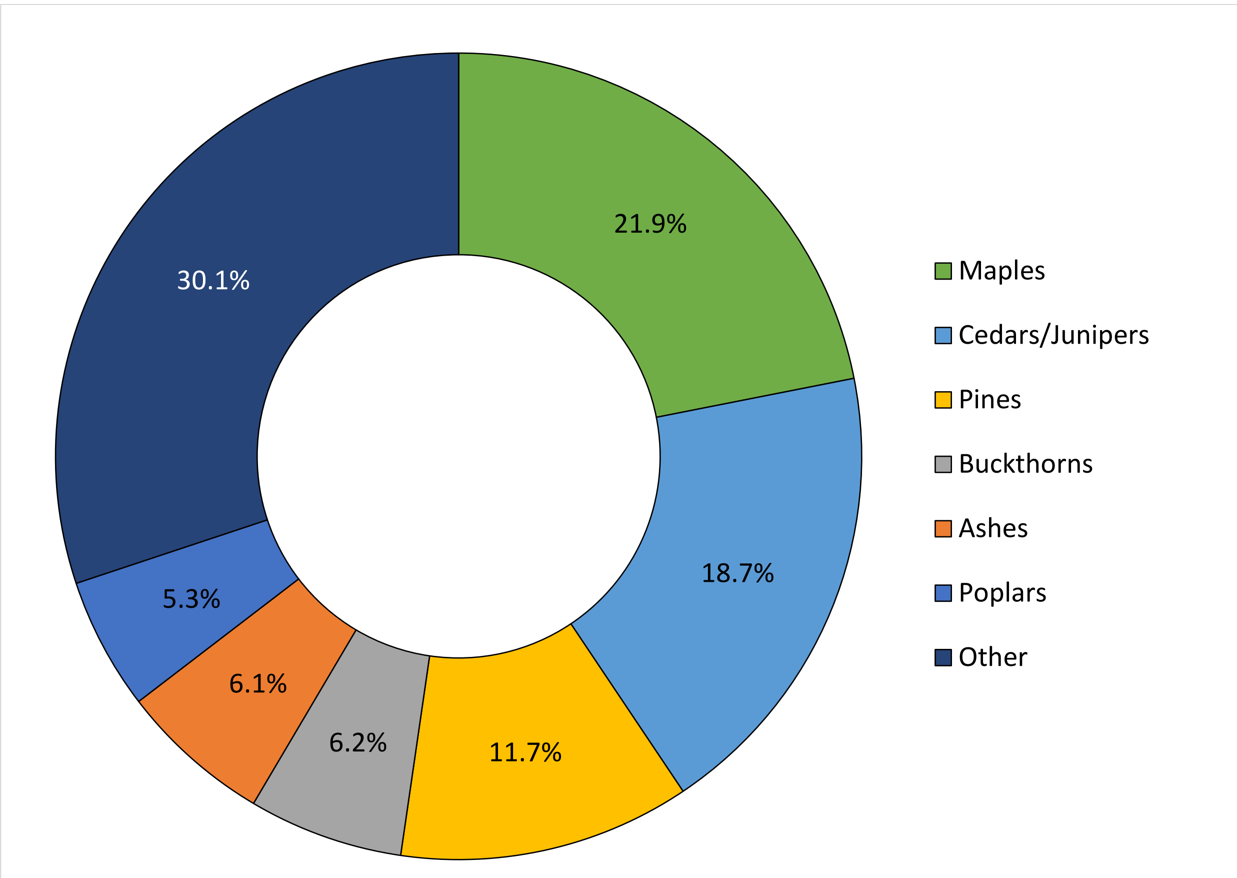


Figure 13. Most dominant tree genera and sub-families in terms of percent (%) of tree population

Table 13. Dominant tree species by percent of total leaf area and percent of total trees within land use stratum in Whitchurch-Stouffville

	Percent of Total Leaf Area		Percent of Total Trees	
Land Use	**Common Name**	**Percent**	**Common Name**	**Percent**
Agriculture	Eastern white cedar	22.7	Eastern white cedar	32.7
	Sugar maple	20.9	European buckthorn	7.0
	Manitoba maple	11.9	Manitoba maple	6.7
			Sugar maple	6.7
Natural Cover – Open Space	Sugar maple	65.5	Sugar maple	33.5
	White spruce	4.8	Staghorn sumac	8.1
	Eastern white cedar	4.3	White spruce	7.2
Residential	Sugar maple	34.3	Sugar maple	18.5
	Eastern white cedar	8.9	Eastern white cedar	13.9
	Northern red oak	8.7	White spruce	8.4
Other Urban	Eastern hemlock	20.6	Eastern white cedar	26.2
	Sugar maple	15.5	Eastern hemlock	10.3
	Silver maple	11.4	European buckthorn	8.7
Other – Institutional	Sugar maple	41.3	Sugar maple	21.3
	Red pine	12.2	Red pine	17.1
	Eastern white pine	7.4	Eastern white cedar	9.1

Species richness is highest in the *Residential* land use stratum (54 species) and can be attributed to the number of exotic horticultural species commonly found in residential gardens. In the context of forest studies that include urban areas, high species richness should not necessarily be viewed as an indication of ecosystem health. Rather, it may simply indicate an abundance of exotic species. Thus, forests often have a species richness that is higher than surrounding rural landscapes. In Whitchurch-Stouffville, 86% of the tree species identified were native to North America.

4.2.3 Size Distribution

All trees measured were grouped into size classes based on diameter at breast height[19]. Approximately 56% of all trees are less than 15.2 cm diameter (Figure 14). A high proportion of trees, 31%, are in the medium size class of 15.2 to 30.5 cm. The proportion of large trees is low; about 13% of the tree population has a diameter of 30.6 cm or greater. The average tree diameter across the forest is 15.9 cm.

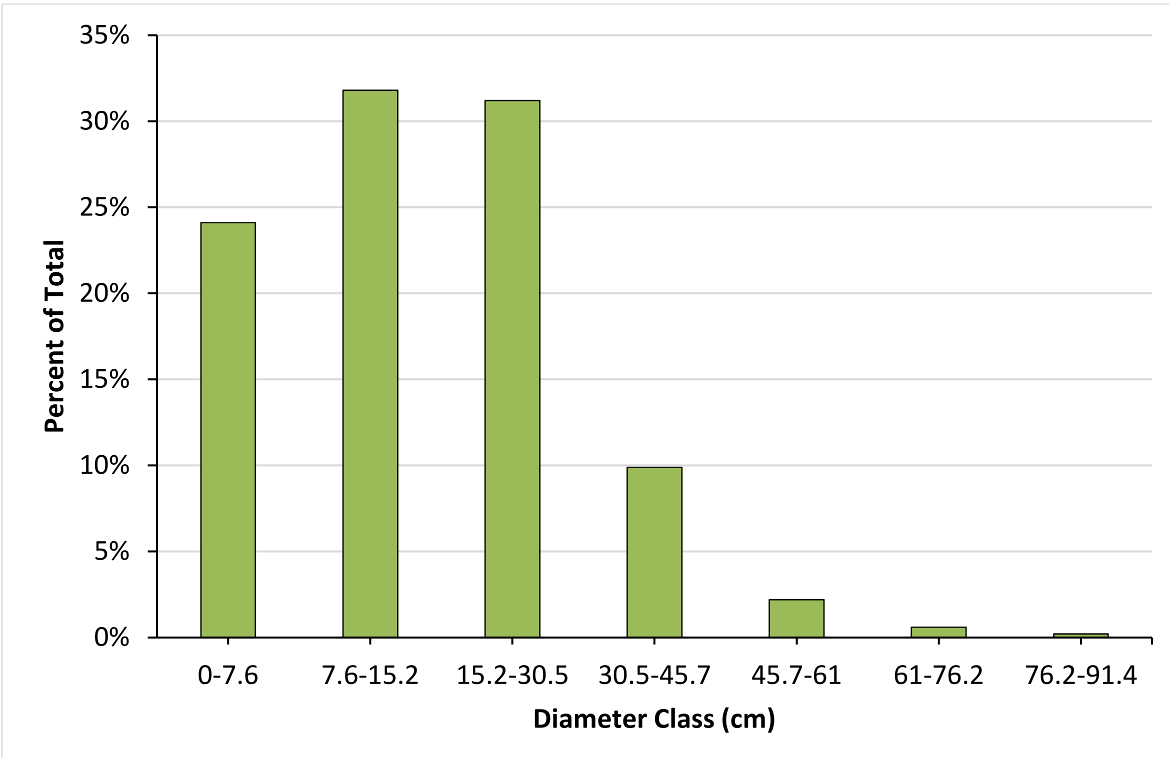


Figure 14. Diameter class distribution of trees in Whitchurch-Stouffville

Figure 15 presents the diameter class distribution by land use for 2024. Across all land use strata, the trend is similar, with the three smallest diameter classes containing the majority of trees, while very few trees are found in the larger (>45.7 cm) diameter classes (~3%) (Figure 15). The largest proportion of large trees are growing on *Residential* lands, with 3.1% in the third largest size class (45.7 cm to 61 cm) and 0.3% of trees in the largest size category (greater than 76 cm diameter). The *Natural Cover – Open Space* stratum has a similar size distribution of

[19] Diameter classes were set by i-Tree Eco, which uses classes set in inches, then converted to centimetres.

large trees, with 2.9% in the third largest size class and 0.5% in the second largest size class (61 cm to 76.2 cm) and largest size class (76.2 cm to 91.4 cm). The *Other Urban* stratum, containing *Utilities and Transportation*, *Right-of-Ways*, and *Commercial/Industrial* land uses, has the largest proportion of small diameter trees, with 50% of its population in the smallest size class (<7.6 cm). More plots in this stratum were completed using the "urban" protocol, measuring any tree with a diameter greater than or equal to 2.54 cm, as opposed to the "forest" protocol where only trees with a diameter greater than or equal to 5 cm were included in analysis.

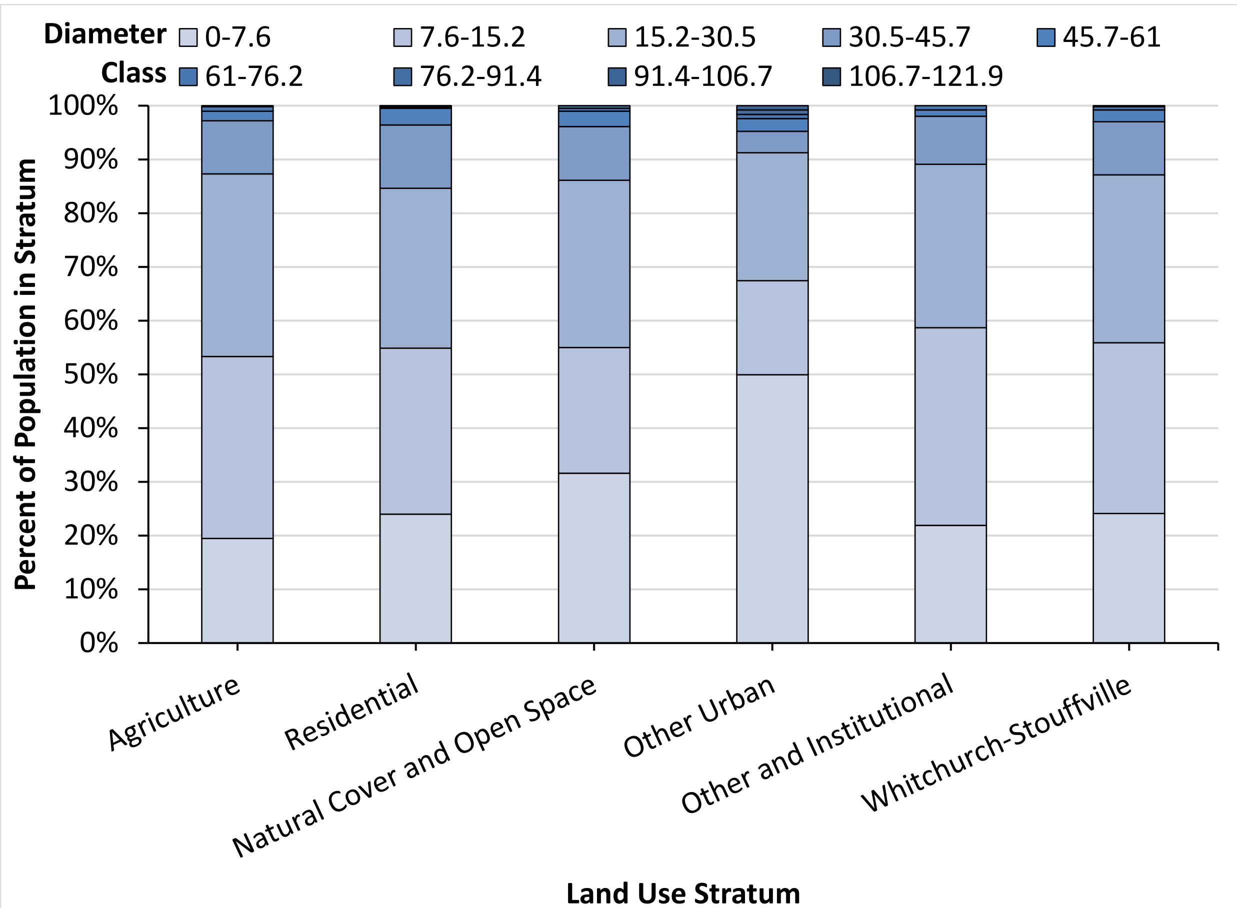


Figure 15. Diameter class (cm) distribution of trees by land use stratum in Whitchurch-Stouffville

4.2.4 Condition

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% dieback) to dead (100% dieback):

- Excellent: < 1% dieback

- Good: 1-10% dieback
- Fair: 11-25% dieback
- Poor: 26-50% dieback
- Critical: 51-75% dieback
- Dying: 76-99% dieback
- Dead: 100% dieback – no leaves / all branches are dead

Basic condition ratings do not incorporate stem defects and root damage. Approximately 48.6% of trees in Whitchurch-Stouffville are estimated to be in either excellent or good condition (Figure 16). If trees in fair condition are considered, the percent of trees in excellent to fair condition is 77.7%. These estimates should be considered cautiously as this measure relies on the judgement of the observer.

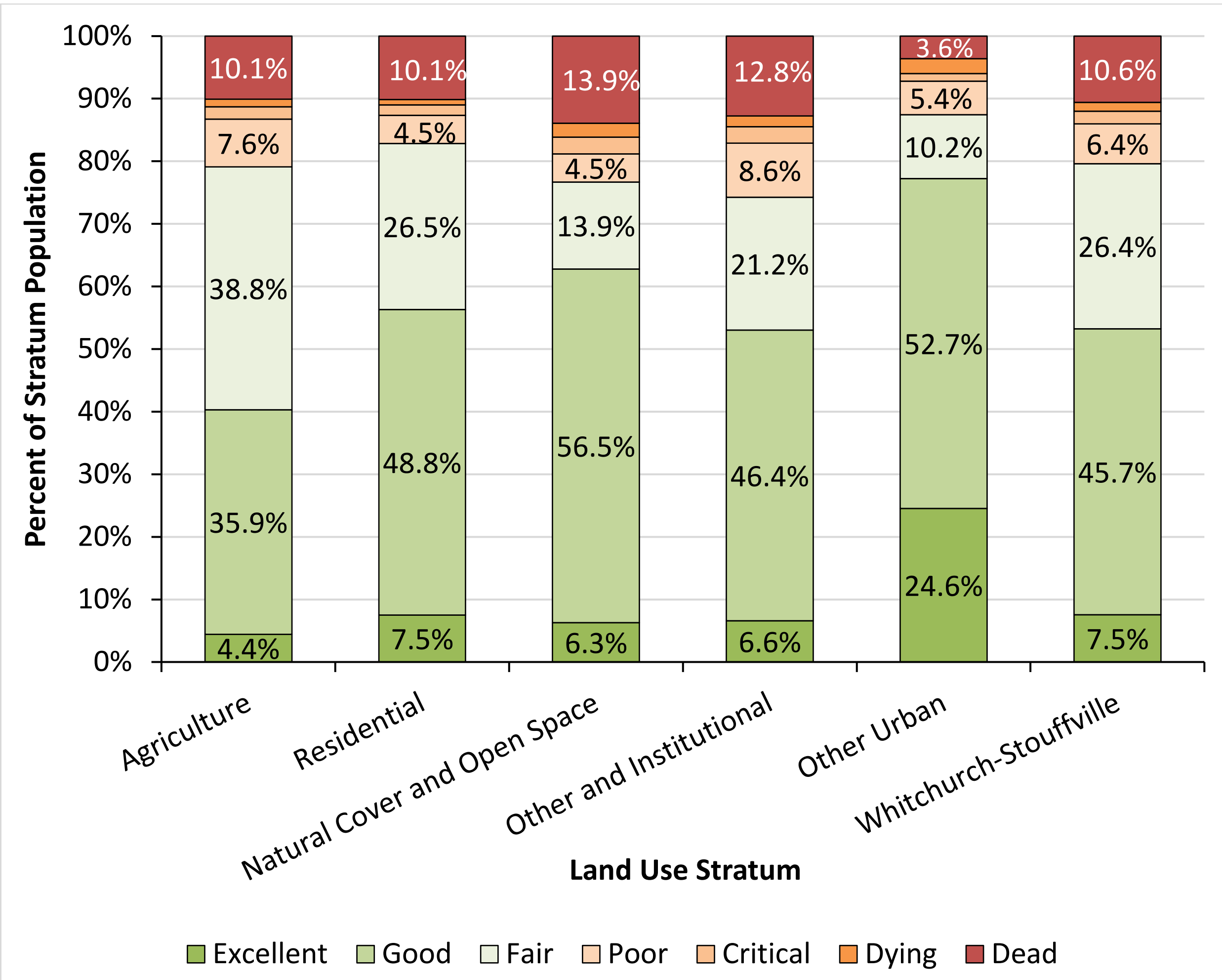


Figure 16. Condition of trees by land use stratum in Whitchurch-Stouffville

The assessment of dead trees is much more straightforward and objective than the condition of living trees and can therefore be compared more reliably. The presence of dead trees across all strata are much higher than in urban municipalities. One potential cause for this is the dominance of natural forest, which are composed of trees across the entire range of health classes, including dying or dead. Often these trees do not pose a risk to homeowners or the public and may be left to stand. In fact, dying or dead trees provide important habitat and resources to wildlife and other organisms. The *Other Urban* stratum had the highest proportion of trees in good and excellent condition, which could be due to the inclusion of more small and young trees, and the more heavily managed nature of urban areas.

Another factor is the dominance of *ash spp*., which is the fifth most dominant genus in the Town. A large proportion of specimens of white, green, and black ash across the Town were found to be dead, at 32%, 55%, and 76%, respectively; together these species comprise 5% of the tree population in Whitchurch-Stouffville. Additionally, *ash spp.*, which were dead and unidentifiable ash represented 1.1% of the total tree population. Given the prominence of ash across the Town's natural areas and in light of impacts from emerald ash borer (*Agrilus planipennis*), the high proportion of dead trees is within expectations. *Open Space – Natural Cover*, *Other – Institutional*, *Agriculture* and *Residential* land uses each have large ash populations (Table 14).

Table 14. Ash number and condition across land use strata

Land Use Class	Species	Tree Number	Description of ash condition: Percent of trees recorded as dead (%)
Agriculture	White ash	42,097	46.2
	Green ash	12,953	75.0
	Black ash	6,477	100
	Dead ash*	16,191	100
Open Space – Natural Cover	White ash	33,062	36.4
	Green ash	30,057	80.0
	Black ash	9,017	100
	Dead ash*	15,028	100
Residential	White ash	63,337	18.5
	Green ash	23,458	10.0
	Black ash	14,075	50.0
	Dead ash*	16,421	100
Other Urban	No ash present	N/A	N/A

Land Use Class	Species	Tree Number	Description of ash condition: Percent of trees recorded as dead (%)
Other – Institutional	White ash	45,313	37.5
	Green ash	25,488	55.6
	Dead ash*	19,824	100

** Represent dead unidentifiable ash spp.*

Other species contributing to the dead tree condition in the *Agriculture* stratum are American elm (*Ulmus americana*, 44%) and yellow birch (*Betula alleghaniensis*, *43*%). In *Residential*, yellow birch (*Betula alleghaniensis,* 57%) and eastern redbud (*Cercis canadensis,* 50%) also add to the dead tree population. Black cherry (*Prunus serotina*, 50%) and red pine (*Pinus resinosa*, 40%) add to the dead trees in *Natural Cover – Open Space*.

To reiterate, it should be noted that much of the Town's tree cover is contributed by natural forested lands where dying and dead trees are not actively removed if they do not pose a risk to infrastructure or public safety.

4.2.5 Additional Health Assessment

Additional data was collected for trunk and root integrity, canopy structure, and canopy vigour to obtain a more holistic understanding of health beyond percentage canopy dieback. A health score ranging from very poor (1) to good (4) was assigned to each element and used to calculate an average health score per tree. Average health scores were then computed per plot and per stratum, and for Whitchurch-Stouffville as a whole.

- Good: A score greater than or equal to 3.25
- Fair: A score between 2.5 and 3.25
- Poor: A score between 1.75 and 2.5
- Very poor: A score less than 1.75

The results of the per stratum analysis are summarized in Figure 17. To increase sample size, *Other – Institutional* and *Natural Cover – Open Space* were grouped into a general category called 'Other Natural', and *Residential* and *Other Urban* were grouped to a category called 'Residential and Other Urban'. As shown in Figure 17, *Agriculture* and *Residential – Other Urban* have an average tree health score that exceeds 3.25, which is considered Good, and Other Natural has a score of 3.20, which is considered Fair.

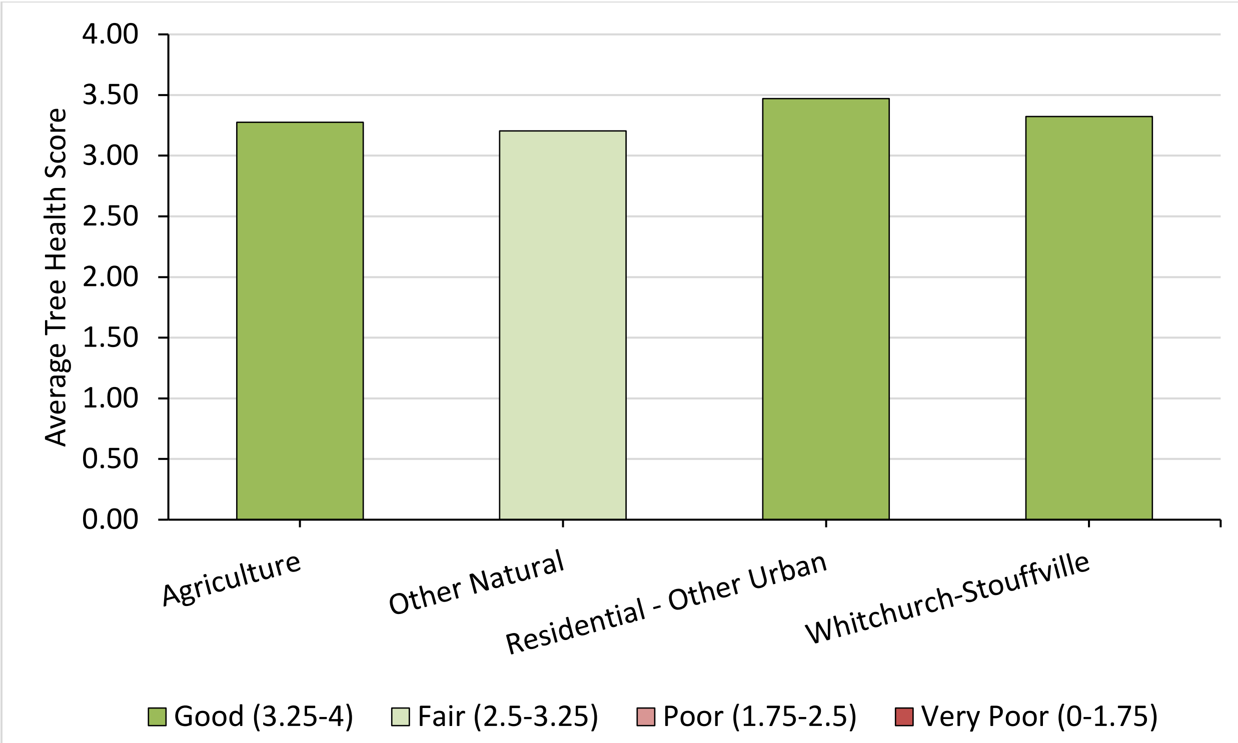


Figure 17. Additional tree health assessment results by stratum

A Kruskal-Wallis test revealed that there is a significant difference in health scores among at least some of the land use strata ($\chi^2 = 7.6668$, df = 2, $p < 0.005$) and pairwise Wilcox testing identified that there are significant differences between strata.

Residential – Other Urban and Agriculture ($p < 0.05$)

Residential – Other Urban and Other Natural ($p < 0.05$)

Residential – Other Urban areas have the highest overall health scores. Forest and unforested plots were also compared using a Wilcoxon rank sum test, which found unforested areas to have significantly higher health scores ($W = 825$, $p < 0.005$). Similar results are found for built and unbuilt areas, where unbuilt areas have a significantly lower health score ($W = 786.5$, $p < 0.05$). This is not surprising because trees in *Residential* areas, *ROW*s, unforested areas, and built areas are subjected to greater management interventions and frequently removed if they are considered hazardous, whereas trees in forested areas that do not threaten infrastructure or human safety are more often left standing even when dead.

4.2.6 Structural Value

The estimated structural value of all trees in Whitchurch-Stouffville in 2024 is approximately $1.87 billion. This value does not include the ecological or societal value of the forest but rather represents an estimate of tree replacement cost if the trees were destroyed. i-Tree Eco assesses structural value using a version of the Council of Tree and Landscape Appraisers Trunk Formula Method (Nowak, 2020). This value is based on species, diameter, condition, and location. A base value of a tree is determined by its replacement cost, which in turn is informed by the maximum diameter trees available for replacement and average cost per square centimetre of trunk area. The base value is adjusted by a species factor (species-specific factors are available for Canada as a whole), condition (the inverse of percent dieback), and land use (as an indicator of location). For non-U.S. countries, the average replacement cost assumes a maximum replacement size of 10 cm and cost per unit area based on the average value of all species within hardwood (dicotyledon) and softwood (conifer) categories. There is a positive relationship between the structural value of a forest and the number and size of healthy trees. Trees in locations that provide more amenities to humans, such as golf courses, are also provided a higher score.

4.3. Forest Function

4.3.1 Carbon Storage and Sequestration

Gross sequestration by trees in Whitchurch-Stouffville is approximately 17,710 tonnes of carbon per year (64,927 tonnes of carbon dioxide per year) with an associated annual value of $18.8 million. Net carbon sequestration[20] in Whitchurch-Stouffville is approximately 10,560 tonnes per year (38,726 tonnes CO_2 per year). Trees in Whitchurch-Stouffville are estimated to store 682,000 tonnes of carbon (2.5 million tonnes of CO_2-equivalents); the value of this service is $725.5 million.

Sugar maple (*Acer saccharum*) – which accounts for 16.1% of the tree population and 35.8% of the leaf area in Whitchurch-Stouffville (5,878.8 ha ±2,674.4) – stores and sequesters the greatest volume of carbon (approximately 30.1% of total carbon stored and 26.4% of net carbon sequestered) (Table 15). Given the dominance of sugar maple across the vertical forest structure, including younger stems, it has become the prominent species for carbon benefits across the Town.

[20] Net sequestration is a measure of the carbon sequestered by trees calculated as the gross carbon sequestered minus the carbon emissions due to decomposition after tree death.

Table 15. Top five species for carbon storage and net sequestration

Carbon Stored			Net Carbon Sequestration		
Species	**Tonnes C**	**Percent**	**Species**	**Tonnes C/year**	**Percent**
Sugar maple	205,093.1	30.1	Sugar maple	2,787.91	26.4
Eastern white cedar	129,046.7	18.9	Eastern white cedar	1,640.34	15.5
Red pine	34,424.4	5.0	Red pine	1,077.94	10.2
Manitoba maple	28,502.4	4.2	Manitoba maple	1,064.58	10.1
White spruce	26,815.8	3.9	Quaking aspen	944.96	8.9

4.3.2 Annual Air Pollution Removal

The i-Tree Eco model quantified pollution removal by trees and shrubs in Whitchurch-Stouffville based on air pollution data from stations in Newmarket and north Toronto in 2019. Pollution removal is greatest for ozone (O_3), followed by nitrogen dioxide (NO_2) and particulate matter less than 2.5 microns ($PM_{2.5}$) (Figure 18). Trees and shrubs remove a total of 447.3 tonnes of air pollution (CO, NO_2, O_3, $PM_{2.5}$, SO_2) per year with an associated removal value of $1.22 million (based on estimated externality costs). The removal of $PM_{2.5}$ has the greatest value in terms of health benefits, followed by ozone.

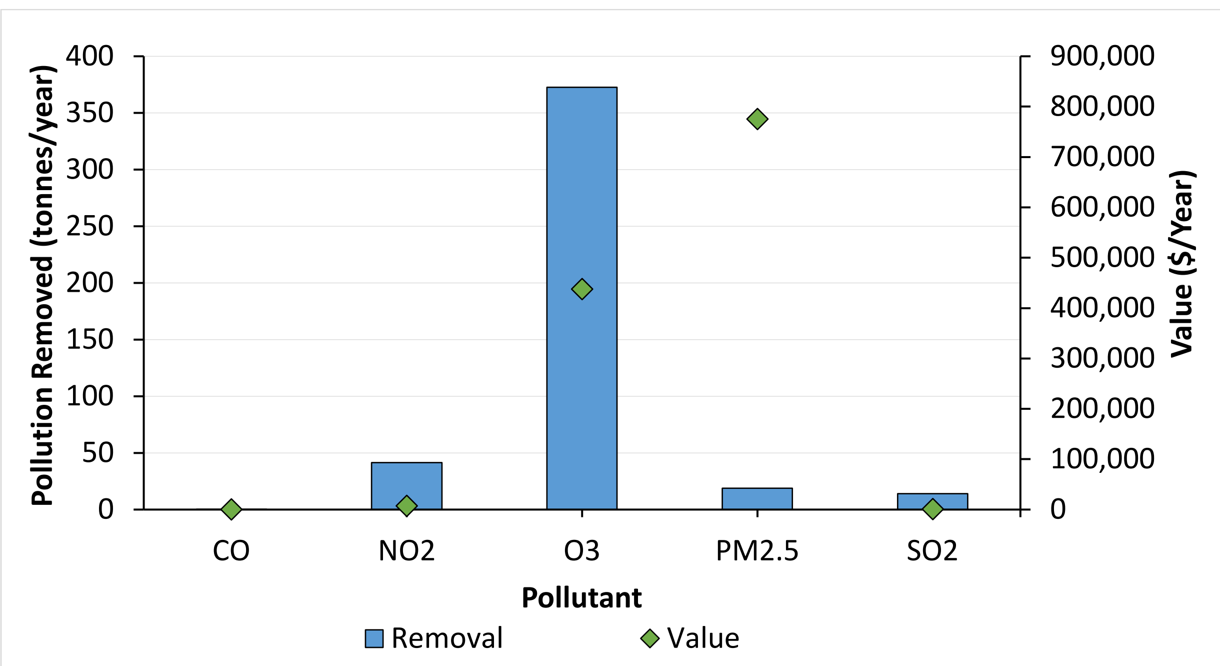


Figure 18. Annual pollution removal by trees and shrubs and associated removal value

4.3.3 Residential Energy Effects

The i-Tree Eco model estimated the effects of trees (≥6.1 m in height and within 18.3 m of a residential building, excluding high rises) on building energy use due to shading, windbreak effects, and local micro-climate amelioration. Estimates are based on field measurements of tree distance and direction to space-conditioned residential buildings[21]. Annually, trees adjacent to residential buildings in Whitchurch-Stouffville are estimated to reduce energy consumption by 113,148 million British thermal units (MBtu) for natural gas use and 1,997 megawatt-hours (MWh) for electricity use (Table 16). Based on average energy costs in 2024, trees in Whitchurch-Stouffville are estimated to reduce energy costs for residential buildings by $599,183 annually (Table 17)[22].

Table 16. Energy savings attributed to trees for residential buildings in Whitchurch-Stouffville in 2024

Energy Units	Heating	Cooling	Total
Natural Gas (Million British Thermal Units)	113,148	N/A	113,148
Electricity (Megawatt-hour)	958	1,040	1,997

[21] Because this model component is designed specifically for the U.S., its utility is limited in international applications. International users will receive energy results that are based on the characteristics of the user-defined U.S. climate region, typical construction practices and building characteristics, and energy composition (i.e., type of and amount used). Therefore, results should be used with caution as they assume that the building types and energy use of the U.S. are the same as those internationally (Nowak, 2020).

The only local values used in the estimates outside the United States are electricity and fuel costs. The remainder of the estimation is based on U.S. conditions from the assigned climate zone. Details on local energy values and the comparisons between international areas and U.S. climate zones is given in (Nowak, 2020).

[22] See Section 3.2.7.2 for the source of electricity and gas costs. Energy savings value is based on the price of $130.00 per MWh and $3.00 per MBtu.

Table 17. Financial savings (Canadian $) in residential energy expenditures during heating and cooling seasons in 2024

Energy Value ($)	Heating	Cooling	Total
Natural Gas	$ 339,526	N/A	$ 339,526
Electricity	$ 124,509	$ 135,148	$ 259,657
Total	**$ 464,035**	**$ 135,148**	**$ 599,183**

4.3.4 Hydrological Effects

i-Tree Eco was used to calculate the hydrological benefits provided by trees in Whitchurch-Stouffville based on 2019 rainfall data from Pearson International Airport[23]. The i-Tree Eco model estimates the amount of rainfall intercepted, stored, evaporated, and transpired by the urban tree canopy as well as the volume of avoided runoff (Nowak, 2020). Results are shown in Figure 19 and summarized in Table 18. Trees in the *Residential* land use stratum provide the greatest hydrological services to the municipality. Rainfall that is prevented from entering the stormwater system reduces the costs of building stormwater infrastructure and the risk of flooding. The overall value of the stormwater benefit in 2024 (measured as avoided runoff) is $232,600 per year based on 2019 precipitation levels[24]. Avoided runoff is lower than urban municipalities since the amount of impermeable surface in rural municipalities is lower.

[23] A total of 94 centimeters of annual precipitation (excluding snow) was recorded in 2019.

[24] The overall value is based on a rate of $2.325/m^3 – the default value from i-Tree Eco converted into CAD. This rate is based on sixteen research studies on costs of stormwater control and treatment (Nowak, 2020).

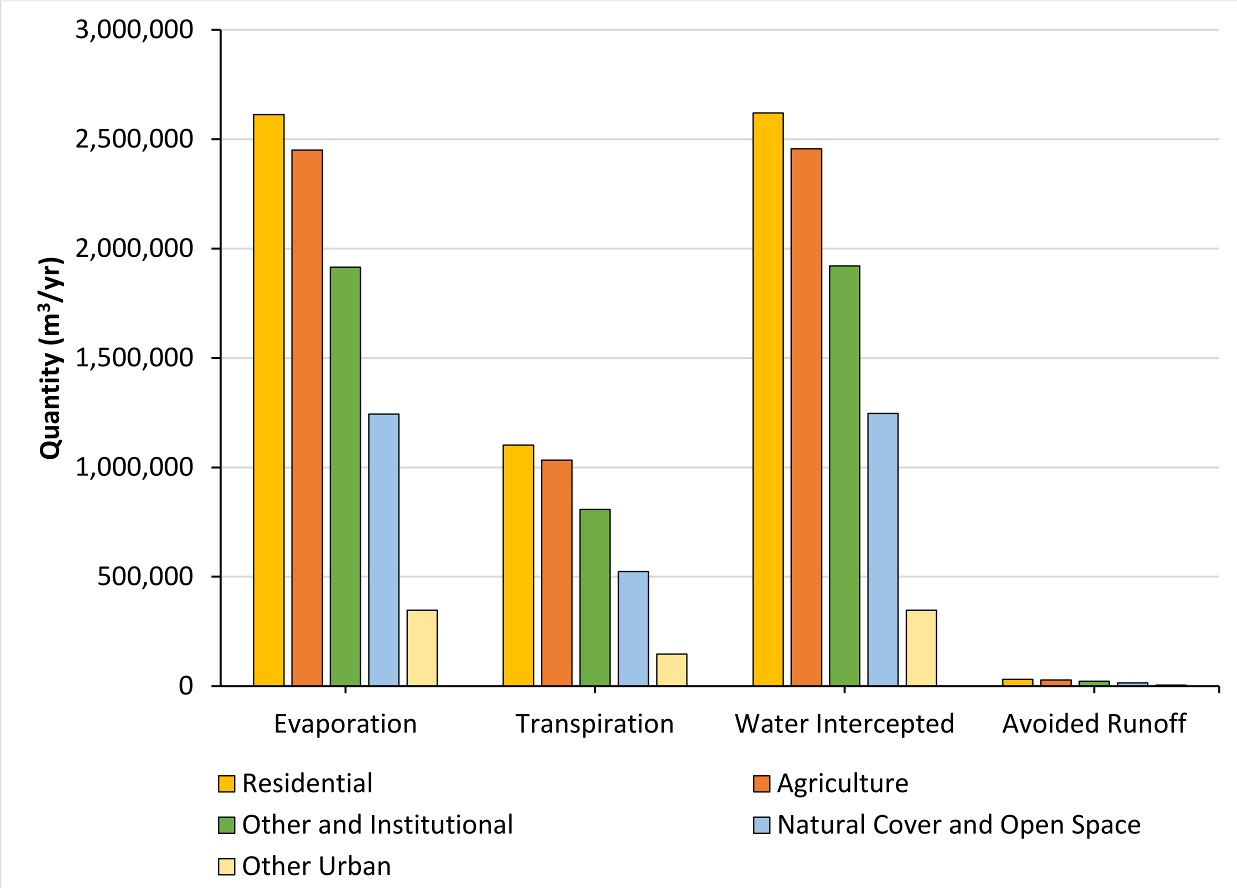


Figure 19. Hydrological services provided by trees in Whitchurch-Stouffville in 2024, based on 2019 precipitation levels

Table 18. Avoided stormwater runoff and value

Land Use Stratum	Avoided Runoff (m^3/yr)	Value ($/yr)
Residential	30,522.07	$ 70,933.86
Agriculture	28,615.69	$ 66,502.86
Other – Institutional	22,370.50	$ 51,989.03
Natural Cover – Open Space	14,527.45	$ 33,761.78
Other Urban	4,050.89	$ 9414.27
Whitchurch-Stouffville	**100,086.59**	**$ 232,601.23**

4.3.5 Other Benefits and Disservices

Whitchurch-Stouffville's forest provides numerous other services, many of which are hard to quantify. For example, it produces 28,162 tonnes of oxygen per year. Under the shade in residential areas, Whitchurch-Stouffville's urban tree canopy reduces the UV index[25] by 69% and by 58% overall, thereby reducing exposure to harmful UV rays and the risk of developing skin cancer.

Unfortunately, trees also have some disservices, though they are outweighed by the benefits trees provide. In addition to being a source of allergens, trees emit volatile organic compounds such as monoterpene and isoprene. Isoprene reacts with other chemicals in the atmosphere to create ozone, a harmful pollutant (Sharkey, Wiberley, & Donohue, 2008). Monoterpenes are in the essential oils of plants, producing odors, such as pine scent, often associated with trees (Cho, et al., 2017). Monoterpenes have anti-inflammatory effects on people, with potential for various medicinal uses (Cho, et al., 2017). A total of 244,542 kg/year is emitted, with the greatest mass being emitted from *Residential* areas which have the most trees. Northern red oak (*Quercus rubra*) emits the most volatile organic compounds at 52,959 kg/year followed by red pine (*Pinus resinosa* – 31,876 kg/year), and sugar maple (*Acer saccharum* – 31,802 kg/year). Coniferous trees are known to emit volatile organic compounds year-round due to foliage retention and to combat heat stress (Naranjo, 2011).

4.4. i-Tree Forecast

Based on the current municipal planting programs, the expected canopy growth, and the anticipated impacts of spongy moth (*Lymantria dispar dispar*), emerald ash borer (*Agrilus planipennis*), and beech bark disease (*Neonectria faginata*), Whitchurch-Stouffville will surpass the recommended canopy cover range, (i.e., 40-45%) over the next thirty years. At the current rate of planting and natural growth, the i-Tree Forecast model estimates that canopy cover will increase by 17.89% to reach 56.79% by 2049[26]. If the planting numbers were doubled, the forecast projects an increase of 17.91% to reach 56.81%. Assuming no planting programs are undertaken, the forecast projects canopy cover will increase by 17.85% to reach 56.75% by 2049. Each planting scenario has little effect on the overall canopy cover. Canopy cover increases will largely consist of existing public and private tree populations having grown and shifted into larger size classes, further emphasizing the importance of maintaining these populations. It is important to note that the annual number of frost-free days in Whitchurch-

[25] UV reduction was calculated in i-Tree Eco using cloud cover data from 2016.

[26] The 2023 canopy cover estimated by i-Tree Eco was 10.78% lower than that estimated from the University of Vermont study. To make the data comparable to the rest of the canopy cover data, this difference was added as a constant to the values calculated in i-Tree Forecast.

Stouffville was increased during the thirty-year simulation period to an average value to account for climactic changes. The longer growing season is more likely to benefit tree growth in the latter half of the simulation period than the earlier half. Thus, canopy growth over the next six years is likely to be less than 2%.

While canopy cover is expected to increase through natural growth of existing trees, the number of trees, as determined by the i-Tree Forecast model, across the municipality is expected to decline in each Forecast scenario. By 2049, the number of trees is expected to decrease from 5.4 million to 3.538 million under the current planting scenario, to 3.545 million under the doubled planting scenario and to 3.530 million under the no planting scenario (). However, it should be noted that real world tree count would be much greater than projected here as i-Tree does not account for natural regeneration. Ultimately the tree planting rates will not keep up with projected tree mortality rates. Continued tree planting remains necessary to maintain trees across all size classes, especially across urbanized private and public land uses, and to replace older trees as they die[27]. Due to the largely natural forest population in Whitchurch-Stouffville, tree planting efforts will not add a lot to the canopy but are still important to ensuring the delivery of vital ecosystem services in more urbanized areas of the Town. The Town should consider a restoration and natural enhancement planting plan to further improve tree planting inputs.

Table 19. Number of trees expected by 2049 under different planting scenarios

Scenario	Number of Trees by 2049
Current Planting	3.538 million
Double Planting	3.545 million
No Planting	3.530 million

As the number of trees decreases and assuming minimal changes in species diversity, the forest will become more susceptible to various impacts ranging from climate change to pests and diseases. There is also a great deal of uncertainty regarding current tree mortality rates, the impacts of climate change, and future pests and diseases. Also, human policies around the protection of natural areas and development that cannot be quantified and made tractable are not included in the i-Tree Forecast model.

[27] i-Tree Eco does not include natural regeneration or ingrowth of trees. In other words, it assumes that the only new trees established in the simulation period are those that are deliberately planted.

4.5. Soil Health

4.5.1 Compaction

Eighty-one plots were measured for compaction. Across the study area, approximately 72.8% of the sampled plots were uncompacted, 19.8% were moderately compacted, and 7.4% were highly compacted[28]. There was no significant difference between compaction on private and public soil (Table 20). This was analysed with the Wilcoxon rank sum test for non-normal data ($W = 526.5$, $p = 0.6216$). There was no significant difference between compaction in the different strata, found with the Kruskal-Wallis rank sum test for non-normal data ($\chi^2 = 0.18803$, $df = 2$, $p = 0.9103$) (Figure 20). There was no significance between built and unbuilt areas, also found using the Kruskal-Wallis rank sum test for non-normal data ($\chi^2 = 2.5299$, $df = 1$, $p = 0.1117$).

Table 20. Soil compaction across private and public lands in Whitchurch-Stouffville. Public lands include municipal, provincial, and conservation authority properties.

Ownership type	Number of plots sampled	Mean Compaction score (± std dev.)	Percent uncompacted (of measured plots)	Percent moderately compacted (of measured plots)	Percent highly compacted (of measured plots)
Whitchurch-Stouffville	81	1.42 (± 0.596)	72.8	19.8	7.4
Private	63	1.41 (± 0.596)	73.0	19.0	7.9
Public	18	1.44 (± 0.593)	72.2	22.2	5.6

[28] These proportions should not be taken as representative of the municipality, but rather of the plots where staff were able to take soil measurements.

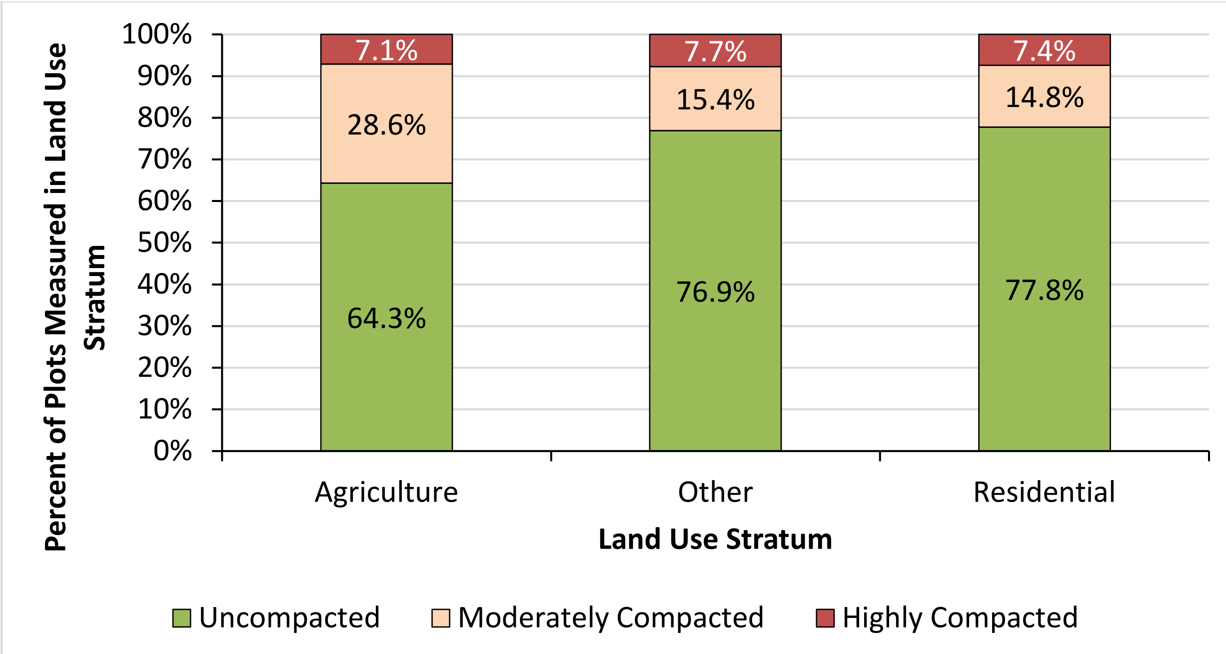


Figure 20. Compaction across aggregated land use strata in Whitchurch-Stouffville

Compaction was also analysed for forested and unforested areas. Using the Wilcoxon rank sum test, it was found that there is a significant difference between the mean compaction values for forested and unforested plots, with unforested plots having significantly higher compaction than forested plots (W = 1047.5, p = 0.01805) (Figure 21).

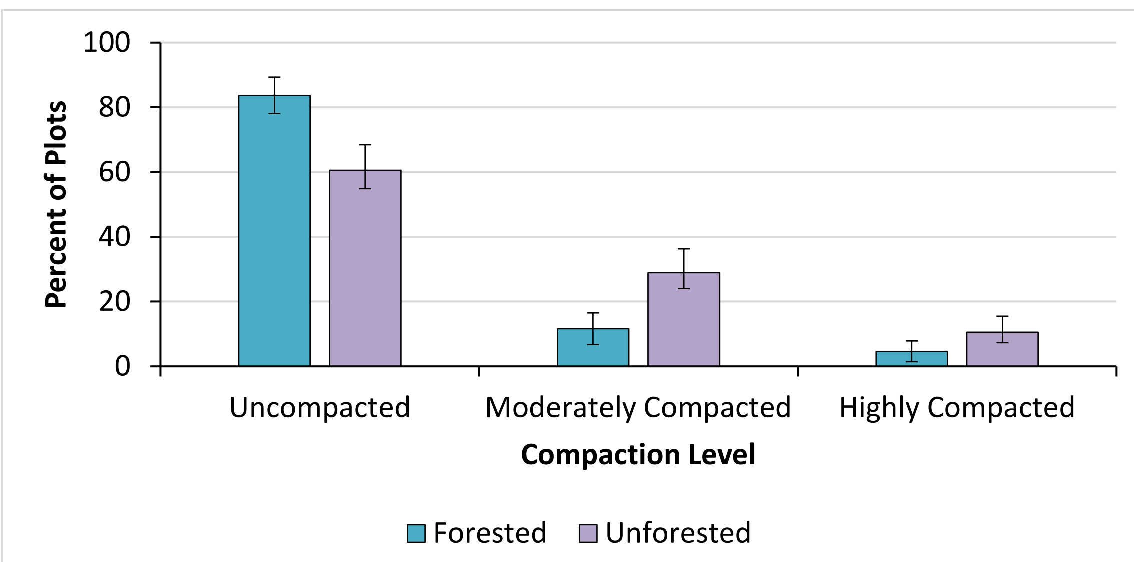


Figure 21. Compaction level of unforested and forested plots

4.5.2 Salinity

Salinity across Whitchurch-Stouffville was inferred from in situ electroconductivity measures and analysed in a lab when in situ measurements were not possible. In total, 81 plots were assessed and found to have a mean of 268.0 µS/cm (± 203.7), median of 236 µS/cm, and a minimum and maximum value of 5.9 µS/cm and 1,340 µS/cm, respectively (Table 21). Using the Wilcoxon rank sum test for non-normal data, it was found that there was no significant difference in electroconductivity between private and public lands ($W = 526$, $p = 0.6455$). Differences across land use strata, *Residential*, *Agriculture*, and *Other* (other land use classes), were also tested using the Kruskal-Wallis rank sum test for non-normal data. Differences were found to be statistically insignificant ($\chi^2 = 0.21251$, df = 2, $p = 0.8992$). Built and unbuilt land was also tested for significance but was not significant using the Kruskal-Wallis rank sum test ($\chi^2 = 0.40658$, df = 1, $p = 0.5237$).

Table 21. Mean electroconductivity for Whitchurch-Stouffville and across unforested and forested lands in Whitchurch-Stouffville

	Number of Plots	Mean (µS/cm) (± std dev)	Median (µS/cm)
Whitchurch-Stouffville	81	268.0 (± 203.7)	236
Unforested	35	302.1 (± 158.4)	261
Forested	46	242.0 (± 230.7)	191.4

Forested and unforested lands were shown to have significantly different electroconductivity when tested using the Wilcoxon rank sum test with continuity correction ($W = 1057$, p-value = 0.01649). Forested lands have significantly lower salinity than unforested lands (Figure 22). As shown in Figure 22, there are four outliers for electroconductivity. The unforested outlier with a mean of 772 µS/cm is plot 124, the unforested outlier with a mean of 686.25 µS/cm is plot 146, the forested outlier with a mean of 1,340 µS/cm is plot 144, and the forested outlier with a mean of 736 µS/cm is plot 64 (Figure 23). Plot 144 is the most extreme outlier. This plot was located between an agricultural field and a pond, and the ground was saturated at the time of data collection, perhaps contributing to the high salinity. The relationship between salinity and tree health is presented in more detail in Section 4.5.4.

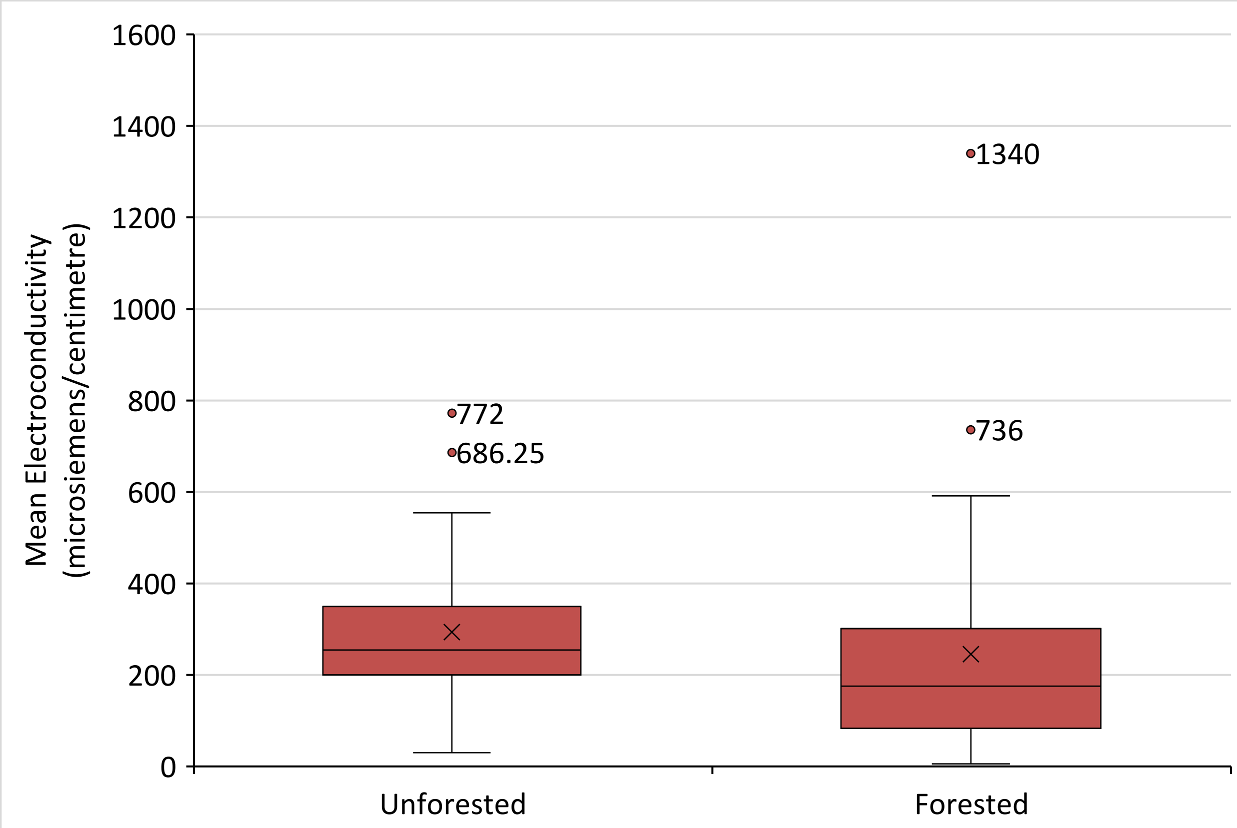


Figure 22. Mean electroconductivity for unforested and forested plots

Figure note: The solid middle line in the figure shows the median value (50th percentile), the X shows the mean, while the lower and upper limits of the coloured boxes indicate the 25th and 75th percentile, respectively. The whiskers (upper and lower black horizontal bars) are the minimum and maximum measurements that are within a normally expected range[29]. The circles indicate outlier values.

[29] The upper value of this range is defined as the 3rd quartile (75th percentile) + 1.5 x interquartile range and the lower value is the 1st quartile (25th percentile) – 1.5 x interquartile range. The interquartile range is the difference between the 3rd quartile and the 1st quartile.

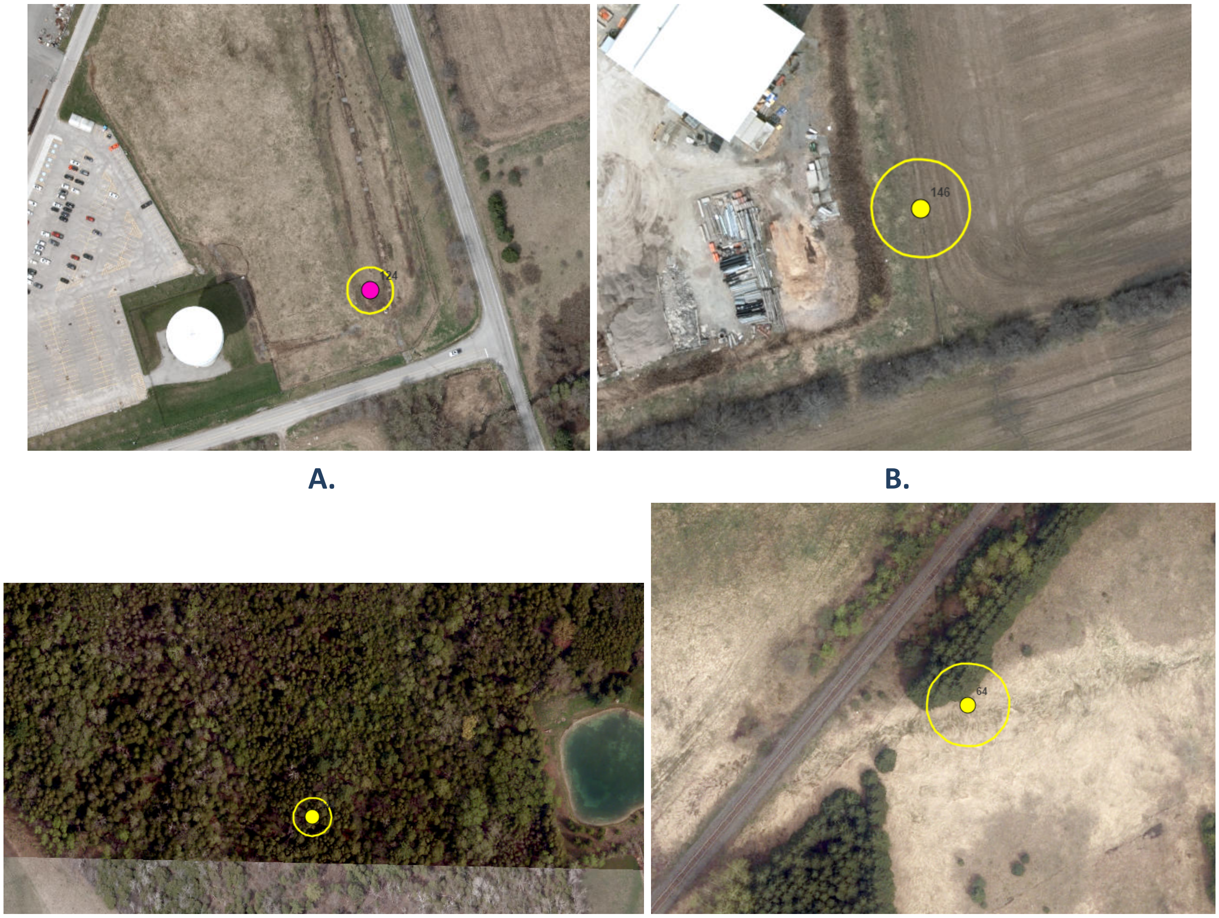


Figure 23. Outlier plots for salinity, A. 124, B. 146, C. 144, D. 64

4.5.3 pH

pH is a measure of the concentration of hydrogen ions in liquids. Values range from 1 (acidic) to 14 (alkaline); 7 is neutral. Eighty-one pH samples were obtained across Whitchurch-Stouffville. The average pH was 6.93 (± 0.559), a median of 7.12, minimum of 5.17 and a maximum of 7.62. The optimal pH range for most plants in southern Ontario is 5.5-7.5 as this is when nutrients are most available, however, optimal ranges vary by species (Ontario Ministry of Natural Resources, 2014).

The relationship between pH and ownership type – private and public (municipal, provincial, and conservation authority lands) was investigated. A Wilcoxon rank sum test for non-normal data found that the difference in pH between public and privately owned plots was not statistically significant ($W = 433$, $p = 0.1293$). pH was also examined by land use stratum. A Kruskal-Wallis rank sum test found that there was no significant difference in pH between plots in different land uses ($\chi^2 = 1.1842$, $df = 2$, $p = 0.5532$). Lastly, pH was also examined in forested and unforested plots, and it was found that pH is significantly higher in unforested plots compared to forested plots, using the Wilcoxon rank sum test (W = 1229, p = 5.381e-05) (Figure 24).

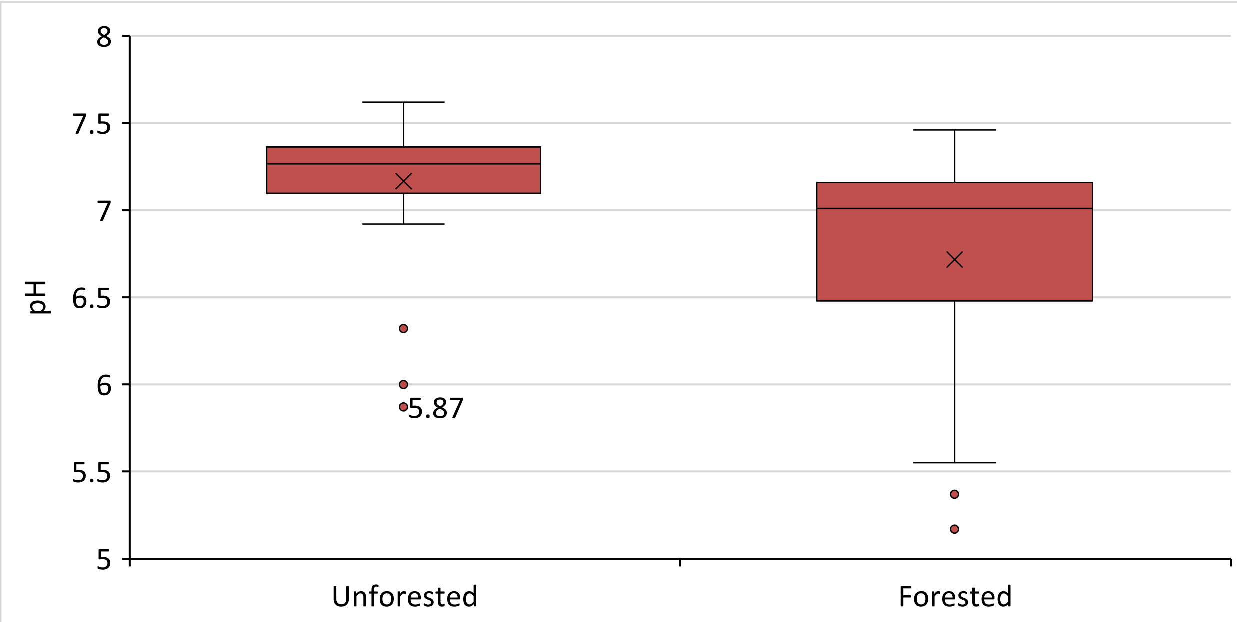


Figure 24. pH in forested and unforested land

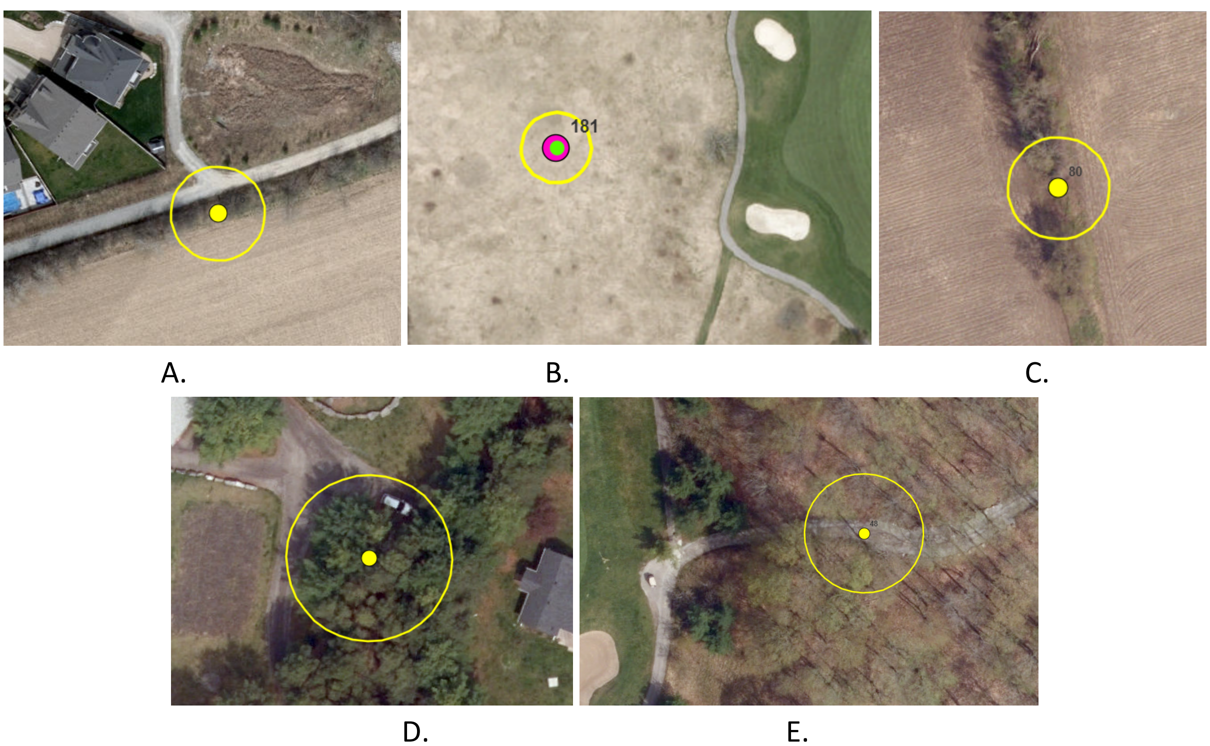


Figure 25. Outlier plots for pH, A. 176, B. 181, C. 80, D. 14, E. 48

There are three outlier values for pH in unforested areas: plot 176 with a pH of 6.32, plot 181 with a pH of 6, and plot 80 with a pH of 5.87. In forested areas, the outliers are plots 14 and 48 with pH values of 5.37 and 5.17, respectively. As shown in Figure 25, the unforested outliers are located in between agricultural fields and in a golf course on a grassland. The low pH could be explained by the proximity to fertilizers. Plot 14 is a small forest patch with gravel paths around the edges. Plot 48 is a forested area in a golf course with a gravel path cutting through the plot. The low pH could be explained by the small sizes of the forests and the gravel paths bringing runoff into the soil.

4.5.4 Relationships between Soil Compaction, Salinity, pH, and Tree Condition

The relationships between tree condition, measured as average percentage crown dieback per plot, and the three soil condition measures, namely, soil compaction, salinity (indicated by electroconductivity) and pH, were explored via correlation testing. Significant negative relationships were found between percent dieback and soil compaction and pH, meaning that dieback decreases as compaction and pH increase. A negative correlation was found between salinity and percent dieback, although this was not significant. Results are summarized in Table 22.

Table 22. Correlation between crown dieback and compaction, salinity, and pH

Dieback vs.	Summary	Degrees of Freedom	Pearson's Correlation Test	Spearman's Correlation Test	Kendall's Correlation Test
Compaction	Significant negative relationship	66	cor = -0.3 p = 0.01122	rho = -0.3 p = 0.01718	tau = -0.2 p = 0.01598
Salinity (electroconductivity)	Non-significant negative relationship	66	cor = -0.07 p > 0.1	rho = -0.08 p > 0.1	tau = -0.06 p > 0.1
pH	Significant negative relationship	66	cor = -0.3 p = 0.02416	rho = -0.3 p = 0.02364	tau = -0.2 p = 0.02986

While we expected higher compaction and pH to be associated with increased average crown dieback, these inverse relationships may be because natural areas, which tend to have lower soil compaction and a wider range of pH values, also have higher proportions of dead or dying trees since they are not required to be removed for safety reasons. Similar effects were observed in other municipalities within York Region. This hypothesis was tested by comparing the mean percent dieback on forested versus non-forested plots using a Mann-Whitney Wilcoxon test. It was revealed that forested plots had a higher average dieback (24.8%) than non-forested plots (10.6%) ($W = 227.5$, $p < 0.01$).

Figure 26 visualizes tree condition and soil condition data as a scatter plot and the linear relationship between these variables is demonstrated by the addition of a regression line. Forested and unforested plots are indicated by green and blue, respectively. It is clear visually that the overall percent dieback is lower on plots not found in forested areas. The relationship between percent dieback and soil condition on forested and unforested plots appears to be quite dissimilar too, although with a smaller sample size from splitting the dataset into forested and unforested it is not possible to test confidently for significance. Crown condition is impacted by many interacting variables and cannot be easily reduced to a single soil variable.

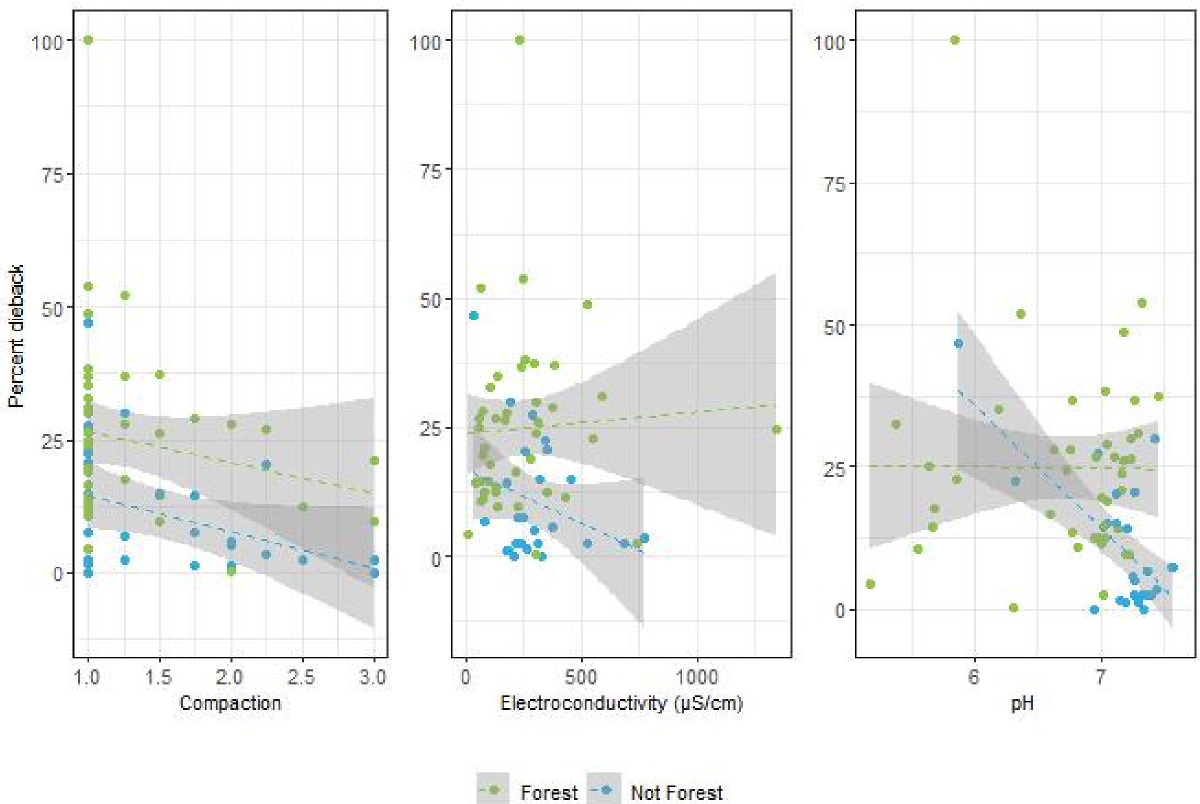


Figure 26. Scatterplots of crown dieback versus soil compaction, electroconductivity (indicator of salinity), and pH for forested and unforested areas

Figure Note: Line indicates a linear regression between percent dieback and the soil condition variable. Separate regression lines were added for forested and non-forested plots. The grey area indicates the standard error.

4.6. Invasive Plants

Out of the 184 plots surveyed, 46% of plots (85 plots in total) had at least one invasive plant species present (Table 23). Invasive plant species were most prevalent in the *Residential* land use stratum (43% of plots), followed by *Other Urban* (39%), and *Other – Institutional* (35%). *Natural Cover – Open Space* had a lower percentage of plots with invasive plants (27%), which is expected since these plots may experience less human disturbance. While it might seem surprising that *Agriculture* has a lower percentage of plots with invasive plants (27%), most plots surveyed in this category occurred in agricultural fields. Agricultural lands do contain forest patches; however, a large proportion of plots surveyed in this category occurred in active agricultural fields with no natural cover. Such sites were determined not to have invasive species via orthophoto analysis.

Table 23. Invasive plant species statistics for Whitchurch-Stouffville and by land use stratum

Land Use Stratum	Number of Plots	Percent Plots with at Least One Invasive Plant Species	Avg. Number of Invasive Plant Species on Invaded Plots	Avg. Spread[30] of Invasive Plants on Invaded Plots	Avg. Num. Species x Avg. Spread
Agriculture	108	26.9	2.1	1.7	3.6
Residential	65	43.1	2.0	1.6	3.2
Natural Cover – Open Space	22	27.3	2.0	1.5	3.0
Other Urban	26	38.5	2.3	1.9	4.3
Other – Institutional	34	35.3	1.8	1.8	3.4
Whitchurch-Stouffville	**184**	**46.2**	**2.1**	**1.7**	**3.5**

[30] Spread is the degree to which the plant was found to have colonized the plot ranging from 1 (one or two small patches) to 4 (across the entire plot and outside).

The results showed that when plots are invaded, they typically have more than one invasive plant species present, although the level of spread was generally low. *Other Urban* had the highest number of invasive plants (average of 2.3), while *Other Urban* and *Other – Institutional* have the greatest average level of spread (1.9 and 1.8, respectively) (Table 23). By multiplying the average number of invasive plants with the average spread, *Other Urban* is shown to have the worst invasion levels, followed by *Agriculture* and *Other – Institutional*.

The most common invasive species, measured by the proportion of plots affected, were European buckthorn (*Rhamnus cathartica,* 34%), Manitoba maple (*Acer negundo*, 19%), garlic mustard (*Alliaria petiolata*, 10%), non-native honeysuckle (*Lonicera spp.*; 8%), and dog strangling vine (*Cynanchum rossicum*, 7%). These species also tended to have a higher spread than the minimum score of 1 per invaded plot. Periwinkle (*Vinca minor*) had the highest degree of spread (2.6) on those plots in which it did occur. Figure 27 shows the proportion of plots impacted and the average spread of invaded plots for all those species detected in this study. Tree of heaven (*Ailanthus altissima*), black alder (*Alnus glutinosa*), and European spindle-tree (*Euonymus europaeus*) were not found in any plots.

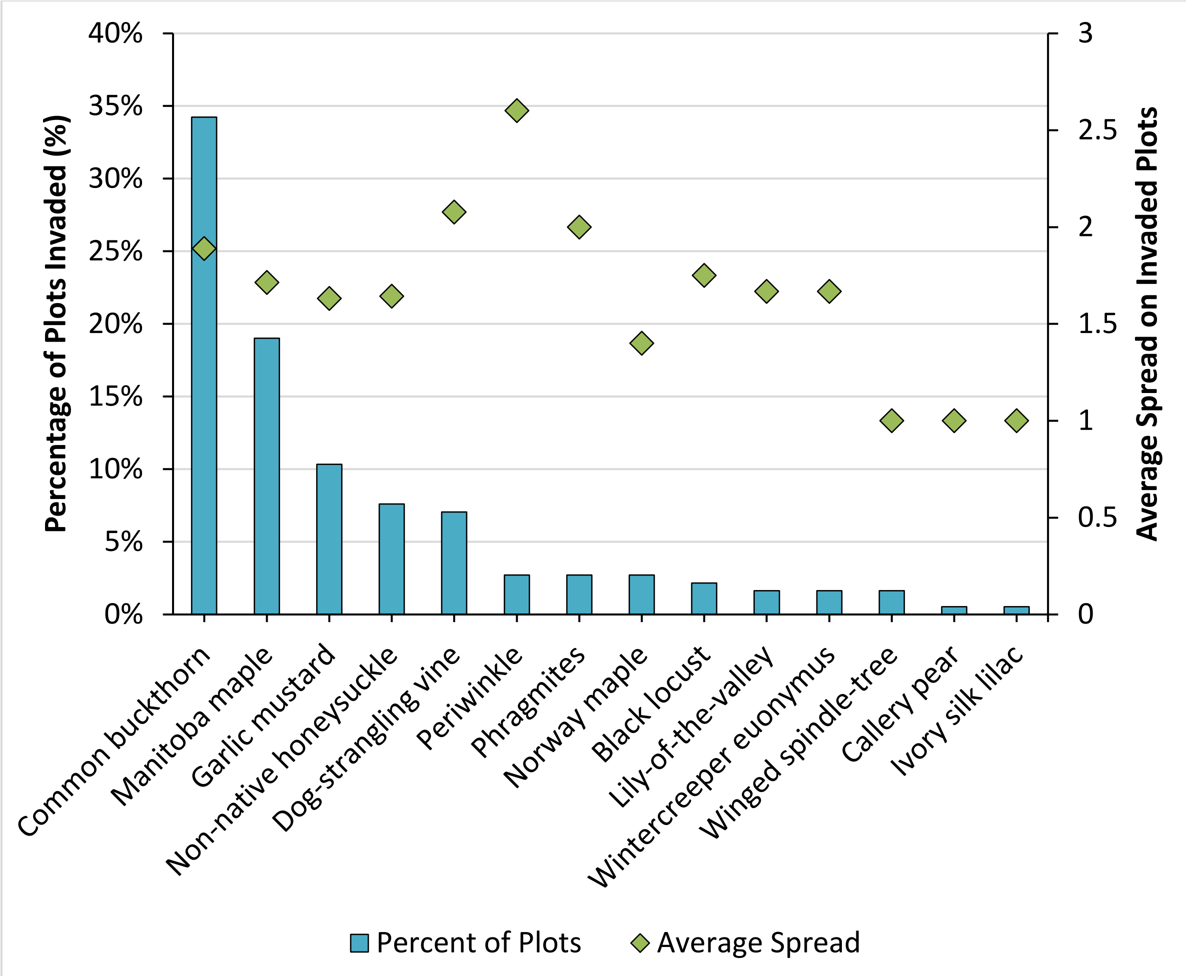


Figure 27. Percent and spread of invasive plant species in Whitchurch-Stouffville

European buckthorn, Manitoba maple, and garlic mustard were most prevalent across most land uses as shown in Table 24. Table 25 lists the land uses on which the most common invasive species were most frequently found.

Due to the presence of natural woodlands in Whitchurch-Stouffville, the presence of invasive plants, pests and diseases was expected. However, invasives do not dominate the species composition like the more urban municipalities in York Region which have higher levels of disturbance and natural vegetation loss. Despite this fact, management and monitoring should be considered to maintain and reduce the impacts of invasive species on the forest.

Table 24. Top three most prevalent invasive species by land use

Land Use Stratum	Three most prevalent Invasive Plant Species (% of Plots)	Percent Plots with at Least One Invasive Plant Species	Avg. Spread of Invasive Plant on Invaded Plots
Agriculture	European buckthorn	23.1	1.8
	Manitoba maple	13.9	1.9
	Garlic mustard	6.5	1.4
Residential	European buckthorn	30.8	1.8
	Manitoba maple	12.3	1.6
	Garlic mustard	9.2	2.0
Natural Cover – Open Space	European buckthorn	18.2	1.5
	Manitoba maple	13.6	1.3
	Garlic mustard	9.1	1.5
Other Urban	European buckthorn	23.1	2.2
	Manitoba maple	15.4	1.5
	Phragmites	11.5	2.3
Other – Institutional	European buckthorn	23.5	2.5
	Manitoba maple	14.7	1.8
	Garlic mustard	5.9	2.0
	Non-native honeysuckle	5.9	1.5
Whitchurch-Stouffville	**European buckthorn**	**34.2**	**1.9**
	Manitoba maple	**19.0**	**1.7**
	Garlic mustard	**10.3**	**1.6**

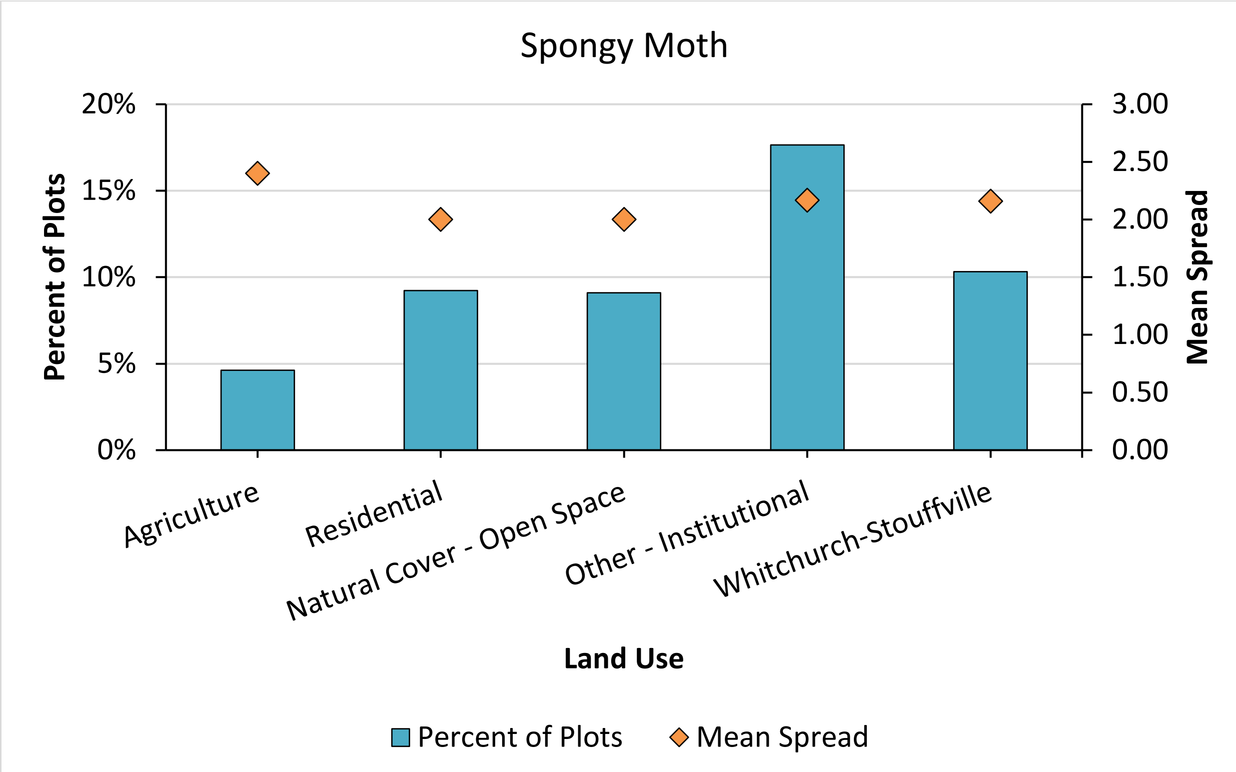
Table 25. Land uses on which most common invasive plant species were most frequently found

Species	Top Three Land Use Stratum on which Species was Most Frequently Found	Percent Plots with Species Present (%)	Avg. Spread of Species on Invaded Plots
European buckthorn	Agriculture	23.1	1.8
	Residential	30.8	1.8
	Other – Institutional	23.5	2.5
Manitoba maple	Agriculture	13.9	1.9
	Residential	12.3	1.6
	Other – Institutional	14.7	1.8
Garlic mustard	Agriculture	6.5	1.4
	Residential	9.2	2.0

4.7. Invasive Pests and Diseases

4.7.1 Invasive Pests

While visiting plots to collect i-Tree Eco and other data, field crews also recorded the presence and degree of spread of emerald ash borer beetle (*Agrilus planipennis*), spongy moth (*Lymantria dispar dispar*), hemlock woolly adelgid (*Adelges tsugae*), and Asian long-horned beetle (*Anoplophora glabripennis*). Signs of hemlock woolly adelgid and Asian long-horned beetle were not observed at any sites. However, signs of spongy moth were present at 10% of plots and emerald ash borer was observed at 13% of plots. Figure 28 shows the percentage of plots where the insect itself (in some stage of lifecycle development) or insect damage was observed per land use type, while the average spread, ranging from the least (1) to the most (3), is shown on the second axis. One indicates that the insect/damage was observed on 1 to 3 trees, two, 4 to 6 trees, and three, more than 6 trees. No invasive pests were found in the *Other Urban* stratum. While these land use strata likely have emerald ash borer and spongy moth presence, due to the low number of sampled sites between these strata there were no recordings of these invasives in field.



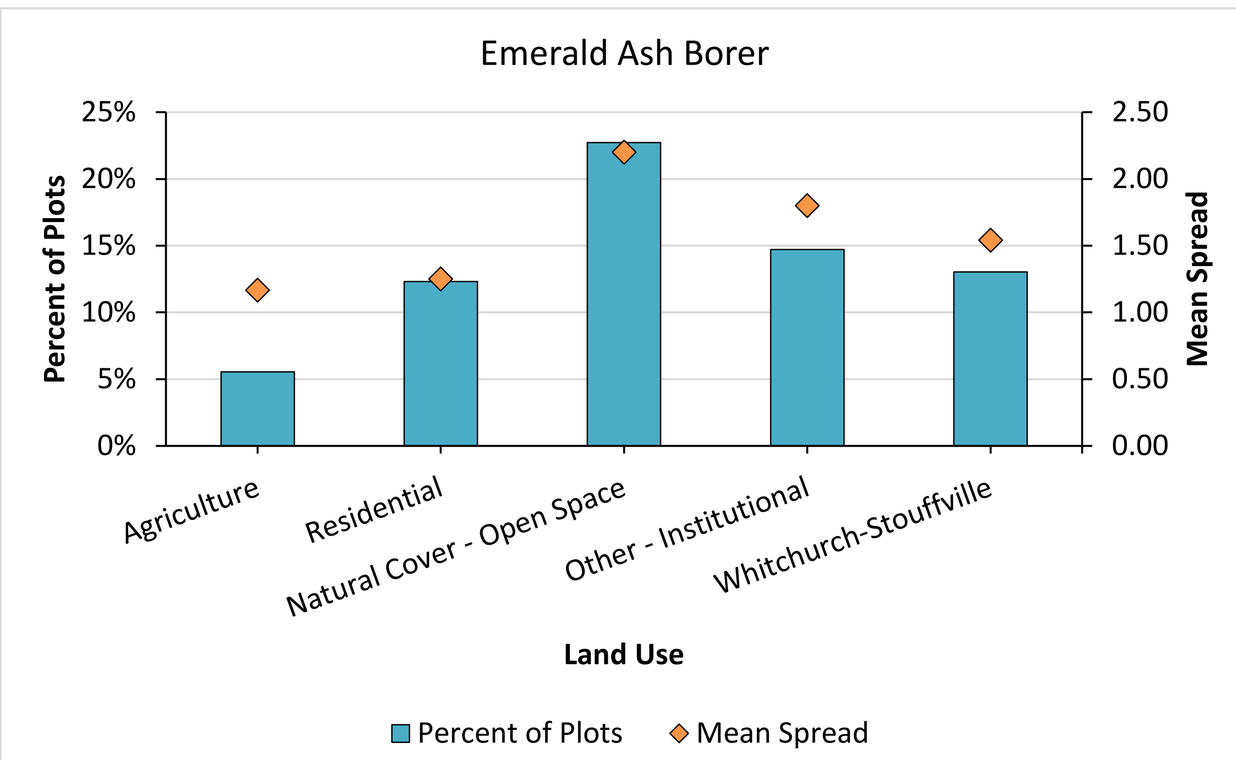


Figure 28. Percent of plots and average spread of spongy moth (top) and emerald ash borer (bottom)

Spongy moth was most frequently observed in *Other – Institutional* lands, whereas emerald ash borer occurred mostly in *Natural Cover – Open Space* (Figure 28). Eighteen percent of plots in *Other – Institutional* had signs of spongy moth, with an average spread of 2.2 indicating that at least 4 to 6 trees were infected per invaded plot. Spongy moth was also prevalent in *Natural Cover – Open Space* and *Residential*. When found in Residential areas (5%), spongy moth spread was greatest at 2.4. Emerald ash borer was highly invaded on *Natural Cover – Open Space* (23%), with a mean spread of 2.2, or 4 to 6 trees on average and *Other – Institutional* (15%), although with a slightly lower average spread (1.8, or on average slightly over 1 to 3 trees).

4.7.2 Invasive Diseases

While collecting field data at plots, crews also checked trees for the presence of beech bark disease (*Neonectria faginata*), beech leaf disease (caused by *Liscotylenchus crenatae ssp. mccannii.*), and Dutch elm disease (*Ophiostoma ulmi*). Due to a low occurrence rate (nine plots had diseases), analysis by strata is not meaningful. All three diseases were observed on one to three trees (Figure 29). Beech bark disease was observed the most, in six plots.

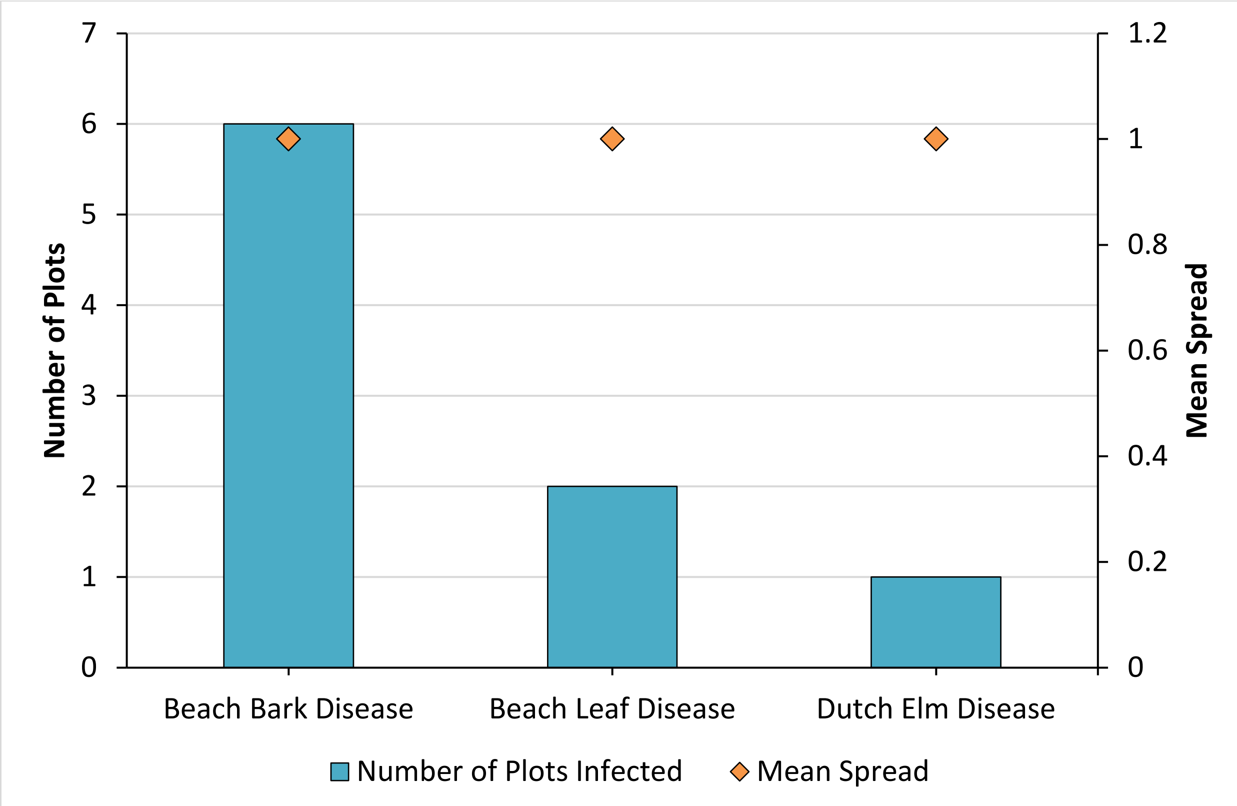


Figure 29. Number of plots infected and average spread of beech bark disease, beech leaf disease, and Dutch elm disease

4.8. Climate Vulnerability

4.8.1 Vulnerability Scores for the Top Twenty Most Abundant Species

Whitchurch-Stouffville's top twenty most abundant tree species were given a climate vulnerability score based on their exposure (occurrence outside of their ideal temperature range) and sensitivity to drought. The results are shown in Table 26.

Some notable highlights:

- The five most common species in Whitchurch-Stouffville's forest make up 51.5% of the tree population of (as discussed in Section 4.2.2).
- The most abundant species found in Whitchurch-Stouffville is the eastern white cedar (*Thuja occidentalis*), representing 18.5% of the tree population across the Town. The second most abundant species is the classic forest and planted species, sugar maple (*Acer saccharum*, 16.1%).
- 14 of the top 20 species, or 70% of the total population, were evaluated as highly or extremely vulnerable to future climate conditions in Whitchurch-Stouffville.

Table 26. Climate vulnerability scores for the top twenty most abundant species in Whitchurch-Stouffville

Vulnerability Score	Vulnerability classifications based on climate projections between 2040 to 2070 assuming the RCP8.5 scenario (PCCP 2021)[31]
Low	Species having low sensitivity to drought and low climatic exposure
Moderate	Species with two moderate rankings or with one moderate and one low ranking of either climate exposure or drought sensitivity
High	Species that had a high ranking of either climate exposure or drought sensitivity
Extremely High	Species that were both high in climate exposure and drought sensitivity rankings

[31] This assessment is based on the Peel Urban Forest Best Practice Guide 4 (2021b) and therefore uses RCP 8.5 (Representative Concentration Pathway) which represents the worst-case scenario for carbon emissions. Alternative vulnerability assessments may consider RCP 4.5, a moderate emission scenario, in which species' climate vulnerability may be shifted towards more modest values than under RCP 8.5. In addition, the selection of sensitivity and exposure criteria may also differ, resulting in further differences in vulnerability score. For more information, CVC's (2023), Climate change vulnerability of treed habitats in the Credit River Watershed, Appendix E, contrasts vulnerability scores of common climate vulnerability assessments. Source: https://cvc.ca/document/climate-change-vulnerability-of-treed-habitats-in-the-credit-river-watershed/

Common Name	Percent of Population (%)	Population with diameter <15.2 cm (%)	Vulnerability Score	Tolerances	Sensitivities	Risks
Eastern white cedar	18.5	51.3	High	• High resistance to ice damage	• Species within York Region at the southern end of their current range	
Sugar maple	16.1	64.3	Moderate		• Sensitive to drought	
European buckthorn	6.2	87.2	High			• Not recommended – invasive
Red Pine	6.0	33.0	High		• Flood intolerant	
Quaking aspen	4.7	51.4	High		• Low resistance to ice damage	
White spruce	3.9	26.3	High	• High resistance to ice damage	• Flood intolerant • Within York Region near the southern end of their current range	
Manitoba maple	3.8	50.4	Low		• Low resistance to ice damage	• Not recommended – potentially invasive

Common Name	Percent of Population (%)	Population with diameter <15.2 cm (%)	Vulnerability Score	Tolerances	Sensitivities	Risks
Eastern hophornbeam	3.5	84.3	Low	• High level of resistance to ice damage • Drought tolerant		
Eastern white pine	3.4	41.2	High	• Drought tolerant	• Flood intolerant	
Eastern hemlock	3.4	35.9	Extreme	• High resistance to ice damage	• Vulnerable to serious pest/disease	
White ash	3.0	84.4	High		• Flood intolerant • Vulnerable to serious pest/disease	• Not recommended
American Basswood	2.4	38.8	Moderate		• low resistance to ice damage	
Scots pine	2.0	19.9	Low		• Flood intolerant	• Not recommended – invasive

Common Name	Percent of Population (%)	Population with diameter <15.2 cm (%)	Vulnerability Score	Tolerances	Sensitivities	Risks
Common apple[32]	2.0	71.0	High			
Green ash	1.5	46.0	High		• Flood intolerant • Vulnerable to pest/disease	• Not recommended
Northern red oak	1.4	38.3	High			
Staghorn sumac	1.3	100	High		• Flood intolerant • Within York Region near the southern end of their current range	
Yellow birch	1.0	11.2	Extreme	• Flood tolerant	• Drought intolerant	
Alternate-leaf dogwood	1.0	100	Extreme			

[32] Common apple was not assessed as part of the Peel Region Urban Forest Best Practice Guides, Guide 4: *Potential Street and Park Tree Species for Peel in a Climate Change Context* (Peel Guide 4). Due to similarities with *Prunus virginiana*, it was given the same score.

Common Name	Percent of Population (%)	Population with diameter <15.2 cm (%)	Vulnerability Score	Tolerances	Sensitivities	Risks
Black Cherry	<0.1	68.6	Moderate	• Species within York Region at the northern end of their current range	• Low resistance to ice damage • flood intolerant	

4.8.2 Impact of Climate Change on the Whitchurch-Stouffville Forest and Top Five Most Abundant Species

Trees in urban areas are exposed to a variety of environmental stressors that are expected to be exacerbated by climate change. Based on the projected climatic conditions under the RCP 8.5 scenario, it is anticipated that Whitchurch-Stouffville's forest will be vulnerable to increased average temperatures, heat events, drought, and changes in precipitation patterns. Additionally, pests and diseases are likely to become more pervasive because of increased average temperatures and shorter, warmer winters. These impacts will directly affect the ability of urban trees to become established and survive.

Table 27 and Table 28 present summary impact statements identifying how stressors brought on by climate change are expected to affect the entire forest and the top five most abundant species growing across Whitchurch-Stouffville.

Table 27. Impacts of climate change on Whitchurch-Stouffville's forest

Climate Stressor	Outcome	Consequence
Increase in the frequency, intensity, and severity of extreme heat and other extreme weather events (e.g., windstorms)	• Greater damage to urban trees (and reduced urban tree canopy cover) • Higher tree mortality	• Loss of ecosystem goods and services provided by trees • Decreased shade from loss of canopy cover • Increased heat island effect in urban areas • Increased maintenance and tree replacement costs

Climate Stressor	Outcome	Consequence
Increase in average temperature, including warmer winters and drier summers	• Increased stress responses, such as loss of leaves and reduced tree growth • Shifting ecoregions for plants and animals • Change in species composition and the establishment of certain species (some species fare well with higher temperatures and drier conditions, while others do not) • Increased risk of pests and diseases • Disruptions in seed production	• Loss of ecosystem goods and services provided by trees • Loss of biodiversity among tree species • Increased maintenance and tree replacement costs • Increased survival and spread of invasive pests and diseases, such as emerald ash borer
Increase in extreme precipitation	• Greater damage to urban trees • Higher tree mortality • Increased risk of pests and diseases • Increased soil erosion • Increased stress and decline in tree growth	• Loss of ecosystem goods and services provided by trees • Increased maintenance and tree replacement costs • Increased survival and spread of invasive pests and diseases, such as emerald ash borer

Table 28. Impact statements for top five most abundant species

Species	Vulnerability	Outcome	Consequence
Eastern white cedar	High	Shifting ecoregion for species	Risk of species extirpation from Whitchurch-Stouffville due to the species being currently at southern end of current range
Sugar maple	Moderate	Decrease in health and increased mortality due to dry conditions and drought	Risk of population decline in Whitchurch-Stouffville; Increased maintenance and monitoring required
European buckthorn	High	Increased temperatures can result in enhanced growth; however, increased droughts can cause stress and negatively impact growth and condition	Climate change impacts could potentially help efforts to control this species
Red pine	High	Decrease in suitability of habitat over time; with more extreme weather events including floods, health will decrease	May see less in Whitchurch-Stouffville; Increased maintenance and monitoring required
Quaking aspen	High	Shifting ecoregion for species; Increase in extreme weather such as ice storm will damage trees	Risk of species extirpation from Whitchurch-Stouffville due to the species being currently at southern end of current range; Increased maintenance and monitoring required

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. Several recommendations are relevant in different sections and appear more than once. The recommendations have been developed in alignment with Whitchurch-Stouffville's existing planning and management documents, including the York Region Forest Management Plan and the Town of Whitchurch-Stouffville's Official Plan.

5.1. State of the Forest

The discussion and recommendations presented in this section pertain to four aspects of forest structure: distribution (subsection 5.1.1), species composition (subsection 5.1.2), age (or size) (subsection 5.1.3), and health (subsection 5.1.4). Many benefits attributed to the forest are largely influenced by these structural elements.

5.1.1 Existing and Possible Forest Distribution

Whitchurch-Stouffville's forest covers approximately 38% of the total land area. Total leaf area in the study area is 618.2 km^2, with a leaf area density of 9.32 m^2/m^2 (leaf area to land area). In the *York Region Forest Management Plan* (2016), two targets were set: a canopy cover of 40 to 45% and a woodland cover of 30% to 32%. As of 2019, Whitchurch-Stouffville's canopy cover was below the proposed target range, at 38.9%, and its woodland cover is within range at 30.9% (York Region, 2021). It is recommended that a time commitment should be set by which to improve the canopy target to the higher proposed range (e.g., 45% canopy cover by 2051). These targets provide valuable inputs for forest managers to plan annual tree planting and restoration projects to meet the targets. A timeline to reach the canopy target makes it more tractable and easier to incorporate into the Town's strategic plan, asset management plan, and budgeting process. Under the current planting plans, it would take Whitchurch-Stouffville approximately 4 years to reach the lower recommended value of 40% canopy cover, meaning the canopy cover may already be at the over 40% in 2024 since the canopy cover data is from 2019. By 2030, canopy cover should reach 45%. However, this assumes no loss of canopy cover to development or on private property and does not factor in natural regeneration. Given these positive projections, it is particularly important to focus on protecting the existing forest canopy to reduce potential losses that i-Tree Forecast could not predict.

Approximately 57.6% of the municipality (11,943 ha) has been identified as possible tree canopy (area theoretically available for additional tree establishment); the majority of this is identified as possible vegetated land cover (9,413 ha). However, it is not practical to plant in all pervious vegetated areas due to site considerations. A large portion of this pervious area is comprised of agricultural lands that are unlikely to be available for planting. Additionally, some potential impervious land (i.e., asphalt, concrete, or bare soil surfaces) may already be approved for development.

Whitchurch-Stouffville has opportunities for planting on both public and private properties across the municipality, but the greatest opportunity to increase the total leaf area and canopy cover is on largely private land in Whitchurch-Stouffville's *Agriculture*, *Residential Low* and *Open Space* land uses. The canopy cover analysis determined that 64%, 60%, and 57% of the land area of *Open space*, *Agriculture*, and *Institutional* categories, respectively, are vegetated cover available for the possible establishment of tree cover, representing 31% of the entire land area across Whitchurch-Stouffville. From a municipal perspective, there is also opportunity to increase canopy cover within the ROWs. However, the opportunities for canopy enhancement identified in ROWs could be limited due to space limitations such as hydro lines above and utilities underground. All available planting locations (based on tree spacing standards) could be occupied, but canopy cover could still be low, given many of the trees are young. In these areas, funding would be better spent on maintenance to ensure tree health and survival. Additionally, although establishing tree canopy in impervious surfaces is more challenging than in pervious cover, it would reduce the heat transfer from such surfaces and the volume of stormwater runoff.

Additionally, Whitchurch-Stouffville has opportunities for planting on private lands such as through LEAF's residential tree planting program, subsidized by York Region. This program could be further subsidized by the Town, which would encourage more people to plant trees on private property. It is necessary to use a variety of tools to engage private property owners including education, incentives, and mechanisms to make it easier to plant and maintain trees. The enforcement of by-laws is also essential to protecting the existing trees on private lands and ensuring that developers protect and plant trees. Development guidelines should ensure that developers include tree planting that follows industry best practices. The Town could look to other municipalities for example guidelines, such as Newmarket's Tree Preservation, Protection, Replacement and Enhancement Policy (2005).

It can be useful to set targets for specific land use types and use a prioritization method or tool to identify planting areas within particular land uses and neighbourhoods. York Region has developed a tree planting prioritization tool that could be adapted and customized for the Town of Whitchurch-Stouffville. The tool allows the user to adjust the weighting of nine criteria (canopy cover, potential canopy, air quality, urban heat island, water quality, stormwater reduction, critical places, vulnerable population, and economic vitality) and identify priority areas for planting at the dissemination block scale.

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 forest should also 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. Many areas have been impacted by emerald ash borer (*Agrilus planipennis*) and the resulting decline in ash tree (*Fraxinus spp.*) populations. These areas can be targeted for the planting of diverse tree and shrub species to ensure succession. Additionally, many areas have been recently impacted by spongy moth (*Lymantria dispar dispar*), particularly natural areas. While spongy moth has and will be problematic for a few years, it does not often cause widespread mortality, however impacted areas should be monitored and restored as needed.

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 human traffic and compaction of root zones. Many of the benefits provided by the 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.

Beyond planting strategies, existing valley systems, woodlots, and wetlands, as well as restoration areas, need to be prioritized. The *Other – Institutional* stratum is of particular interest given that it represents a number of vacant lands, woodlots, and valley lands. These may represent fragmented systems similar to those found in the *Natural Cover* land use which should be considered for protection. Protection of fragmented networks can improve species migration efforts while limiting edge effects from future development and provide corridors for species range shifts as climate change impacts continue to increase.

The distribution of the 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 forest are an asset that belong to the entire community and must be managed in a manner that ensures equitable access by all residents.

Recommendation 1: Create an (Urban) Forest Management Plan for the Town of Whitchurch-Stouffville and include: a canopy cover target; species diversity; forest health, maintenance, and monitoring; invasive species management; soil conservation strategies; and climate change mitigation and adaptation approaches.

The Town of Whitchurch-Stouffville Official Plan includes a recommendation to work with York Region to create an urban forest management plan.

Recommendation 2: The next Town of Whitchurch-Stouffville Official Plan update should include a commitment to a 45% canopy cover target to align with the York Region Forest Management Plan. Additionally, the development of a woodland cover target should be further explored as a component of an overall canopy target by assessing the feasible restoration potential across the Town's natural areas.

- Whitchurch-Stouffville is on track to achieve the 45% target with natural growth of the canopy if the existing canopy is protected. Planting efforts should be focused on urbanized areas with lower canopy cover to increase tree equity.

Recommendation 3: Assess how land uses contribute to canopy and identify areas for increasing canopy.

Recommendation 4: Create a tree canopy development and maintenance strategy to reach and maintain the goal of 40% canopy cover by 2051.

Recommendation 5: Work with York Region to customize and utilize the Region's tree planting prioritization tool for Whitchurch-Stouffville to improve equitable canopy cover distribution, the maximization of ecological benefits and ecosystem services, target areas impacted by invasive pests, and target high emissions zones. Use this to create a planting priority map to designate high priority areas for future plantings.

- Use other tools, such as the Conservation Authority's *Climate Resilient Planting for the Lake Simcoe Watershed* (2024) to analyze the quality and connectivity of the forest and optimize species diversity. Plant species that complement one another to increase diversity of the ecosystem.

Recommendation 6: Continue to develop mechanisms to encourage and support private landowners (particularly commercial and industrial landowners, and property developers) to protect and enhance canopy and educate those landowners about maintenance best practices.

- For example, maintain online presence and promote educational resources and materials, including LEAF programs and York Region's Grow Your Legacy program.

Recommendation 7: Continue to plant, prune, and replace trees on municipal properties. Evaluate planting and maintenance budgets regularly as the Town grows and assumes responsibility for new roads, parks, and facilities.

- Reassess tree care and maintenance practices for trees in highly urbanized areas. Indicators associated with street tree mortality should be considered, including plant hardiness and tolerances to harsher urban conditions, tree pit enhancements, direct tree care/stewardship.

Recommendation 8: Consider the development of a Naturalization and Restoration plan to bolster planting inputs in the natural heritage system and other naturalized areas.

- The Town of Whitchurch-Stouffville should continue to reforest lands across Whitchurch-Stouffville in order to expand forest cover and to strengthen ecological linkages. The Town should prioritize large non-treed sites within valley lands and abutting existing forests for the greatest ecological benefits. Other planting opportunities such as understory plantings should also be considered to increase diversity in existing forested areas. Use of high-quality native planting stock grown from locally adapted seed sources is strongly encouraged in all municipal planting projects, particularly in locations adjacent to natural areas. Planting stock availability will be directly dependent on the supply levels of local nurseries. Whitchurch-Stouffville should work with local growers to ensure that this demand can be met. 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 forest will have the opposite effect and will increase the vulnerability to invasive pests and diseases.

Recommendation 9: Continue assessing forest structure, function, and distribution every 10 years through the Forest Studies.

5.1.2 Tree Species Effects

Leaf morphology is influenced by species characteristics and varies across the forest. For example, the dominant tree species in the study area, eastern white cedar (*Thuja occidentalis*), a narrow-leaved species comprises 18.5% of all trees across the municipality, but only contributes 11% of the leaf area across the forest. The second most common species, sugar maple (*Acer saccharum*), is a broad-leaved species and while being the second-largest contributor to the tree population (16.1%), it is by far the largest contributor to leaf area (35.8%) across Whitchurch-Stouffville.

Species composition in Whitchurch-Stouffville is influenced by the pattern of vegetation distribution between land uses. As such, species common in the *Agriculture* land use, the dominant land use stratum in a rural municipality, strongly influence municipal-scale species composition. For example, eastern white cedar, the dominant species in this stratum, represents 32% of all trees in this land use and is the most common species in Whitchurch-Stouffville when expressed as a percent of total trees. This is due to extensive use of the species in hedgerows.

The most dominant species in Whitchurch-Stouffville in terms of tree leaf area are sugar maple (*Acer saccharum*, 35.8%), eastern white cedar (*Thuja occidentalis*, 11%), and northern red oak (*Quercus rubra*, 4.3%). Together, these three species represent 51% of the total tree leaf area across Whitchurch-Stouffville. These species represent some of the largest contributors to tree diversity in the region and are a good sign of forest succession. In terms of percent of population, eastern white cedar (*Thuja occidentalis*, 18.5%), sugar maple (*Acer saccharum*, 16.1%), and European buckthorn *(Rhamnus cathartica*, 6.2%) are most abundant comprising 41% of the total trees.

These genera are distributed across land use categories as they thrive in natural areas as well as high traffic urban zones. A high relative abundance of maple is typical in the forests of this ecoregion; however, the lack of diversity among genera is a threat to the sustainability of the forest. This is of particular concern in Whitchurch-Stouffville since 52% of the tree population and 55% of the leaf area are represented by 5 species. It is also of concern that European buckthorn, a non-native invasive species that displaces native vegetation, is slowly becoming more prevalent across land uses. Additionally, dominant species like eastern white cedar and emerging European buckthorn populations are not large trees and will not offer the same benefits and canopy as other species.

It is important for forests, in an urban context, to establish and maintain a diverse tree population (Leff, 2016). This increases the resilience of the forest to stressors such as species-specific insects or diseases and climate change. Thus, a forest that is not sufficiently diverse is at risk of widespread canopy loss. A greater diversity of tree species also supports more biodiversity and a wider range and quantity of ecosystem services (Gamfeldt, et al., 2013). While native and introduced tree species have a place in forests, some introduced species can pose a risk to native plants if they spread easily and out-compete or displace native species.

In general, it is important to establish native species that support greater levels of biodiversity and ecosystem resilience. In addition, the Sustainable Forest Guide (Leff, 2016) recommends that no single species (native or not) represent more than 5% of the total tree population in a municipality, no genus more than 10% and no family more than 15%. By these standards, Whitchurch-Stouffville is unfortunately overly dominated at the species, genera, and family levels. However, despite being overly dominated according to the Sustainable Forest Guide, there is no species representing more than 20% of the population which is more likely in urban municipalities given urban landscape planting practices. Regardless, monitoring species composition provides an indicator of the diversity of a forest and how

Recommenda. on 4 from 2017 Forest Study:

- no species represents more than 5% of total population
- no genus represents more than 10% of total population
- no family represents more than 20% of the intensively managed tree population both municipal-wide and at the neighbourhood level

vulnerable it might be to threats such as climate change and introduced pests. Changes over time indicate which species might be struggling with environmental shifts and which might be thriving or perhaps becoming invasive and therefore requiring management intervention or changing planting strategies. It is important to note that these rules apply well to intensively managed urban trees, but not natural areas. Climatic and soil conditions, and natural disturbance patterns generally establish the diversity of species in natural forests.

The impact of the emerald ash borer infestation highlights the risk associated with a lack of species diversity. Ash species were distributed across all land uses in Whitchurch-Stouffville, reflecting the ability of these species to thrive in both natural areas and high traffic urban environments where soil quality is low. Unfortunately, while Whitchurch-Stouffville still has a white and green ash population, their overall condition is very poor (47% and 33%, respectively, where white ash represents half of the ash population). Additionally, the forest is now recovering from a widespread spongy moth outbreak which feeds on a greater variety of species (discussed further in subsection 5.3.2).

The frequency and severity of pest outbreaks is increasing, creating an even greater need for diversity and resilience. Whitchurch-Stouffville is located in an ecoregion capable of supporting a high level of diversity, relative to other ecoregions in Canada (ecodistrict 6E-7—the Great Lakes – St. Lawrence Forest Region, and ecodistrict 7E-4—Carolinian Forest Region). Therefore, more aggressive diversity targets may be feasible. In addition, by utilizing a diverse mix of species from the Carolinian zone, the more diverse ecodistrict type, Whitchurch-Stouffville's forest will be more adaptable to both the predicted and unknown impacts of climate change. Whitchurch-Stouffville is advised to establish a species composition for intensively managed urban trees which no species represents more than 5% of the tree population, no genus represents more than 10% of the tree population, and no family represents more than 20% of the total tree population.

When developing species diversification programs consideration must be given to the potential damage of multi-host pests. The Pest Vulnerability Matrix is a model developed to visualize and assess the susceptibility of the forest to outbreaks of insects and diseases based on species composition and diversity (Laćan & McBride, 2008). The model predicts how the introduction of certain tree species, or a new pest species, will affect the overall vulnerability of the forest and has been applied locally; Vander Vecht and Conway (2015) explored the vulnerability of Toronto's forest to pests using the Pest Vulnerability Matrix. Using a model such as the Pest Vulnerability Matrix during tree species selection will help account for potential damage by future pest outbreaks, particularly by multi-host pests.

Diversity targets must also include a spatial scale 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. Efforts must be made to encourage and support nurseries, private landowners, and developers to sell or plant a greater diversity of native and suitable non-native, non-invasive species. Whitchurch-Stouffville should consider adding an educational campaign focused on species diversity for private landowners that ties in with any existing programming.

The use of high-quality native planting stock grown from locally adapted or suitable seed sources is strongly encouraged in all municipal planting projects, particularly in locations adjacent to natural areas. Planting stock availability will be directly dependent on the supply levels of local nurseries. 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 (discussed further in section 5.4.2). A reliance on clones in the 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. Species ranges should be considered when planting in the future as well to accommodate for a shifting climate (i.e., planting species at the northern half of their range as opposed to southern).

Recommendation 1: Create an (Urban) Forest Management Plan for the Town of Whitchurch-Stouffville and include: a canopy cover target; species diversity; forest health, maintenance, and monitoring; invasive species management; soil conservation strategies; and climate change mitigation and adaptation approaches.

Recommendation 10: In line with current practices, continue to establish a diverse tree population in intensively managed urban areas, in which no species represents more than 5% of the tree population, no genus represents more than 10% of the tree population, and no family represents more than 20% of the intensively managed tree population both municipal-wide and at the neighbourhood level.

- In 2017, the above recommendation was made to guide the establishment of a diverse tree population in Whitchurch-Stouffville. The current composition of the Town's forest does not yet reflect this ratio, however it should be noted that planting and management changes since the last study require sufficient establishment time frames which may not yet be reflected in this iteration of the Forest Studies. Each of the top three species represents more than 5% of the tree population (eastern white cedar (*Thuja occidentalis,* 19%), sugar maple (*Acer saccharum,* 16%), European buckthorn (*Rhamnus cathartica,* 6%)). The three most common genera each represent more than 10% of the tree population (maple (*Acer spp.,* 21.9%), cedars and junipers (*Cupressoideae* sub-family, 18.7%), and pines (*Pinus spp.*, 11.7%)).

Recommendation 11: Develop an invasive species management strategy. Apply targeted removal of high priority invasive plant species at high priority sites following best practices. Include the use of tools such as a Pest Vulnerability Matrix to aid in species selection for planting trees and shrubs.

- Given the sensitivity of native species to climate change, establishing a diverse forest composed of both native and suitable non-native non-invasive species will support the resiliency of the forest to stressors.
- Using a model such as the Pest Vulnerability Matrix during tree species selection will help account for potential damage by future pest outbreaks, particularly by multi-host pests.
- Develop a monitoring and action strategy for invasive species, including pests and diseases, and continue taking proactive approaches to address new and emerging invasive species, such as hemlock woolly adelgid and oak wilt.

Recommendation 12: Utilize native and appropriate non-native, non-invasive planting stock in intensively managed areas. Increase genetic diversity of tree populations by using the guidance provided by the Ontario Tree Seed Transfer Policy. This policy is intended to help managers source seed based on the projected changes in climate to increase the likelihood of producing trees well-adapted to current and future conditions.

- This recommendation was made in the 2017 report and has been updated for the 2024 report. Given the anticipated increase in invasive pest outbreaks because of climate change, it is essential to enhance the diversity of the forest to ensure it is resilient to insect and disease outbreaks.

Recommendation 13: Develop a street tree inventory and monitoring program that assesses diameter, condition and mortality for the purpose of informing maintenance, service requests, tree replacement and species selection. Update every five years.

5.1.3 Tree Size Effects

The proportion of large trees in Whitchurch-Stouffville is good for a municipality in the Greater Toronto Area; approximately 13% of the tree population has a diameter of 30.6 cm or greater, in contrast to 10% for urban municipalities[33]. The results of the i-Tree Eco analysis revealed the following diameter class distribution in Whitchurch-Stouffville: 56% of trees were less than 15.2

[33] Average percentage of tree population with diameter of 30.6 cm or greater across urban municipalities (Vaughan, Markham, and Richmond Hill) as part of the Forest Studies.

cm diameter, 31% were between 15.3 and 30.5 cm, 12% were between 30.6 and 61 cm, and 1% were greater than 61 cm.

Diameter class distribution of the tree population is influenced by a variety of factors. In addition to the age distribution of the forest, the land use land cover history and form strongly influence average tree size, as well as the natural growth patterns and characteristic forms of the dominant species. Much of the urban development in Whitchurch-Stouffville has occurred quite recently. Consequently, the trees planted at these new development sites have not yet reached maturity. In these more open spaces, they have the potential to become large in the future if they are well maintained and protected. However, most of Whitchurch-Stouffville's tree population occurs within natural forest remnants where tree structure is driven by light availability and space constraints. Despite competition with other trees, large older trees tend to be found in mature woodland stands where they have had the opportunity to reach a mature age. However, large trees are still underrepresented across Whitchurch-Stouffville. Therefore, it is vital that trees are maintained and protected to ensure these services are delivered into the future. With respect to species form, the most common species, eastern white cedar, typically maintains a small, shrubby form even at maturity, whereas sugar maple, the second most commonly occurring species can become very large.

Much of Whitchurch-Stouffville's forest consists of natural woodlands, due to the rural nature of the Town. Typical woodlands rely on natural regeneration for forest succession, resulting in a J-shaped curve for size distribution (Oliver & Larson, 1996). Natural regeneration is the primary means for forest succession across the Town. However, urban areas of the municipality rely on tree planting for forest succession, so managers should plan for future succession by planting replacement trees well in advance of mature tree decline and removal.

As trees increase in size, their environmental, social, and economic benefits increase as well. Young urban trees show an exponential increase in ecosystem service contribution within their early growth windows. Given the increase in light availability and lack of competition in most urban environments, young urban trees have been shown to have accelerated carbon cycling by up to four times compared to their natural counterparts (Smith, Dearborn, & Hutyra, 2019). As trees continue to age, their resources shift from focusing on primary growth to secondary growth and the once rapid increases in carbon cycling and associated ecosystem services slow down. Large trees provide larger energy savings, air and water quality improvements, runoff reductions, and visual impacts than smaller trees. They also contribute more to increases in property values, sequester and store more carbon dioxide, and provide greater infrastructure repair savings. For example, in Modesto, California, the shade from large-stature trees over city streets was projected to reduce costs for repaving by 58% (financial savings of CAD \$7.13/m^2) over a 30-year period when compared to unshaded streets (McPherson & Muchnick, 2005). In comparison, shade from small-stature trees was projected to save only 17% in repaving costs (financial savings of $2.04/m^2$). However, in the winter climate of York, shaded streets require more salt to address snow and ice.

Recommendation 1: Create an Urban Forest Management Plan for the Town of Whitchurch-Stouffville and include: a canopy cover target; species diversity; forest health, maintenance, and monitoring; invasive species management; soil conservation strategies; and climate change mitigation and adaptation approaches.

Recommendation 14: Evaluate and develop the strategic steps required to increase the number and proportion of large, mature trees across Whitchurch-Stouffville's forest including the Town's natural forests, street and park trees and trees on private lands.

- This can be achieved using a range of tools including Official Plan planning policy, by-law enforcement, and public education. Maintenance and monitoring of new plantings are critical to ensure that juvenile trees are healthy and able to grow to maturity. Where tree preservation cannot be achieved, an Official Plan policy could be considered that would require compensation for the loss of mature trees and associated ecosystem services.

Recommendation 15: Continue to review and enhance tree preservation requirements in municipal guidelines and regulations for sustainable streetscape and subdivision design standards (and particularly soil volume) to support tree establishment and eliminate conflict between natural and grey infrastructure.

5.1.4 Tree Health Effects

Quantifying ecosystem services associated with the Town's forest is critical when it comes to evaluating and managing green infrastructure in municipalities. However, the provision of ecosystem services is predicated on the health of the forest. While the i-Tree Eco model allows for the assessment of basic condition (percent dieback), a finer scale assessment of individual tree health is not built into the application, which would provide a better understanding of forest health across Whitchurch-Stouffville. It is particularly important to understand the health of trees in more heavily urbanized environments where tree services are of greater demand and benefit and where investments are being made in tree planting. Since Whitchurch-Stouffville opted for an additional tree health survey to complement the i-Tree Eco survey, field staff assessed the canopy structure, canopy vigour, foliage abnormalities, and trunk and root integrity of individual trees within plots. Tree health scores were then aggregated and averaged by stratum types to assess average tree health, with a higher score indicating better health and lower score indicating poor health (four-point scale from very poor (1) to good (4)). Due to a low sample size, the *Other – Institutional* and *Natural Cover – Open Space* strata were grouped together under ‘Other Natural’ and *Residential, Commercial – Industrial,* and *Utilities & Transportation* strata were grouped together under ‘Residential – Other Urban’.

The *Residential – Other Urban* land use stratum scored the highest average of any strata at 3.47 which falls into the ‘good’ category, the highest score for tree health. Residential trees are typically manicured and pruned, similar to public trees in rights-of-way (ROW), to reduce risks associated with damaged or dying branches. Having a high score here is reassuring as these trees typically face harsher urban environments, specifically those that fall in ROW which are included in this stratum type. Trees within ROWs are highly exposed to harsh urban stressors while providing the greatest benefit with respect to services in densely populated areas where emissions and urban heat island effects are most pronounced (Nowak & Crane, 2002). The integration of better soil health practices and irrigation systems would benefit trees within these constricted growing environments and should be considered by commercial and industrial landowners.

Trees in *Other Natural* are not managed as intensively for structural damage such as dead, dying, or broken branches like those in built-up environments. Additionally, being largely natural lands, the impacts of pests and diseases such as emerald ash borer have had pronounced impacts on the tree health score in the land use stratum. Dying and dead trees in natural areas are not removed unless they pose a risk to public safety (e.g., on trails) and dead trees contribute to the overall health score, many of which have been impacted by emerald ash borer. Additionally, the various ecosystems across this stratum and their microclimates contribute to the success of trees in each natural system. For example, tree species within a wetland ecosystem often face greater risk of site-related mortality associated with saturated soils.

Tree health was also analysed by whether the plot was forested or unforested and whether the plots were in built areas or unbuilt areas. Trees in forested and unbuilt plots had significantly lower health scores, which makes sense since natural areas are less heavily managed, so dead and dying trees are left standing instead of being removed for safety concerns. This decreases the overall health scores in forested and unbuilt areas. However, the lower health scores do not necessarily mean these forested areas are in poor health. To have a healthy natural forest, it is important to have some trees with dead wood and cavities, since they provide habitat, structural diversity, and add organic matter to an ecosystem (OMNR, 2004). The tree health scores are a better indicator for individual tree health and apply best to intensively managed urban areas.

The Town of Whitchurch-Stouffville and York Region actively maintain publicly owned trees. Whitchurch-Stouffville, through York Region, also partners with Local Enhancement and Appreciation of Forests (LEAF) on the Backyard Tree Planting program, which includes consultation with tree specialists on tree care. The tree health assessment provides a useful overview of the general condition of trees on different land uses across Whitchurch-Stouffville. This program could be built upon by having it subsidized by the Town, making it more affordable. Overall, Whitchurch-Stouffville's average tree health score is 3.32 which falls into the 'Good' category and is a positive sign of the average health of trees across the municipality. The score indicates that trees across the municipality, for the most part, should be delivering services within an expected capacity. However, as urban stressors in specific land use strata continue to increase, compounded by effects of climate change, they should be managed to promote future tree health so that the canopy cover across Whitchurch-Stouffville continues to provide benefits for years to come.

5.2. Forest Function

The following is a discussion of the services (benefits) that have been quantified by the i-Tree Eco model for effects on air quality, stormwater runoff, residential energy effects, and climate change mitigation and adaptation. All forest benefits should increase in Whitchurch-Stouffville as a result of the implementation of the recommendations shared in this report. In addition, recommendations are provided here to address further needs and opportunities.

It should be noted that changes have been made to the i-Tree Eco suite of software[34] since the 2016 study, therefore the quantified benefits cannot be directly compared between the study years.

5.2.1 Effect on Air Quality

Trees and shrubs in Whitchurch-Stouffville removed a total of 447 tonnes of air pollution (CO, NO_2, O_3, $PM_{2.5}$, SO_2) annually with an associated removal value of $1.22 million annually. Pollution removal is greatest for ozone (O_3), followed distantly by nitrogen dioxide (NO_2) and particulate matter less than 2.5 microns ($PM_{2.5}$). 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 increase susceptibility to respiratory infections (Environmental Protection Agency (EPA), 2003). Ozone is linked with an increased number of daily deaths, respiratory deaths, and cardiovascular deaths (Manisalidis, Stavropoulou, Stavropoulos, & Bezirtzoglou, 2020). Exposure to ambient nitrogen dioxide is shown to have an interaction with the immune system which could increase the risk of respiratory tract infections (Chen,

[34]Refer to i-Tree Suite Change Log here for additional information on changes to the model: https://www.itreetools.org/documents/186/iTree_suite_change_log.pdf

Kuschner, Gokhale, & Shofer, 2007). $PM_{2.5}$ is shown to cause similar effects with acute exposure leading to irritation of the eyes, nose, throat, and lungs with potential for effects related to toxicity and inflammatory responses (Feng, Gao, Liao, Zhou, & Wang, 2016). Fine particulate matter has also been linked to cardiovascular diseases and raised infant mortality (Manisalidis, Stavropoulou, Stavropoulos, & Bezirtzoglou, 2020). Environmental pollution is now a concern as well, with the increasing presence of air pollution following the rapid urbanization of many municipalities, the compounded effects of air pollution on temperature regimes can have consequences on the frequency or presence of many infectious diseases and natural disasters (Manisalidis, Stavropoulou, Stavropoulos, & Bezirtzoglou, 2020). These pollutants are emitted primarily from the burning of fossil fuels, vehicular engines, and industry.

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, Morton, Ogilvie, Maarouf, & Kelleher, 2002). For example, the occurrence of oppressive air masses that bring hot, humid and/or smoggy conditions is projected to increase from 5% of summer days to 23-39% by 2080. This means that the Greater Golden Horseshoe Region will likely experience more frequent, 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, Whitchurch-Stouffville's forest plays an important role in community wellness, particularly for those more vulnerable members of the population.

The i-Tree Eco results show that larger diameter trees remove more pollution on average, per tree, than smaller trees. Similarly, trees were found to remove greater volumes of pollution than shrubs. In both cases, pollution removal capacity was a direct function of leaf area. Selecting species that are well adapted to local conditions and require little to no maintenance is recommended as they will typically have longer life spans providing long term filtration of air pollutants. Additionally, studies have shown that areas with high levels of ground emissions, such as vehicular traffic along a highway, should be targeted for plantings. As pollutants are released upwards from areas of high emission, the adjacent planted areas can increase immediate removal while limiting trapping pollutants beneath the canopy (Nowak, Hirabayashi, Bodine, & Greenfield, 2014).

However, it is important to note that trees and shrubs emit volatile organic compounds such as monoterpene and isoprene. These compounds are natural chemicals that make up essential oils, resins, other plant products, and are the precursor chemicals to ozone and carbon monoxide formation (Kramer & Kozlowski, 1979). An estimated total of 244.5 tonnes/yr of volatile organic compounds (201,109 kg/yr of monoterpenes and 43,434 kg/yr of isoprene, respectively) are emitted annually with the largest portion of the emissions coming from

Residential, Other – Institutional, and *Agriculture,* which have the most trees. However, this process is temperature dependent and given that trees typically contribute to lowering air temperature, the net results are still often positive in terms of the impact of trees on air quality. To put this number in perspective, total annual volatile organic compound emissions from Whitchurch-Stouffville from all sources are about 1,277 tonnes (The Conference Board of Canada, 2024).

Recommendation 1: Create an Urban Forest Management Plan for the Town of Whitchurch-Stouffville and include: a canopy cover target; species diversity; forest health, maintenance, and monitoring; invasive species management; soil conservation strategies; and climate change mitigation and adaptation approaches.

Recommendation 16: Bolster evergreen tree population across the municipality to improve year-round pollution removal services.[35]

- By planting evergreen species, with foliage all year round, such species can provide air pollution removal benefits during the leaf-off seasons (late fall to early spring) when deciduous trees cannot.

5.2.2 Effect on Stormwater Runoff

Stormwater runoff is a concern in urbanized landscapes as cities continue to develop and extreme weather events increase in frequency due to climate change. As built infrastructure is implemented, the associated increase in impervious surfaces can function to increase runoff (Hirabayashi, 2013). The increase in impervious land cover allows contaminants such as oils and fertilizers to be transported by runoff into adjacent channels, streams, and ground water. As polluted stormwater feeds into the hydrological system, it can have cascading effects on sensitive species and nutrient imbalances (Kollin, 2006). Green infrastructure can help mitigate these negative impacts by retaining stormwater. The trees of Whitchurch-Stouffville provide a hydrological benefit with a stormwater offset estimated at 100,087 m^3 across the municipality, valued at $232,601 annually. The *Residential* and *Agriculture* land use strata provide the greatest benefits and avoid approximately 30,522 m^3 and 28,616 m^3 of stormwater runoff, respectively. This large contribution is based on the prominent natural woodlands that fall on large agricultural and residential properties.

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[35] Some evergreen species emit high levels of volatile organic compounds, however this should not preclude them from planting programs. When possible and appropriate, consider planting low volatile organic compound emitting species.

Green infrastructure, and trees specifically, provide a host of services relevant to stormwater runoff. Foliage and branches intercept precipitation which functionally reduces a portion of precipitation that may otherwise become runoff. Additionally, canopies reduce soil erosion caused by direct rainfall and allow soils to store larger volumes of precipitation (Brandt, 1988). At the ground level, runoff infiltrates the soil, and pollutants are naturally filtered and broken down by roots and microbial life (Schloter, Nannipieri, Sørensen, & van Elsas, 2018).

To have a healthy, functional hydrological network, a balance between green and grey infrastructure should be considered in development planning. For example, green infrastructure provides shading which can improve pavement lifespans while allowing for natural stormwater runoff controls and should be weighted in tandem with grey infrastructure.

Recommendation 1: Create an Urban Forest Management Plan for the Town of Whitchurch-Stouffville and include: a canopy cover target; species diversity; forest health, maintenance, and monitoring; invasive species management; soil conservation strategies; and climate change mitigation and adaptation approaches.

Recommendation 15: Continue to review and enhance tree preservation requirements in municipal guidelines and regulations for sustainable streetscape and subdivision design standards (and particularly soil volume) to support tree establishment and eliminate conflict between natural and grey infrastructure.

- Green infrastructure should be incorporated into grey infrastructure planning and development as it can function to intercept precipitation, cool paved surfaces, directly remove air pollution, and improve soil content available for runoff capture in urbanized areas.

Recommendation 17: Continue applying soil enhancement techniques and enhanced rooting environments (i.e., silva cells, aeration, vertical mulching, etc.) on a project-by-project basis for street trees, particularly in constrained spaces such as intensification areas.

- Utilizing these technologies at selected sites in the short-term may provide a cost-effective means of integrating these systems into the municipal budget. Silva cells can function to improve stormwater runoff channels.

Recommendation 18: Explore the opportunity to utilize the Sustainable Technology Evaluation Program Treatment Train Tool to evaluate and quantify the stormwater benefits of planting trees.

- The Low Impact Development Treatment Train Tool provides the ability to design and evaluate different urban tree planting scenarios at the site level to determine stormwater management benefits and can be a very effective way to demonstrate the benefits of urban tree planting.

5.2.3 Effect on Residential Energy Bills

Trees that are adjacent to buildings can reduce the demand for heating and air conditioning through their moderating influence on solar insulation and wind speed. In addition, trees ameliorate climate by transpiring water from their leaves, a process that has a cooling effect on the atmosphere. Thus, the effective placement of trees or shrubs can insulate or lower building temperatures. McPherson and Simpson (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 emission reductions from forests 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 & McPherson, 2000). In Whitchurch-Stouffville, the annual demand for heating and cooling was reduced by approximately 133,148 MBtu and 1,997 MWh, with an associated annual financial savings of $796,900. The relatively small benefit to residential owners is likely influenced by much of the tree cover in Whitchurch-Stouffville occurring in natural woodlands, plantations and large spaces removed from direct influence on residential properties[36].

Given Whitchurch-Stouffville's colder winter climate, there were greater savings associated with the reduction of heating ($682,548) than cooling ($114,356), primarily related to a decrease in the need for natural gas ($577,194). This may also be due to current tree species and placement, which can have significant impact on potential energy savings. For example, evergreen 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, large deciduous trees planted on the east and west sides of a house will shade buildings during hot summer months, but after their leaves have dropped, will allow heat to reach homes in the winter (Ko, 2018). However, as climate projections predict an increase in cooler days, the Town should consider

[36] The i-Tree Eco model estimated the effects of trees (≥ 6.1 m in height and within 18.3 m of a residential building, excluding high rises) on building energy use due to shading, windbreak effects, and local micro-climate amelioration.

whether this might impact species selection. Public education and outreach will be required to communicate these benefits and to provide direction for strategic planting around buildings to enhance energy savings.

Recommendation 1: Create an Urban Forest Management Plan for the Town of Whitchurch-Stouffville and include: a canopy cover target; species diversity; forest health, maintenance, and monitoring; invasive species management; soil conservation strategies; and climate change mitigation and adaptation approaches.

Recommendation 19: Following the Town of Whitchurch-Stouffville's Official Plan recommendation to encourage green roofs (Section 6), consider including the potential of trees to provide energy savings when developing planting guidelines or standards.

- Tree species selection and placement should be targeted to provide summer shade and reduce winter wind speeds around residential buildings.

5.2.4 Climate Change Mitigation and Adaptation

Trees can mitigate climate change by sequestering atmospheric carbon and then storing it long-term as woody biomass. During photosynthesis, atmospheric carbon dioxide (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).

In Whitchurch-Stouffville, trees sequester approximately 17,706 tonnes of carbon annually (value of $2.0 million), with net sequestration at 10,561 tonnes per year, and store approximately 681,923 tonnes of carbon (value of $78.3 million). The annual carbon sequestration by trees in Whitchurch-Stouffville is equivalent to the annual carbon emissions from 3,940 automobiles or powering 2,232 single family homes[37].

The forest can also decrease carbon dioxide levels by reducing the demand for heating and air conditioning in residential buildings, subsequently avoiding carbon emissions by power plants. In Whitchurch-Stouffville, the annual demand for heating and cooling was reduced by approximately 113,148 MBtu for natural gas use (heating) and 1,997 MWh for electricity

[37] Values approximated using Whitchurch-Stouffville's gross annual carbon sequestration value in the United States EPA Greenhouse Gas Equivalencies Calculator: https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

(heating and cooling). Ontario's energy grid is currently nuclear and hydro dominant, with relatively low carbon emissions. However, it is projected to become more dependent on natural gas as nuclear plants are being closed for refurbishment or are decommissioned. Therefore, the reduced demand for heating due to the forest may have a more substantial impact on natural gas use in the future.

Nowak and Crane (2002) argued that carbon released through tree management activities must be accounted for when calculating the net effect of forests on atmospheric carbon dioxide. Tree care practices often release carbon into the atmosphere due to fossil fuel emissions from maintenance equipment. 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, dependent on the species. If trees succumb to early mortality, sustaining the tree population will lead to net emissions of carbon throughout the life cycle of that population (Nowak & Crane, 2002). This observation further highlights the importance of selecting low maintenance, well-adapted native species with the goal of maximizing tree health and longevity. Additionally, there should be a shift towards the use of electric tools to reduce the small-scale carbon emissions directly associated with maintenance.

When selecting trees for planting, it is also important to consider which have a greater potential for carbon sequestration and storage. In Whitchurch-Stouffville, sugar maples (*Acer saccharum*) store the greatest volume of carbon (approximately 30% of total carbon stored) and are also responsible for the most annual net sequestration (26% of total net sequestered carbon and 21.1% of gross sequestration). This is a native species with only moderate climate change vulnerability, but planting should also consider the diversity of the forest. The second species to store the most carbon was the highly vulnerable eastern white cedar (*Thuja occidentalis,* approximately 19% of total carbon stored). Eastern white cedar also sequesters the second greatest volume of carbon (approximately 13% of gross sequestration).

As climate change continues, the role of trees, and to a larger extent the forest, will become increasingly important to mitigate heat stress especially in urban areas which are already warmer than surrounding regions due to the urban heat island effect (LSRCA, 2018). Shade trees can decrease near-surface air temperatures by an average of 3°C by intercepting solar radiation and evapotranspiration, improving pedestrian thermal comfort, and decreasing human mortalities during heatwaves (Wang, Wang, & Yang, 2018; Wong, Tan, Kolokotsa, & Takebayashi, 2021). Thus, by improving and maintaining the forest, Whitchurch-Stouffville is investing in public health.

Municipalities will need to change their approach to forestry to adapt to the changing climate. The Lake Simcoe Region Conservation Authority (2018) published a report on how to adapt forestry programs for climate change, including many suggestions for how to improve forest management as the climate changes. The report includes a list of species that will be appropriate for planting in the future to guide forest managers, including some species that are not currently suitable but will become suitable with time and assisted migration. In a changing climate, managers should also consider improving tree risk management, adaptive management techniques, improving species, genetic, and ecosystem diversity, and other techniques. Whitchurch-Stouffville could benefit from many of the suggestions in the report, and staff should review them and implement recommendations accordingly.

Recommendation 1: Create an Urban Forest Management Plan for the Town of Whitchurch-Stouffville and include: a canopy cover target; species diversity; forest health, maintenance, and monitoring; invasive species management; soil conservation strategies; and climate change mitigation and adaptation approaches.

Recommendation 20: Consider including species' capacity for carbon storage and sequestration when developing planting lists or guidelines and future Urban Forest Management Plans.

- The Town should explore the potential to modify York Region's Tree Planting Prioritization Tool with species-specific criteria to shift planting recommendations to native and appropriate non-native, non-invasive species that have a higher capacity for carbon storage and sequestration.

Recommendation 21: As outlined in the Whitchurch-Stouffville Official Plan (Section 1.2.2.2), the Town should support the advancement in stewardship of green infrastructure and invest in climate change mitigation and resilience.

- Consider developing a green infrastructure (GI) / nature-based solutions life cycle management plan. This will extend the life of GI assets and promote the climate change mitigation benefits of such infrastructure.
- Reference the City of Toronto 'Life Cycle Activities for Green Infrastructure in the Right-of-Way' to aid in completion of the plans.

Recommendation 22: Under the context of a changing landscape and climate, consider monitoring stand level dynamics and growth trends for select key tree species.

- Stand level dynamics refer to the interactions among individual plants and abiotic factors in a group of mostly homogenous trees.
- For example, partner with York Region to conduct studies or growth trials.

5.3. Sustaining a Healthy Forest

5.3.1 Soil Health

The chemical and physical properties of soil influence its fertility and the capacity for plant growth (Pickett S. , et al., 2011). The primary concerns for rural soils, which are predominant in Whitchurch-Stouffville, are field runoff impacts and the consequent pollution deposits, soil stripping, and erosion from large precipitation events. This is of specific concern given that most active agricultural lands are routinely tilled and provide channels for runoff which exacerbates soil stripping and eventually leads to soil erosion (Zhang, Liu, Cheng, & Huang, 2016). In contrast, soils in urbanized areas are highly vulnerable to disturbances, and often become modified due to direct effects, such as construction activities, and indirect effects, such as pollution (Foldal, Leitgeb, & Michel, 2022; Lehmann & Stahr, 2007; Pouyat & Trammell, 2019). Consequently, urban soils often have disrupted natural soil structures, mixed soil horizons, and are blended with fabricated materials (e.g., bricks, glass, crushed stones) (Foldal, Leitgeb, & Michel, 2022; Pouyat & Trammell, 2019; Pouyat, Yesilonis, Russell-Anelli, & Neerchal, 2007). Additionally, urban soils are characterized by high levels of compaction, salinity, and alkalinity because of intensive human management and deposition of toxic elements from impermeable surfaces (Foldal, Leitgeb, & Michel, 2022; Lehmann & Stahr, 2007; Pickett S. , et al., Urban ecological systems: Scientific foundation and a decade of progress, 2011; Pouyat & Trammell, 2019; Pouyat, Yesilonis, Russell-Anelli, & Neerchal, 2007).

Results from the Whitchurch-Stouffville soil health assessment showed that soils in forested areas across the municipality have a slightly lower pH than soil in unforested areas, and compaction is higher in unforested lands. The observed patterns of higher compaction, salinity, and pH levels in Whitchurch-Stouffville are aligned with prior research examining the properties of urban soils altered by human activities (e.g., soils on developed land, soils adjacent to roads) (Foldal, Leitgeb, & Michel, 2022). These factors contribute to lower fertility and sub-optimal conditions for plant growth in urban soils (Pouyat, Yesilonis, Russell-Anelli, & Neerchal, 2007). Tree condition was found to decrease as soil compaction and pH increased. This can likely be explained by the fact that natural areas – which were the least compacted and had lower pH levels – had higher proportions of dead trees.

Rural or agricultural soils are typically found to be significantly healthier than their urban counterparts. For example, soil compaction is often considered the greatest inhibitor to tree health since compaction functions to reduce water and nutrient availability for trees. Rural soils are often composed of a larger representation of microbial communities as well which are shown to reduce salinity stress and have greater function with less available carbon than urban microbial communities (Yang, Campbell, Clark, Cameron, & Paterson, 2006). Findings suggest that reduced microbial communities in urban soils may function as an indicator of pollutant heavy metal stress on soil health.

While rural soils may experience less pollutant metal stress due to a general lack of major industrial plants and lighter vehicular traffic, the stresses unique to active agricultural lands may still eventually deteriorate future rural soil conditions. It should be noted that the immense hydrological benefits, and more specially avoided runoff, provided by Whitchurch-Stouffville's forests helps alleviate runoff stress across the Town. However, as much of Whitchurch-Stouffville's lands are converted agricultural croplands, there is need to consider private landowner engagement programs to promote monitoring and management strategies to alleviate runoff stress and continue to promote the high functioning rural soils of Whitchurch-Stouffville. The planting of hedgerows and buffer trees and vegetation around fields may help to reduce runoff and erosion.

Human disturbance that causes movement of soil, particularly for construction, in combination with the intensity of land use in urban areas contributes to higher compaction levels, impeding healthy plant growth (Foldal, Leitgeb, & Michel, 2022; Kaye, Groffman, Grimm, Baker, & Pouyat, 2006; McDonnell & Pickett, 1990; Pouyat, Yesilonis, Russell-Anelli, & Neerchal, 2007). Higher compaction is typical of urban soils, leading to reduced root growth, lower soil water-holding capacity, restricted oxygen penetration, and greater surface water flow (Pickett S. , et al., Urban ecological systems: Scientific foundation and a decade of progress, 2011; Pouyat, Yesilonis, Russell-Anelli, & Neerchal, 2007). Better management is essential to reduce the compaction of soils and increase their productivity (De Kimpe & Morel, 2000; Scharenbroch, Lloyd, & Johnson-Maynard, 2005). Preventing soil compaction is more cost-effective than implementing corrective actions and can be achieved by reducing foot and vehicular traffic on root zones of trees during construction and ensuring adherence to proper soil installation procedures (Peel Climate Change Partnership (PCCP), 2021a). Mulch and underplanting are useful amendments because they help mitigate compaction and protect exposed soils from external pollutants (Peel Climate Change Partnership (PCCP), 2021a; Pickett S. , et al., Urban ecological systems: Scientific foundation and a decade of progress, 2011). Remedial measures should also be considered to improve compacted soils. For example, aerating compacted urban soils, particularly in exposed areas, would be beneficial to improve air flow to roots (De Kimpe & Morel, 2000). Additionally, increasing organic matter content by adding topsoil or compost to urban soils can help add nutrients and soil decomposers to soils (Pickett S. , et al., Urban ecological systems: Scientific foundation and a decade of progress, 2011).

Soils provide many ecosystem services, with healthy soils providing more services than unhealthy soils (Kibblewhite, Ritz, & Swift, 2008). Agricultural practices can degrade soil by prioritizing crop growth over other ecosystem services such as carbon sequestration or water retention. To maintain a balance in ecosystem services, including agricultural production, sustainable practices must be adopted (Kibblewhite, Ritz, & Swift, 2008). In agricultural areas, shelter trees can improve soil properties by reducing erosion, increasing carbon sequestration, and improving nutrient additions to soils (Casement & Timmermans, 2007; Rempel, Kulshreshtha, Amichev, & Van Rees, 2017). Marginal lands on edges of agricultural fields can be improved with healthier trees, which will improve the quality of the soils in the adjacent agricultural fields (Young, 2000). The Town and local farmers should aim to improve the health of trees in agricultural areas to improve overall soil health and the longevity of these areas.

In urban environments, there is concern about the application of road salts in winter resulting in salt accumulation in adjacent soils. Road salts are composed of sodium, calcium, magnesium, and potassium chlorides (Sustainable Technologies Evaluation Program, 2019). Excess salts hinder plant growth by affecting the soil-water balance. They also decrease soil microorganism activity which in turn impacts important soil processes such as respiration, residue decomposition, nitrification, and denitrification. Soils with a high concentration of sodium salts (sodic conditions) have additional problems, such as poor soil structure, poor infiltration or drainage, and toxicity for many plants (USDA, 2014). Higher exposure to heavy metals and other pollutants as well as saline or sodic conditions are also indicative features of urban soils (Manta, Angelone, Bellanca, Neri, & Sprovieri, 2002; Pickett S. , et al., Urban ecological systems: Scientific foundation and a decade of progress, 2011; Pickett S. , et al., 2001; Pouyat, Yesilonis, Russell-Anelli, & Neerchal, 2007). The results of the salinity analysis were consistent with findings in the literature, showing higher salt levels in the soils of built and developed land use types. The Town should engage private landowners so that they can be more aware of the harmful impacts salt has on tree growth and encourage them to follow best practices for winter ice management as outlined in Sustainable Technologies Evaluation Program (2019).

Urban soils commonly have an increased pH due to leaching of cement or masonry from the built environment (Foldal, Leitgeb, & Michel, 2022; Lehmann & Stahr, 2007; Pouyat, Yesilonis, Russell-Anelli, & Neerchal, 2007). pH levels influence nutrient availability, uptake, and tree growth (Mississippi State University Extension (MSU), 2022). Soil bacteria transform nutrients in organic matter, making them accessible to trees. These bacteria are most effective in slightly acidic soils, so soils with higher pH levels have a lower availability of certain nutrients. However, it is important to recognize that tree species have different preferred pH levels and tolerances (Mississippi State University Extension (MSU), 2022). Therefore, a finer scale soil assessment in the future would provide a more thorough understanding of the relationship between soil pH and tree health. Species-specific pH tolerances should be considered when tree planting sites are identified in future initiatives.

The Town of Whitchurch-Stouffville is less urbanized in comparison to several other Greater Toronto Area municipalities, but the negative impact of development should not be overlooked. Despite the Town having a large natural forest cover system, as development pressures intensifies and populations expand, the impacts on urban soils may increase. The Town should consider soil remediation, enhancing, and buffering techniques to avoid urban soil degradation as urbanization expands.

Recommendation 1: Create an Urban Forest Management Plan for the Town of Whitchurch-Stouffville and include: a canopy cover target; species diversity; forest health, maintenance, and monitoring; invasive species management; soil conservation strategies; and climate change mitigation and adaptation approaches.

Recommendation 17: Continue applying soil enhancement techniques and enhanced rooting environments (i.e., silva cells, aeration, vertical mulching, etc.) on a project-by-project basis for street trees, particularly in constrained spaces such as intensification areas.

- Green infrastructure should be incorporated into grey infrastructure planning and development as it can function to intercept precipitation, cool paved surfaces, directly remove air pollution, and improve soil content available for runoff capture in urbanized areas.
- One area to focus on would be Main Street, where there is potential for the use of Silva Cells to ensure it does not become a heat island.

Recommendation 23: Ensure best practices for healthy soils are implemented in Whitchurch-Stouffville's public and private urban areas in the planning of corporate or public planting programs, from site selection and assessment to species selection. Consider reference tools and programs such as the Sustainability Metrics program used by Markham, Richmond Hill, and Vaughan.

Recommendation 24: Manage compaction, salinity, and pH on public property through amendments and remedial measures like mulching and planting of herbaceous cover and shrubs on a case-by-case basis.

Recommendation 25: Continue to educate private homeowners and industrial and commercial landowners about soil best practices.

- For example, private landowners are encouraged to use less salt for de-icing, and to follow best practices for applying salt as outlined in *Sustainable Technologies Evaluation Program Winter Salt Management* (2019). Additionally, education opportunities should be leveraged through planning application processes to ensure developers are aware of soil best practices.

5.3.2 Invasive Plant Species

Invasive species' inherent capacity to outcompete native plants and change plant community composition is a growing biodiversity, economic, and social concern. In Whitchurch-Stouffville, the most commonly found invasive plant species in terms of proportion of plots affected are European buckthorn (*Rhamnus cathartica,* 21%), Manitoba maple (*Acer negundo*, 34%), garlic mustard (*Alliaria petiolata*, 10%), non-native honeysuckle (*Lonicera spp.*, 8%), and dog strangling vine (*Cynanchum rossicum,* 7%). These species are known to dominate ground vegetation and have various strategies to limit competition with native flora. Some examples of their impacts include the explosive establishment and growth of dog strangling vine from forest edge to interior, the allelopathic properties of garlic mustard to limit native species success while establishing a seed bank for as long as 5 years (Blossey, Nuzzo, & Davalos, 2017). Additionally, European buckthorn's prolific seed production and dispersal ability can lead to the development of blanket thickets of seedlings that, once established along disturbed edge or urban environments, allows the species to easily displace native flora from the ground level up. The capacity for European buckthorn to spread is compounded by other invasive properties, severely limiting the establishment of native plant species in natural, peri-urban, and urban settings (Ontario's Invading Species Awareness Program, 2024).

With respect to the percentage of total stems across the municipality, European buckthorn is the largest concern, and in terms of total leaf area Manitoba maple is the most dominant invasive plant species. Additionally, European buckthorn is the most dominant invasive species across all land use types, followed by Manitoba maple and garlic mustard which permeate nearly all land use strata at a lower intensity. These three species are the most abundant invasive plant species overall and disproportionately represent invasive plant establishment across all land use strata.

An overall invasive score, derived from multiplying the average spread and average number of invasive species, shows that the spread of invasives in *Other Urban* (score of 4.3) is the greatest concern, followed by *Agriculture* (score of 3.4) and *Other – Institutional* (3.4). In the *Other Urban, Other – Institutional*, and *Agriculture* land use strata, over 38.5%, 35.3%, and 26.9% of plots, respectively, had at least one invasive plant species present. *Residential* and *Open Space – Natural Cover* or *Other – Institutional* (specifically the *Other* land use) strata often exhibit a tandem effect where residential invasive populations escape and drive the spread of invasives in natural areas leading to cascading negative effects on the capacity of natural areas to deliver ecosystem services (Hands, Shaw, Gibson, & Miller, 2018). The prevalence of invasives in the *Residential* stratum (40%) is of special concern in Whitchurch-Stouffville given this tandem effect. As more exotic species are planted in *Residential* lands, it is expected that this stratum will continue to support invasive species.

Natural forested areas and woodlot patches in rural municipalities tend to be largely connected. However, as urbanization expands, the presence of developed lands will slowly increase the vulnerability of natural areas in the Town to invasion. Forests and woodlot edges are typically degraded and comprised of a microclimate and species composition uncharacteristic of typical, large intact woodlots (Kowarik & Lippe, 2011). These exposed forest edges can enable invasive species to gain a footing in woodland patches, which expand further into the woodlot over time (Cadenasso & Pickett, 2001). Residential areas are a common source of invasive species (with an average of 2.5 invasive species per residential plot found in this study). Restoring and protecting the edge of urban woodlots and forests with native pioneer species and resilient herbaceous plantings can help provide a buffer against the common dispersal strategies of garden escapees.

Given that invasive plant species tend to have few natural controls to prevent establishment relative to their propagation rate, continued monitoring and action will be required to curb current numbers and limit spread. European buckthorn, Manitoba maple, garlic mustard, non-native honeysuckle, and dog strangling vine should be considered high priority and given special emphasis in targeted management and education given their abundance and their potential to outcompete and displace native trees at the ground layer.

Continued effort in selecting healthy and resilient native stock for plantings across all land use strata will improve the native species capacity to outcompete invasive species. Additionally, some hybrid cultivars are well adjusted to harsher environments like the disturbed sites on *Commercial – Industrial* and *Other – Institutional*. Planting species like honey locust (*Gleditsia triacanthos*) and silver maple (*Acer saccharinum*) and their hybrids can limit the success of invasive species like phragmites (*Phragmites australis*) and European buckthorn at the sites where they go unchecked.

Lastly, continuing to share information with the public will help foster the collective effort and citizen science required to mitigate large scale invasive spread. An educational outreach program on common invasive plant species, their consequences on the landscape and next steps for limiting impact should be developed. There are many existing educational resources developed by conservation authorities and other environmental agencies that the Town can use and leverage with minimal investments. Staff should also be trained and educated on current best practices for invasive species so that they can best deliver resources to the public (for example, promoting volunteer removal events as part of staff-led seminars).

Recommendation 1: Create an Urban Forest Management Plan for the Town of Whitchurch-Stouffville and include: a canopy cover target; species diversity; forest health, maintenance, and monitoring; invasive species management; soil conservation strategies; and climate change mitigation and adaptation approaches.

Recommendation 11: Develop an invasive species management strategy. Apply targeted removal of high priority invasive plant species at high priority sites following best practices. Include the use of tools such as a Pest Vulnerability Matrix to aid in species selection for planting trees and shrubs.

Recommendation 26: Explore the development and implementation of a municipal-led invasive plant, pest, and disease education and volunteer program to enhance awareness of invasive plants, pests, and pathogens and proper removal practices.

Recommendation 27: The Town should consider the development of an invasive species density and priority map as part of the Urban Forest Management Plan to better understand the presence of common invasive plants and pests across the Town. Once developed, target high priority areas for monitoring and treatment.

Recommendation 28: The Town should consider working with York Region on a test study on the application of biological herbicides as means to treat invasive plants in high priority areas deemed unsuitable for traditional chemical herbicide treatments.

- For example, LALCIDE CHONDRO, a fungal based biological herbicide containing the fungal pathogen *Chondrostereum purpureum* can be used to treat cut stumps and prevent resprouting and regrowth of buckthorn.

Recommendation 29: Develop a comprehensive woodlot management strategy to address invasive species.

5.3.3 Tree Pests and Diseases

Exotic insect pests pose a serious threat to the health of forests and street trees as no natural controls have been 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 costs, a loss of species diversity, and a shift to earlier age class distributions.

Invasive pest species of particular interest are emerald ash borer (*Agrilus planipennis*) and spongy moth (*Lymantria dispar dispar*). The recent infestation of spongy moth across Whitchurch-Stouffville was pervasive, with the moth present at 10% of plots. i-Tree Eco analysis suggests that 10% of the Town's tree population – with a replacement value of $187 million – are susceptible to defoliation by spongy moth. Spongy moth populations are cyclical, with outbreaks occurring every 7 to 10 years. Spongy moth caterpillars – which emerge between early May to mid-July before metamorphosis – do not show strong preferences for select tree species. Most healthy deciduous trees can tolerate one to several years of defoliation by spongy moth since they can recover each growing season. However, coniferous trees that have been defoliated will face severe, detrimental effects as only a small proportion of needles are replenished each year (Ontario, 2023). Thus, there will be a continued need for appropriate management responses.

Unlike spongy moth, emerald ash borer specifically targets ash trees (*Fraxinus spp.*). Emerald ash borer was observed on 13% of field plots in this study. The number of ash trees showing signs of emerald ash borer represents a large proportion of the ash in Whitchurch-Stouffville. At this stage, emerald ash borer has decimated most ash populations in Whitchurch-Stouffville with the remaining population's overall condition being very poor, particularly white ash which was the dominant ash species found (average condition of 47%). Mature urban ash trees deemed to be high value should be continually monitored and treated with TreeAzin following the recommended schedule.

Tree diseases have also become a more prevalent concern as novel diseases begin to shift northwards as their ranges expand. Beech bark disease (*Neonectria faginata*) was observed on 3% of plots. Their impacts on natural tree populations are of concern because Whitchurch-Stouffville falls in the Carolinian Forest Region, which is typically characterized by sugar maple (*Acer saccharum*) and American beech (*Fagus grandifolia*). In the remnant Carolinian forest patches and woodlots, the prevalence of beech bark disease can have long term consequences on beech health and should be monitored. Other pests and diseases that were not observed in Whitchurch-Stouffville, include Asian long-horned beetle (*Anoplophora glabripennis*), hemlock woolly adelgid (*Adelges tsugae*), and oak wilt (*Bretziella fagacearum*). Hemlock woolly adelgid and oak wilt are impending threats for southern Ontario, given their rapid spread and the damage and mortality they have caused in nearby regions south of the border. Newly discovered established hemlock woolly adelgid populations have been reported in south-eastern Ontario. The Invasive Species Centre and the Canadian Food Inspection Agency have issued a notice to record and report any sightings of hemlock woolly adelgid and have encouraged practitioners to adopt the Canadian Food Inspection Agency protocol for surveying for hemlock woolly adelgid. Whitchurch-Stouffville should take a proactive approach to hemlock woolly adelgid management. Furthermore, while oak wilt was not observed in Whitchurch-Stouffville yet, a proactive approach to managing the disease should be considered as it begins to appear at the southern extent of the Canadian border and elsewhere in the province.

To address future pest outbreaks, the Township should incorporate a species diversification program with consideration to the potential damage of multi-host pests. The Pest Vulnerability Matrix is a model developed to visualize and assess the susceptibility of the forest to outbreaks of insects and diseases based on species composition and diversity (Laćan & McBride, 2008). The model predicts how the introduction of certain tree species, or a new pest species, will affect the overall vulnerability of the forest. The model has been applied for Toronto, in research by Vander Vecht, & Conway (2015), which explored the vulnerability of Toronto's forest to pests using the Pest Vulnerability Matrix. Using a model such as the Pest Vulnerability Matrix during tree species selection will help account for potential damage by future pest outbreaks, particularly by multi-host pests.

Recommendation 1: Create an Urban Forest Management Plan for the Town of Whitchurch-Stouffville and include: a canopy cover target; species diversity; forest health, maintenance, and monitoring; invasive species management; soil conservation strategies; and climate change mitigation and adaptation approaches.

Recommendation 8: Consider the development of a Naturalization and Restoration plan to bolster planting inputs in the natural heritage system and other naturalized areas.

- The Town of Whitchurch-Stouffville should prioritize large non-treed sites (ex. decommissioned agricultural lands) abutting existing forests for the greatest ecological benefits. Other planting opportunities such as understory plantings should also be considered to increase diversity in existing forested areas. Use of high-quality native planting stock grown from locally adapted seed sources is strongly encouraged in all municipal planting projects, particularly in locations adjacent to natural areas. Planting stock availability will be directly dependent on the supply levels of local nurseries. Whitchurch-Stouffville should work with local growers to ensure that this demand can be met. 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 forest will have the opposite effect and will increase the vulnerability to invasive pests and diseases.

Recommendation 10: In line with current practices, continue to establish a diverse tree population in intensively managed urban areas, in which no species represents more than 5% of the tree population, no genus represents more than 10% of the tree population, and no family represents more than 20% of the intensively managed tree population both municipal-wide and at the neighbourhood level.

- Establishing and maintaining a high species diversity will reduce the vulnerability of the forest to outbreaks of new invasive pests and diseases.

Recommendation 11: Develop an invasive species management strategy. Apply targeted removal of high priority invasive plant species at high priority sites following best practices. Include the use of tools such as a Pest Vulnerability Matrix to aid in species selection for planting trees and shrubs.

- Develop a monitoring and action strategy for invasive species, including pests and diseases, and continue taking proactive approaches to address new and emerging invasive species, such as hemlock woolly adelgid and oak wilt.
- The Town should consider implementing survey protocols to monitor and report pests and diseases of concern that have yet to reach Whitchurch-Stouffville (e.g., oak wilt) and plan for responsive actions in the case that they do reach the municipality. Whitchurch-Stouffville should also develop and implement a management plan for spongy moths to investigate the potential use of biotic control agents.
- The Region has completed threat assessments for both hemlock woolly adelgid and oak wilt to better understand potential impacts and costs for managing and mitigating impacts to regional lands and assets. Formal and informal monitoring for hemlock woolly adelgid and oak wilt are also underway. The Town should consider knowledge sharing and collaboration where possible with respect to the development of a monitoring/action strategy.

Recommendation 26: Explore the development and implementation of a municipal-led invasive plant, pest, and disease education and volunteer program to enhance awareness of invasive plants, pests, and pathogens, and proper removal practices.

Recommendation 30: Consider an inventory of public woodlands to understand the spread of invasive species.

5.4. Past and Future

5.4.1 Trajectory and Future Projections

The i-Tree Eco suite includes a forecast component that utilizes structural estimates generated via the i-Tree Eco model, such as number of trees, species composition and size, alongside growth, mortality, and planting rates to estimate future forest conditions across a thirty-year span (USDA Forest Service, 2021). The forecast predicted a positive trajectory for canopy cover, reaching the recommended canopy range by 2030 under all three simulation scenarios. All scenarios included expected canopy growth and the continued impact of emerald ash borer, spongy moth (*Lymantria dispar dispar*), and beech bark disease (*Neonectria faginata*). The first scenario also included Whitchurch-Stouffville's current planting programs and predicted that canopy cover would reach 56.79% by 2049. In the second, planting inputs were doubled, and canopy cover was forecast to reach 46.81% by 2049. Lastly, under a no planting scenario, canopy cover was expected to reach 56.75% by 2049. Assuming planting programs are implemented as planned and tree maintenance and management are sustained, the potential increase in canopy cover is likely achievable. However, it may be worth considering a dedicated naturalization or restoration planting program to increase planting inputs into the future, especially since i-Tree Eco does not include loss of trees from urbanization and decisions made by private landowners. Future versions of this study should aim to include the impacts of development on canopy cover projections.

While the potential increase in canopy cover output by the Forecast model may be feasible, the projected loss of trees due to increased mortality as trees mature should be considered in Whitchurch-Stouffville's planting plans. By 2049, the tree population, as derived from the forecast model, is expected to decline from 5.4 million to 3.538 million under the current planting scenario, to 3.545 million under the doubled planting scenario, or to 3.530 million under the no planting scenario. As the canopy across Whitchurch-Stouffville continues to mature (largely consisting of existing trees that have shifted into larger size classes) the overall expected losses are anticipated to outpace the rate of canopy growth eventually. While the contrast between scenarios is not drastic, expected tree numbers across each scenario further highlights the need to continue plantings and the required maintenance in priority areas. Maintaining planting plans for thirty years would reduce some of the loss associated with high mortality rates for trees in urban spaces. Furthermore, to ensure the success of new plantings, there is a need to develop a post-tree planting management strategy to alleviate some of the causes associated with high mortality rates in young, newly planted urban trees (Smith, Dearborn, & Hutyra, 2019). Ultimately, while the projected canopy cover and tree number estimates provide a lens to the future of Whitchurch-Stouffville's forest, they should be considered in the context of an ever-changing climate, future land use changes, and the impacts of urban conditions on tree health. The model does not consider any natural regeneration, so it overestimates the loss of trees. Especially in a rural municipality, there will be a lot of natural regeneration occurring, replenishing many of the trees lost. This is a large flaw in the i-Tree Forecast model, so the results should be viewed critically.

The forecast cannot accurately account for complex changing conditions, specifically climate change. One example being the exclusion of natural regeneration from the model's consideration which accounts for the vast majority of turnover in natural forested systems. Additionally, frost-free days were increased in Whitchurch-Stouffville to account for a changing climate, however this does not completely capture the dynamic nature and compounded effects of climate change. One such impact is the shifting geographical ranges of common and dominant tree species. For example, eastern white cedar is at its southernmost extent in Whitchurch-Stouffville and is at risk of being extirpated (as detailed in the climate vulnerability assessment, see Section 5.4.2). Given that the species accounts for the second largest tree population, this risk is of the utmost concern. Actions should be taken to encourage planting alternative, less vulnerable native and naturalized species, where possible, and eastern white cedar should be monitored in natural settings for restoration management as they dominate fresh-moist ecosites.

Additionally, the northward shift of species' range can function to introduce pests and diseases novel to the region. As of 2023, oak wilt (*Bretziella fagacearum*) has now crossed into Canada from the United States and has been reported in Niagara. Hemlock woolly adelgid (, *Adelges tsugae*) has been reported in the Niagara Peninsula at Wainfleet, Fort Erie, and most recently in Hamilton. Both are of concern to Whitchurch-Stouffville in the near future and should be monitored. Successful planning for the future would benefit the resiliency of the Town against such stressors and should be done in conjunction with the Region and the province.

The Forecast outputs should be considered critically given the limited capacity to consider all possible factors that influence future canopy cover in the model and the uncertainty surrounding future climatic changes. However, the results of the forecast are currently encouraging, and provide guidance to suggest the Town should continue with restoration, tree planting, replacement, maintenance, and monitoring on public and private property – especially as Whitchurch-Stouffville continues to urbanize.

Recommendation 1: Create an Urban Forest Management Plan for the Town of Whitchurch-Stouffville and include: a canopy cover target; species diversity; forest health, maintenance, and monitoring; invasive species management; soil conservation strategies; and climate change mitigation and adaptation approaches.

Recommendation 31: Develop a post tree planting management and monitoring strategy to complement the tree maintenance program in order to ensure tree survivorship and mitigate common stressors in the urban environment.

- It is recommended that management, monitoring, and maintenance begin directly after tree planting. Monitoring of municipal plantings should be undertaken for at least five years following planting (year 1, 3 and 5). Some stressors to mitigate include soil compaction, salt pollution, mechanical injuries, and drought related stress.

5.4.2 Climate Vulnerability and Resilience

Changes in climate conditions are expected to profoundly alter the environmental conditions across Southern Ontario, limiting the capacity of many tree species to cope as their optimal climatic ranges shift. A critical assessment of the climate vulnerability of Whitchurch-Stouffville's most common species was conducted to understand the expected impacts on the Town's forest, and ensure the adequate protection, planning, planting, and monitoring of trees across the municipality.

The results of the climate vulnerability assessment showed that of the twenty most abundant tree species in Whitchurch-Stouffville, fourteen of the species were rated as highly or extremely vulnerable to climate change under the "business-as-usual" emissions scenario[38], including four of the top five species (eastern white cedar; European buckthorn; red pine; and quaking aspen). These fourteen species make up 57.3% of the total population of trees across the Whitchurch-Stouffville forest. Only three of the top twenty species were assigned a low vulnerability score, two of which are not recommended for planting because they are invasive (Manitoba maple and Scots pine). Three species were given a moderate vulnerability score.

The five most common species make up 51.5% of the population of trees across the municipality. The dominance of the population by a few species makes the forest more vulnerable to the impacts of climate change. The two most dominant species – eastern white cedar and sugar maple– account for 18.5% and 16.1% of the tree population in Whitchurch-Stouffville, respectively. Sugar maple has moderate vulnerability due to the species' sensitivity to drought. This is somewhat reassuring as the dominant species in Whitchurch-Stouffville tends to be found in natural areas with some protection against pronounced drought effects. However, as drought impacts are expected to increase, natural areas, particularly edges facing urbanized areas, should be considered for protection, or buffering to alleviate impacts of a future climate on the species. On the other hand, eastern white cedar represents the largest concern with respect to climate vulnerability given that it is the most prevalent species across the Town and is highly vulnerable to climate change. The species is currently at the southern extent of its suitable climatic range, and as a result there is a risk the species will be extirpated from Whitchurch-Stouffville in the future.

There is a strong need to monitor the population as the impacts of climate change worsen. Eastern white cedar is planted extensively by private landowners, particularly in hedgerows. Therefore, Whitchurch-Stouffville should actively encourage private landowners to plant alternative species in place of eastern white cedar. Additionally, European buckthorn being the dominant invasive plant in Whitchurch-Stouffville, is of special concern because it is highly invasive and has a pervasive population. However, climate change impacts could potentially help efforts to control this species because it is highly sensitive to drought. Nonetheless, effective European buckthorn removal and restoration programs are necessary to control the population across Whitchurch-Stouffville (see Section 5.3.1). Effective control of the species will allow for natural regeneration of less vulnerable, native forest species found in the region such as sugar maple.

[38] This was assessed under RCP 8.5 conditions (see Section 3.7 for details on the assessment method).

Another important factor for the vulnerability of Whitchurch-Stouffville's forest to climate change is the size distribution of the dominant species. The populations of the top five most common species (except for eastern white pine and sugar maple) are primarily young, averaging less than 20 cm diameter. While overall most of the tree population is in the first and second smallest size classes (5.0 – 15.2 cm diameter classes), it is likely that climate change impacts will affect seedling establishment, particularly in natural areas as they continue to become more fragmented.

Trees that are already in poor condition are more vulnerable to the stressors of climate change. While the average condition score for the forest is 76%[39], white ash (eleventh most abundant) has the worst condition score of any prominent species at 47%. This is within expected conditions for ash species due to the impacts of emerald ash borer. However, the other prevalent species that are highly and extremely vulnerable to climate change impacts will require greater maintenance and monitoring, given that they are likely to decline in condition and suffer higher mortality rates due to more extreme precipitation and flood events, and increased drought.

The resilience of Whitchurch-Stouffville's forest to climate change can be improved through the adoption of the following recommendations, in conjunction with those of the York Region Forest Management Plan, Town of Whitchurch-Stouffville Strategic Plan, and Town of Whitchurch-Stouffville Official Plan. The Town of Whitchurch-Stouffville needs an Urban Forest Management Plan. One of the objectives of the plan should be to identify ecosystem integrity as a sustainability priority. The plan should call for future-oriented objectives aligned with this climate vulnerability assessment which include increasing biodiversity, increasing townwide canopy cover to 45%, and supporting habitat. Given that 70% of the top twenty trees across Whitchurch-Stouffville are considered highly or extremely vulnerable to climate change, the future health and survival of the Town's forest is at risk if proactive, adaptive management is not undertaken.

Recommendation 1: Create an Urban Forest Management Plan for the Town of Whitchurch-Stouffville and include: a canopy cover target; species diversity; forest health, maintenance, and monitoring; invasive species management; soil conservation strategies; and climate change mitigation and adaptation approaches.

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[39] As a reminder, condition is the inverse of percentage crown dieback, thus, a condition score of 85% means an average dieback of 15%.

Recommendation 12: Utilize native and appropriate non-native, non-invasive planting stock in intensively managed areas. Increase genetic diversity of tree populations by using the guidance provided by the Ontario Tree Seed Transfer Policy. This policy is intended to help managers source seed based on the projected changes in climate to increase the likelihood of producing trees well-adapted to current and future conditions.

- Utilize the recommendations from *Adapting Forestry Programs for Climate Change* (LSRCA, 2018).

Recommendation 32: Assess the Town's current recommended planting list based on the climate vulnerability of each species. Shift recommendations to native and appropriate non-native, non-invasive species that have a higher tolerance and lower vulnerability to climate change impacts.

- Consider using the Peel Region Urban Forest Best Practice Guide 4 (Peel Climate Change Partnership (PCCP), 2021b) to help with this.

Recommendation 33: Educate and incentivize private landowners to plant a greater diversity of native, resilient species as part of the Town planting programs, to increase the functional diversity of species planted in Whitchurch-Stouffville. Encourage private landowners to plant alternatives to eastern white cedar and sugar maple, given their prominence and high vulnerability to climate change.

Recommendation 34: The Town should work with York Region to explore assisted range expansion, assisted migration, and increase proactive, long-term monitoring of species identified as highly and extremely vulnerable to climate change.

- The Region of York is exploring the feasibility and practicality of assisted range expansion/assisted migration. The Town should consider collaboration and/or partnership with the Region to explore the potential of assisted range expansion/assisted migration in Whitchurch-Stouffville.
- The Town should consult the Lake Simcoe Region Conservation Authority report *Adapting Forestry Programs for Climate Change* (2018) to aid in planning for changes to appropriate seed stock.

5.5. Forestry and Asset Management

Asset management planning is intended to support the management of municipal assets over their entire life cycle to ensure sustainable service delivery, manage risks to an acceptable level, and keep costs to a minimum. In recognition of the essential role played by green infrastructure in municipal service provision, *Ontario Regulation 588/17 Asset Management Planning for Municipal Infrastructure* (2017) directs municipalities to include green infrastructure assets in asset management plans by July 2024. The regulation defines green infrastructure as "an infrastructure asset consisting of natural or human-made elements that provide ecological and hydrological functions and processes and includes natural heritage features and systems, parklands, stormwater management systems, street trees, urban forests, natural channels, permeable surfaces and green roofs" (Ontario, 2017). This presents an opportunity to prioritize green infrastructure assets in conjunction with traditional assets to support their long-term funding needs for development, maintenance, enhancement, and replacement.

Recommendation 35: Begin integrating individual trees and forests into asset management planning, starting with the development of an inventory.

Recommendation 36: Continue to integrate green infrastructure into asset management planning, particularly municipal natural assets like woodlands and wetlands that have not yet been incorporated.

Recommendation 37: Continue to refine and update public and private tree bylaws while improving enforcement.

6.0 Summary of Recommendations

The following is a summary of each recommendation in the report, grouped by category. They are colour-coded based on priority, with turquoise aiming for completion within 1-5 years and magenta aiming for completion within 5-10 years. Recommendations in **bold** are particularly important.

6.1. Planting

Recommendation 5: Work with York Region to customize and utilize the Region's tree planting prioritization tool for Whitchurch-Stouffville to improve equitable canopy cover distribution, the maximization of ecological benefits and ecosystem services, target areas impacted by invasive pests, and target high emissions zones. Use this to create a planting priority map to designate high priority areas for future plantings.

Recommendation 8: Consider the development of a Naturalization and Restoration plan to bolster planting inputs in the natural heritage system and other naturalized areas.

Recommendation 10: In line with current practices, continue to establish a diverse tree population in intensively managed urban areas, in which no species represents more than 5% of the tree population, no genus represents more than 10% of the tree population, and no family represents more than 20% of the intensively managed tree population both municipal-wide and at the neighbourhood level.

Recommendation 12: Utilize native and appropriate non-native, non-invasive planting stock in intensively managed areas. Increase genetic diversity of tree populations by using the guidance provided by the Ontario Tree Seed Transfer Policy. This policy is intended to help managers source seed based on the projected changes in climate to increase the likelihood of producing trees well-adapted to current and future conditions.

Recommendation 16: Bolster evergreen tree population across the municipality to improve year-round pollution removal services.

Recommendation 19: Following the Town of Whitchurch-Stouffville's Official Plan recommendation to encourage green roofs (Section 6), consider including the potential of trees to provide energy savings when developing planting guidelines or standards.

Recommendation 20: Consider including species' capacity for carbon storage and sequestration when developing planting lists or guidelines and future Urban Forest Management Plans.

Recommendation 32: Assess the Town's current recommended planting list based on the climate vulnerability of each species. Shift recommendations to native and appropriate non-native, non-invasive species that have a higher tolerance and lower vulnerability to climate change impacts.

Recommendation 35: Begin integrating individual trees and forests into asset management planning, starting with the development of an inventory.

6.2. Maintenance

Recommendation 4: Create a tree canopy development and maintenance strategy to reach and maintain the goal of 40% canopy cover by 2051.

Recommendation 7: Continue to plant, prune, and replace trees on municipal roads, parks, and other municipal properties. Evaluate planting and maintenance budgets regularly as the Town grows and assumes responsibility for new roads, parks and facilities.

Recommendation 13: Develop a new street tree inventory and monitoring program that assesses diameter, condition and mortality for the purpose of informing maintenance, service requests, tree replacement, and species selection. Update every five years.

Recommendation 14: Evaluate and develop the strategic steps required to increase the number and proportion of large, mature trees across Whitchurch-Stouffville's forest including the Town's natural forests, street and park trees, and trees on private lands.

Recommendation 17: Continue applying soil enhancement techniques and enhanced rooting environments (i.e., silva cells, aeration, vertical mulching, etc.) on a project-by-project basis for street trees, particularly in constrained spaces such as intensification areas.

Recommendation 22: Under the context of a changing landscape and climate, consider monitoring stand level dynamics and growth trends for select key tree species.

Recommendation 24: Manage compaction, salinity, and pH on public property through amendments and remedial measures like mulching and planting of herbaceous cover and shrubs on a case-by-case basis.

Recommendation 31: Develop a post tree planting management and monitoring strategy to complement the tree maintenance program in order to ensure tree survivorship and mitigate common stressors in the urban environment. For example, trees should be structurally pruned five years post planting.

6.3. Private trees

Recommendation 6: Continue to develop mechanisms to encourage and support private landowners (particularly commercial and industrial landowners, and property developers) to protect and enhance canopy and educate those landowners about maintenance best practices.

Recommendation 15: Continue to review and enhance tree preservation requirements in municipal guidelines and regulations for sustainable streetscape and subdivision design standards (and particularly soil volume) to support tree establishment and eliminate conflict between natural and grey infrastructure.

Recommendation 25: Continue to educate private homeowners and industrial and commercial landowners about soil best practices.

Recommendation 33: Educate and incentivize private landowners to plant a greater diversity of native, resilient species as part of the Town planting programs, to increase the functional diversity of species planted in Whitchurch-Stouffville. Encourage private landowners to plant alternatives to eastern white cedar and sugar maple, given their prominence and high vulnerability to climate change.

6.4. Policies & procedures

Recommendation 1: Create an Urban Forest Management Plan for the Town of Whitchurch-Stouffville and include: a canopy cover target; species diversity; forest health, maintenance and monitoring; invasive species management; soil conservation strategies; and climate change mitigation and adaptation approaches.

Recommendation 2: The next Town of Whitchurch-Stouffville Official Plan update should include a commitment to a 45% canopy cover target to align with the York Region Forest Management Plan. Additionally, the development of a woodland cover target should be further explored as a component of an overall canopy target by assessing the feasible restoration potential across the Town's natural areas.

Recommendation 3: Assess how land uses contribute to canopy and identify areas for increasing canopy.

Recommendation 9: Continue assessing forest structure, function, and distribution every 10 years through the Forest Studies.

Recommendation 18: Explore the opportunity to utilize the Sustainable Technology Evaluation Program Low Impact Development Treatment Train Tool to evaluate and quantify the stormwater benefits of planting trees.

Recommendation 21: As outlined in the Whitchurch-Stouffville Official Plan (Section 1.2.2.2), the Town should support the advancement in stewardship of green infrastructure and invest in climate change mitigation and resilience.

Recommendation 23: Ensure best practices for healthy soils are implemented in Whitchurch-Stouffville's public and private urban areas in the planning of corporate or public planting programs, from site selection and assessment to species selection. Consider reference tools and programs such as the Sustainability Metrics program used by Markham, Richmond Hill, and Vaughan.

Recommendation 34: The Town should work with York Region to explore assisted range expansion, assisted migration, and increase proactive, long-term monitoring of species identified as highly and extremely vulnerable to climate change.

Recommendation 36: Continue to integrate green infrastructure into asset management planning, particularly municipal natural assets like woodlands and wetlands that have not yet been incorporated.

Recommendation 37: Continue to refine and update public and private tree bylaws while improving enforcement.

6.5. Invasive species

Recommendation 29: Develop a comprehensive woodlot management strategy to address invasive species.

Recommendation 11: Develop an invasive species management strategy. Apply targeted removal of high priority invasive plant species at high priority sites following best practices. Include the use of tools such as a Pest Vulnerability Matrix to aid in species selection for planting trees and shrubs.

Recommendation 26: Explore the development and implementation of municipal-led invasive plant, pest, and disease education and volunteer programs to enhance awareness of invasive plants, pests, and pathogens and proper removal practices.

Recommendation 28: The Town should consider working with York Region on a test study on the application of biological herbicides as means to treat invasive plants in high priority areas deemed unsuitable for traditional chemical herbicide treatments.

Recommendation 27: The Town should consider the development of an invasive species density and priority map as part of the Urban Forest Management Plan to better understand the presence of common invasive plants and pests across the Town. Once developed, target high priority areas for monitoring and treatment.

Recommendation 30: Consider an inventory of public woodlands to understand the spread of invasive species.

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Appendix A: MPAC Land Use Categories

Table 29. Description of Land Use Classes (Canopy cover metrics by MPAC land use for each class are listed in Appendix B: Land Cover and Canopy Cover Metrics for Whitchurch-Stouffville and MPAC Land Uses)

Generalized Land Use Class	MPAC Land Uses within each Generalized Class
Open space	Municipal parks, golf courses, cemeteries, and campgrounds. Open space was combined with the natural cover land use class for this report.
Residential Low	Single family detached houses, semi-detached houses, residence with a commercial unit, residence with commercial/industrial use building, linked homes, community lifestyle homes, townhouse/row houses, clergy residences, house-keeping cottages, group homes, student housing, bed & breakfasts. The residential low land use category was combined with the residential medium/high land use stratum.
Residential Medium / High	Townhouse blocks, row housing (3 – more) under single ownership, residential property with four-self contained units, rooming or board houses; bachelorettes, cooperative housing, multi-residential (7 or more), condominium units. Residential medium/high was combined with the residential land low use class.
Commercial	Office buildings, retail, Beer Stores or LCBOs, restaurants, cinemas, concert halls, entertainment complexes, automotive service centres, fuel stations, automotive shops/dealers, shopping centres, department stores, banks and financial institutions, supermarkets, hotels, motels, lodges, inns, resorts, commercial condominiums, parking lots or garages, funeral homes, bowling alleys, casinos, crematoriums, vacant commercial lands. The commercial land use category was combined with industrial land use.

Generalized Land Use Class	MPAC Land Uses within each Generalized Class
Utilities & Transportation	Communication buildings, hydraulic, fossil or nuclear generating stations, transformer stations, Hydro Rights-of-Ways, wind turbines, airports, public transportation-easements and rights, bridges/tunnels, pipelines, compressor stations, railway rights-of-ways, railway buildings and lands, rail stations/yards, airport leasehold or hangers, subway stations, transit garages, public transportation, lighthouses, wharves and harbours, canals and locks, navigational facilities, historic site/monuments, communication. Utilities & transportation lands were combined with rights-of-way for the i-Tree Eco assessment.
Industrial	Mines, mine tailings, oil/gas wells, sawmill/lumber mills, forest products, heavy manufacturing, pulp and paper mills, cement/asphalt manufacturing, steel mills, automotive assembly or parts plant, shipyards, steel production, smelters, foundries, distilleries/breweries, grain elevators and handling, process elevators, slaughterhouses, food processing plants, freezer plants, warehouses, dry cleaning, R&D facilities, other industrial, printing plants, truck terminals, major distribution centres, petro-chemical plants, oil refineries, tank farms, bulk oi,/fuel distribution terminals, gravel pits, quarries, sand pits, peat moss operations, heat or steam plants, sewerage treatments, water treatments, recycling plants, power dams, vacant industrial lands. The industrial land use category was combined with the commercial land use category.
Institutional	Post-secondary educational, educational residence, school, day care, other education, institutional residence, hospital, senior care facility/retirement/nursing/old age homes, other heath care facilities, penitentiary or correctional facilities, places of worship, museums or art galleries, libraries, conference centres, banquet or assembly halls, clubs, research facilities, military properties, post offices/depots, fire halls, ambulance stations, police stations. The institutional land use category was combined with the other land use category for this assessment.

Generalized Land Use Class	MPAC Land Uses within each Generalized Class
Agricultural	Farms with or without buildings, farms with or without residence, wineries, grain/seed and feed operations, tobacco farms, ginseng farms, exotic farms, nut orchards, farms with gravel pit, farms with campground, intensive farm operations, large scale greenhouses, large scale swine or poultry operations, agricultural research facilities, farms with oil/gas, portion being farmed
Natural Cover	Managed forest properties, provincial or federal parks, lands designated/zoned for open space, conservation authority lands. Natural cover was combined with the open space land use class for this report.
Other	Water, marina, billboard, island, time-share, seasonal/recreational dwelling, mining lands, non-buildable land walkways, buffer/berm, stormwater management pond, vacant residential land, vacant lot, residential dockominium, boathouse, vacant recreational, common land, co-ownership, life lease, racetrack, exhibition/fair grounds, sports complex, amusement park, sport club, golf centre/driving range, condominium development land, property in process of redevelopment, residential development land, cooperative housing, vacant land condominium, condominium parking space/locker unit The other land use category was combined with the institutional land use category for this assessment.
Rights-of-way	Rights-of-ways including smaller roads and adjacent ROW. Added to land use layer by UVM by filling in the gaps between parcel boundaries. Rights-of-ways were included in the utilities & transportation stratum for this report.

Appendix B: Land Cover and Canopy Cover Metrics for Whitchurch-Stouffville and MPAC Land Uses

Existing and potential canopy cover were calculated per MPAC (2019) land use stratum using the UVM land cover dataset (current to 2019). Section 3.1 Canopy Cover Analysis provides details on the mapping method, the MPAC land use categories, and definitions for possible vegetated and impervious canopy, as well as unsuitable.

Please note that all percentages are computed out of the total land area which excludes water, while the "Total Area" column includes water.

Table 30. Canopy cover metrics by MPAC Land uses

MPAC Land Use	Total Area	Existing Canopy	Possible Vegetated	Possible Impervious	Canopy - Possible Area	Unsuitable	Existing Canopy	Possible Vegetated	Possible Impervious	Canopy - Possible Percent	Unsuitable	Canopy Cover as a Percent of Total CC
	ha	ha	ha	ha	ha	ha	%	%	%	%	%	%
Agriculture	9829	2439	5854	1381	7235	53	25	60	14	74	1	30.1
Residential Low	4311	2312	1423	203	1626	304	55	34	5	38	7	28.6
Other	2527	1680	550	212	762	28	68	22	9	31	1	20.7
Natural Cover	1014	782	132	16	149	4	84	14	2	16	0	12.5
Commercial	731	373	202	117	319	25	52	28	16	44	3	4.6
ROW	1264	219	481	316	796	233	18	39	25	64	19	2.7
Open Space	932	191	582	120	702	7	21	65	13	78	1	2.4
Residential Medium / High	56	38	21	6	27	11	32	38	11	49	19	0.5
Industrial	274	24	94	131	225	23	9	35	48	83	8	0.3
Utilities & Transportation	68	23	13	7	21	24	34	20	11	30	36	0.3
Institutional	110	16	61	21	83	9	15	57	20	76	9	0.2

Appendix C: Parameters Used for i-Tree Forecast

Table 31. General simulation parameters used for i-Tree Forecast

Parameter	Value	Comments
Simulation period	2023 – 2052 (30 years)	
Length of frost-free season	178 days	Average of current frost-free season and projected frost-free season according to Historical and Future Climate Trends in York Region
Base annual tree mortality rate for healthy trees (dieback < 50 %)	1.6%	The base annual mortality rate for health trees was set at 4.0 % by i-Tree Eco. However, the York Region Green Infrastructure Asset Management Plan listed an annual mortality rate of 1.3% for rural trees, 1.6% for suburban trees, and 2% for urban trees. Given that Whitchurch-Stouffville contains a mix of land uses, the average value was used for healthy trees.
Base annual tree mortality rate for sick trees (dieback 50-75 %)	13.1% (default)	Default values were used as no locally applicable data on the impact of health on annual mortality.
Base annual tree mortality rate for dying trees (>76 % dieback)	50% (default)	
Base annual tree mortality rate for dead trees (100% die back)	100% (default)	

Table 32. Simulation parameters for pests

Insect	Start of outbreak and duration	Annual mortality rate from outbreak[40]	Plant host trees during event (i.e., plant trees affected by pest/disease)?	Notes
Emerald ash borer	2023, 3 years	Default value: 3.3%41	No	Mortality rates in Michigan at the peak of the outbreak were as high as 100% (Klooster, et al., 2014). However, since we are passed the peak in Ontario the lower value recommended by i-Tree Eco will be used. Emerald ash borer is nearing past its peak and phasing out in Ontario according to TRCA staff.
Spongy moth	2023, 3 years	4.4%	No	Mortality rate depends on the crown condition prior to defoliation, the extent of defoliation, and the number of years defoliation was seen (Davidson, Gottschalk, & Johnson, 1999). Davidson, Gottschalk, & Johnson (1999) found that mortality rates within 5 years could be as high as 50% following two consecutive severe defoliations of a tree with fair crown condition and as low as 7% for a single year of defoliation in a tree with good crown condition. The default value of 10% annual mortality rate is consistent with assuming two severe defoliations of a tree with fair or poor crown condition. A more conservative estimate would be to assume 2 years of defoliation of a tree in good crown condition. Davidson, Gottschalk, & Johnson (1999) found a mortality rate of 22 % over 5 years, translating to an annual mortality rate of 4.4%. The default value provided by i-Tree Eco is 10.0 %.

[40] Mortality rates only apply to species affected by pest.

[41] Default mortality rates are based on a synthesis of literature by the i-Tree Eco team.

Insect	Start of outbreak and duration	Annual mortality rate from outbreak[40]	Plant host trees during event (i.e., plant trees affected by pest/disease)?	Notes
Beech Bark Disease	2023, 10 years	2.35 % (Default is 4.7%)	No	According to Reed et al. (2022), beech bark disease has been in Ontario since the 2000s and is moving eastwards and northwards. Mortality also occurs within a long timeframe of five to ten years. So, it is anticipated that it will be here for still many years. Their study of plots around Lake Erie indicated that 4% of Beech trees were affected. Mortality rate for trees with a high density of scale was 50% within 10 years. That translates to 0.5% per year. Therefore, the annual mortality rate was reduced from the default mortality rate of 4.7% to 2.35% (0.5 x 4.7). The default value provided by i-Tree Eco is 4.7%.

Appendix D: Forest Composition and Structure

Table 33. Whitchurch-Stouffville composition and structure by species

Species		Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
Common Name	Scientific Name	Number	SE	(ha)	SE	(tonne)	SE	(tonne)	SE	(%)
Northern white cedar	*Thuja occidentalis*	1,127,518	±385,790	6,809.846	±2,148.044	13,095.857	±4,130.853	258,093.491	±84,262.960	77.12
Sugar maple	*Acer saccharum*	980,009	±187,166	22,129.343	±4,887.856	13,331.732	±2,944.669	410,186.270	±89,050.883	88.88
European buckthorn	*Rhamnus cathartica*	376,535	±111,519	1,031.526	±326.797	458.456	±145.243	20,472.166	±6,469.547	77.32
Red pine	*Pinus resinosa*	366,541	±128,873	2,631.853	±976.724	3,870.372	±1,436.359	68,848.795	±24,339.348	69.66
Quaking aspen	*Populus tremuloides*	288,141	±99,176	1,203.308	±428.031	947.561	±337.059	37,718.960	±15,818.874	74.48
White spruce	*Pice glauca*	236,147	±107,407	2,308.138	±816.932	3,707.851	±1,312.341	53,631.597	±26,307.991	69.28
Eastern white pine	*Pinus strobus*	235,755	±88,668	2,649.256	±1,267.191	1,703.811	±814.966	26,075.811	±12,410.768	81.58
Boxelder	*Acer negundo*	231,933	±82,404	2,764.251	±1,202.478	2,528.818	±1,100.062	57,004.861	±26,891.958	77.98
Eastern hophornbeam	*Ostrya virginiana*	216,434	±61,938	1,697.705	±557.295	1,108.307	±363.817	10,266.246	±3,744.106	82.41
Eastern hemlock	*Tsuga canadensis*	208,274	±74,223	2,431.516	±1,030.616	2,258.514	±957.288	41,325.061	±21,560.638	82.44
White ash	*Fraxinus americana*	183,809	±43,573	495.072	±123.926	281.307	±70.416	17,222.756	±6,246.393	47.30

Species		Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
Common Name	**Scientific Name**	**Number**	**SE**	**(ha)**	**SE**	**(tonne)**	**SE**	**(tonne)**	**SE**	**(%)**
American basswood	*Tilia americana*	143,919	±51,465	2,242.477	±857.990	654.700	±250.494	27,084.787	±10,029.904	84.45
Scots pine	*Pinus sylvestris*	123,491	±57,272	1,202.295	±666.661	1,158.839	±642.565	22,792.041	±12,378.193	77.89
Common apple	*Morus domestica*	122,866	±79,187	567.045	±260.345	488.874	±224.455	43,023.497	±32,149.971	83.64
Green ash	*Fraxinus pennsilvanica*	91,956	±28,150	290.359	±167.923	189.393	±109.532	14,304.575	±6,678.266	32.59
Northern red oak	*Quercus rubra*	82,483	±31,871	2,823.649	±1,169.527	2,249.919	±931.894	40,567.012	±16,983.764	87.39
Staghorn sumac	*Rhus typhina*	79,246	±55,663	57.362	±35.374	50.975	±31.435	1,238.937	±811.802	71.97
Ash spp.	*Fraxinus spp.*	67,465	±22,216	0.000	±0.000	0.000	±0.000	13,179.216	±5,634.758	0.00
Yellow birch	*Betula alleghaniensis*	63,048	±22,682	958.151	±433.203	396.750	±179.380	22,391.995	±8,728.249	58.76
Alternateleaf dogwood	*Cornus alternifolia*	58,286	±29,209	81.343	±48.630	54.232	±32.422	998.967	±559.355	69.80
Black cherry	*Prunus serotina*	55,690	±15,916	349.631	±138.201	271.158	±107.183	29,772.669	±17,576.319	66.69
Black walnut	*Juglans nigra*	51,179	±21,261	979.747	±566.992	785.242	±454.430	8,420.163	±5,376.126	93.17
Blue spruce	*Picea pungens*	48,654	±24,013	1,008.943	±642.288	1,679.892	±1,069.411	15,927.092	±10,021.895	95.80
American elm	*Ulmus americana*	44,192	±19,104	164.383	±80.238	119.560	±58.359	8,141.215	±5,053.017	53.59
Dotted hawthorn	*Cretaegus punctata*	41,865	±35,845	64.741	±46.056	48.769	±34.694	1,234.887	±868.372	69.43

Species		Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
Common Name	Scientific Name	Number	SE	(ha)	SE	(tonne)	SE	(tonne)	SE	(%)
Red maple	*Acer rubrum*	38,380	±20,067	327.150	±221.336	220.333	±149.068	10,715.220	±6,952.378	79.08
American beech	*Fagus grandifolia*	37,792	±14,298	471.237	±231.458	200.808	±98.631	8,195.755	±5,092.991	76.10
Norway maple	*Acer platanoides*	36,593	±17,941	201.909	±97.625	108.981	±52.693	1,409.433	±618.081	94.58
American mountain ash	*Sorbus americana*	32,383	±29,276	119.778	±116.786	95.062	±92.687	3,130.723	±3,091.741	65.65
Paper birch	*Betula papyrifera*	30,693	±11,572	539.210	±221.204	377.096	±154.699	16,935.587	±7,560.715	74.05
Pear hawthorn	*Cretaegus calpodendron*	30,496	±30,489	17.898	±17.894	13.482	±13.479	1,748.728	±1,748.355	42.62
Black ash	*Fraxinus nigra*	29,568	±17,923	11.206	±11.203	6.671	±6.669	1,462.214	±913.868	13.45
Freeman maple	*Acer x freemanii*	27,815	±13,414	765.262	±432.706	430.721	±243.545	9,336.674	±5,054.425	89.53
Hardwood	*Magnoliopsida spp.*	22,750	±11,175	0.000	±0.000	0.000	±0.000	11,287.232	±6,376.974	0.00
Balsam fir	*Abies balsamea*	21,747	±15,461	173.732	±143.077	180.971	±149.038	2,854.489	±2,018.511	58.45
Balsam poplar	*Populus balsamifera*	21,657	±15,075	19.689	±17.711	14.206	±12.779	1,308.724	±1,243.043	31.44
Scarlet hawthorn	*Crataegus coccinea*	18,617	±8,763	62.231	±31.792	46.878	±23.949	1,371.244	±729.702	85.28
Black locust	*Robinia pseudoacacia*	13,514	±8,303	131.306	±99.222	70.694	±53.420	1,948.736	±1,565.064	91.53
Norway spruce	*Picea abies*	11,729	±6,025	359.008	±212.955	598.347	±354.926	3,798.244	±2,030.767	89.30

Species		Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
Common Name	Scientific Name	Number	SE	(ha)	SE	(tonne)	SE	(tonne)	SE	(%)
Bitternut hickory	*Carya cordiformis*	10,043	±6,004	68.759	±50.292	43.223	±31.614	761.360	±553.709	94.50
Eastern red cedar	*Juniperus virginiana*	10,043	±6,004	6.850	±4.496	19.034	±12.493	180.772	±116.072	90.91
Sweet crabapple	*Morus coronaria*	9,715	±9,713	28.451	±28.447	24.529	±24.525	1,303.104	±1,302.903	67.50
Common chokecherry	*Prunus virginiana*	9,504	±5,823	24.317	±19.378	18.850	±15.022	429.870	±306.047	97.03
Red hickory	*Carya glabra*	9,383	±9,381	49.062	±49.052	32.956	±32.949	1,094.537	±1,094.304	94.50
Austrian pine	*Pinus nigra*	9,383	±7,367	245.316	±240.362	236.449	±231.674	2,706.249	±2,672.301	94.50
European mountain ash	*Sorbus aucuparia*	8,902	±6,523	67.113	±56.472	53.265	±44.819	625.793	±456.016	90.68
European beech	*Fagus sylvatica*	8,496	±8,495	2.845	±2.844	1.424	±1.423	60.188	±60.177	94.50
Honeylocust	*Gleditsia triacanthos*	8,010	±4,561	187.256	±127.844	196.100	±133.882	1,628.581	±1,176.537	90.26
Ginkgo	*Ginkgo biloba*	7,098	±5,272	25.383	±22.593	24.386	±21.705	91.837	±75.736	97.85
Siberian elm	*Ulmus pumila*	7,037	±7,036	43.791	±43.782	29.826	±29.820	2,041.033	±2,040.598	62.50
Butternut	*Juglans cinerea*	6,477	±4,548	128.228	±109.702	70.840	±60.606	1,526.034	±1,361.662	72.50
European white elm	*Ulmus laevis*	5,645	±4,034	88.671	±75.640	60.394	±51.519	789.574	±750.578	94.50
Silver maple	*Acer saccharinum*	4,813	±4,812	284.975	±284.916	149.995	±149.964	11,706.716	±11,704.284	82.50

Species		Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
Common Name	**Scientific Name**	**Number**	**SE**	**(ha)**	**SE**	**(tonne)**	**SE**	**(tonne)**	**SE**	**(%)**
Northern catalpa	*Catalpa speciosa*	4,813	±4,812	1.720	±1.720	1.047	±1.047	12.104	±12.102	97.00
Black maple	*Acer nigrum*	4,692	±4,691	15.286	±15.283	8.604	±8.602	274.644	±274.585	88.50
Eastern redbud	*Cercis canadensis*	4,692	±4,691	4.339	±4.338	2.779	±2.778	220.175	±220.128	47.25
Callery pear	*Pyrus calleryana*	4,692	±4,691	31.446	±31.439	23.658	±23.653	1,063.937	±1,063.711	88.50
American hornbeam	*Carpinus caroliniana*	3,238	±3,238	21.553	±21.550	12.985	±12.983	138.396	±138.375	94.50
Black hawthorn	*Crataegus douglasii*	3,238	±3,238	5.686	±5.685	4.283	±4.283	47.322	±47.315	82.50
Cottonwood spp.	*Populus spp.*	3,238	±3,238	0.000	±0.000	0.000	±0.000	1,340.434	±1,340.227	0.00
Balm-of-gilead	*Populus balsamifera*	3,238	±3,238	177.210	±177.183	127.867	±127.847	2,144.436	±2,144.105	94.50
Wildgoose plum	*Prunus americana*	3,238	±3,238	0.407	±0.407	0.315	±0.315	38.157	±38.151	13.00
Rowan Mountain Ash	*Sorbus discolor*	3,238	±3,238	56.891	±56.883	45.152	±45.145	1,086.627	±1,086.459	94.50
Rock elm	*Ulmus thomasii*	3,238	±3,238	51.802	±51.794	35.283	±35.278	1,186.447	±1,186.264	62.50
Maple spp.	*Acer spp.*	2,832	±2,832	0.000	±0.000	0.000	±0.000	1,171.466	±1,171.259	0.00
Flowering dogwood	*Cornus florida*	2,832	±2,832	3.240	±3.240	2.518	±2.517	48.145	±48.136	94.50

Species		Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
Common Name	Scientific Name	Number	SE	(ha)	SE	(tonne)	SE	(tonne)	SE	(%)
Pine spp.	*Pinus spp.*	2,832	±2,832	0.000	±0.000	0.000	±0.000	1,468.350	±1,468.091	0.00
Bigtooth aspen	*Populus grandidentata*	2,832	±2,832	3.036	±3.035	1.549	±1.549	32.356	±32.350	94.50
Tree of heaven	*Ailanthus altissima*	2,406	±2,406	1.487	±1.486	2.287	±2.287	5.387	±5.386	99.50
European hornbeam	*Carpinus betulus*	2,406	±2,406	7.243	±7.241	4.363	±4.362	116.303	±116.279	94.50
White poplar	*Populus alba*	2,406	±2,406	4.630	±4.629	4.026	±4.025	13.181	±13.179	94.50
Paperbark maple	*Acer griseum*	2,346	±2,345	1.484	±1.484	0.835	±0.835	28.071	±28.065	94.50
Horse chestnut	*Aesculus hippocastanum*	2,346	±2,345	0.379	±0.379	0.265	±0.265	2.984	±2.983	62.50
River birch	*Betula nigra*	2,346	±2,345	6.761	±6.759	5.241	±5.239	31.783	±31.777	94.50
Kentucky Coffee tree	*Gymnocladus dioicus*	2,346	±2,345	0.693	±0.692	0.599	±0.598	5.521	±5.519	99.50
Tamarack	*Larix laricina*	2,346	±2,345	2.298	±2.298	1.486	±1.486	19.110	±19.106	82.50
Apple spp.	*Morus spp.*	2,346	±2,345	0.928	±0.928	0.800	±0.800	10.813	±10.811	82.50
Swamp cottonwood	*Populus heterophylla*	2,346	±2,345	3.896	±3.895	2.811	±2.811	13.275	±13.273	94.50
Sweet cherry	*Prunus avium*	2,346	±2,345	1.742	±1.742	1.348	±1.348	23.980	±23.975	99.50
Pin oak	*Quercus palustris*	2,346	±2,345	23.020	±23.015	20.835	±20.830	296.831	±296.768	94.50

Species		Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
Common Name	Scientific Name	Number	SE	(ha)	SE	(tonne)	SE	(tonne)	SE	(%)
Japanese tree lilac	*Syringa reticulata*	2,346	±2,345	0.463	±0.463	0.447	±0.447	7.467	±7.466	82.50
Littleleaf linden	*Tilia cordata*	2,346	±2,345	16.250	±16.247	12.174	±12.171	60.393	±60.381	94.50
Study Area		**6,099,623**	**±665,195**	**61,836.465**	**±6,961.710**	**55,089.968**	**±6,291.070**	**1,361,279.816**	**±155,141.591**	**75.75**

Table 34. Whitchurch-Stouffville composition and structure by stratum and species

	Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
Species	Number	SE	(ha)	SE	(tonne)	SE	(tonne)	SE	(%)
Stratum: Agriculture									
Balsam fir	9,715	±9,713	34.962	±34.957	36.419	±36.413	1,457.239	±1,457.014	59.00
Freeman maple	3,238	±3,238	32.408	±32.403	18.241	±18.238	452.929	±452.859	82.50
Boxelder	136,007	±63,077	2,105.872	±1,170.056	1,926.513	±1,070.401	43,524.156	±25,909.814	72.30
Norway maple	12,953	±10,197	55.649	±39.540	30.037	±21.342	517.937	±374.721	91.50
Sugar maple	136,007	±56,314	3,687.117	±1,484.432	2,221.289	±894.290	79,448.354	±34,799.932	87.27
Yellow birch	22,668	±13,962	150.320	±83.576	62.245	±34.607	6,750.719	±5,132.572	50.57
Paper birch	12,953	±7,841	310.544	±180.046	217.179	±125.915	6,342.621	±3,947.555	82.50
American hornbeam	3,238	±3,238	21.553	±21.550	12.985	±12.983	138.396	±138.375	94.50
Alternateleaf dogwood	38,859	±23,971	37.540	±24.294	25.028	±16.197	712.044	±491.530	68.42
Scarlet hawthorn	12,953	±7,841	38.376	±26.567	28.909	±20.013	857.767	±623.351	86.50
Black hawthorn	3,238	±3,238	5.686	±5.685	4.283	±4.283	47.322	±47.315	82.50

	Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
Species	**Number**	**SE**	**(ha)**	**SE**	**(tonne)**	**SE**	**(tonne)**	**SE**	**(%)**
Dotted hawthorn	38,859	±35,719	54.472	±44.897	41.034	±33.821	982.621	±830.935	68.42
Ash spp.	16,191	±10,646	0.000	±0.000	0.000	±0.000	2,740.836	±1,891.880	0.00
White ash	42,097	±19,214	77.099	±51.399	43.809	±29.206	5,723.351	±3,152.057	28.69
Black ash	6,477	±6,476	0.000	±0.000	0.000	±0.000	365.912	±365.856	0.00
Green ash	12,953	±7,841	7.536	±7.535	4.915	±4.915	2,590.465	±1,845.449	23.63
Butternut	6,477	±4,548	128.228	±109.702	70.840	±60.606	1,526.034	±1,361.662	72.50
Black walnut	12,953	±6,343	71.127	±56.143	57.007	±44.997	693.246	±560.757	94.50
Hardwood	3,238	±3,238	0.000	±0.000	0.000	±0.000	5,187.057	±5,186.256	0.00
Common apple	80,957	±74,520	312.864	±203.083	269.733	±175.086	4,304.622	±3,527.828	97.94
Eastern hophornbeam	29,144	±16,595	191.757	±99.112	125.184	±64.703	2,046.457	±1,612.215	78.67
White spruce	19,430	±13,644	334.060	±218.912	536.643	±351.666	5,176.821	±3,614.850	92.17
Blue spruce	22,668	±19,651	619.709	±542.842	1,031.816	±903.832	9,864.214	±8,554.814	96.64
Red pine	61,527	±46,119	326.528	±254.465	480.189	±374.213	6,654.144	±5,403.613	58.55
Eastern white pine	84,195	±59,301	1,506.128	±1,151.718	968.633	±740.703	13,264.295	±9,918.560	88.81
Cottonwood spp.	3,238	±3,238	0.000	±0.000	0.000	±0.000	1,340.434	±1,340.227	0.00
Balm-of-gilead	3,238	±3,238	177.210	±177.183	127.867	±127.847	2,144.436	±2,144.105	94.50
Quaking aspen	126,292	±57,457	617.029	±322.676	485.888	±254.096	14,409.505	±9,205.831	80.54
Wildgoose plum	3,238	±3,238	0.407	±0.407	0.315	±0.315	38.157	±38.151	13.00
Black cherry	9,715	±5,532	125.071	±97.546	97.000	±75.652	20,382.084	±16,857.533	59.00
Sweet crabapple	9,715	±9,713	28.451	±28.447	24.529	±24.525	1,303.104	±1,302.903	67.50
European buckthorn	142,484	±50,306	369.854	±161.546	164.379	±71.798	8,997.296	±4,518.408	75.30

	Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
Species	**Number**	**SE**	**(ha)**	**SE**	**(tonne)**	**SE**	**(tonne)**	**SE**	**(%)**
Black locust	6,477	±6,476	26.268	±26.264	14.142	±14.140	323.269	±323.219	97.00
American mountain ash	32,383	±29,276	119.778	±116.786	95.062	±92.687	3,130.723	±3,091.741	65.65
European mountain ash	3,238	±3,238	55.213	±55.205	43.820	±43.813	391.027	±390.967	94.50
Rowan mountain ash	3,238	±3,238	56.891	±56.883	45.152	±45.145	1,086.627	±1,086.459	94.50
Northern white cedar	663,844	±343,520	4,011.721	±1,837.703	7,714.848	±3,534.045	143,181.629	±66,292.865	75.55
American basswood	48,574	±28,416	673.878	±496.588	196.741	±144.981	8,691.505	±6,496.990	81.87
Eastern hemlock	106,863	±61,023	1,072.822	±806.433	996.491	±749.055	23,349.861	±19,952.807	85.21
American elm	29,144	±17,830	92.753	±59.494	67.462	±43.272	7,669.193	±5,044.352	42.61
European white elm	3,238	±3,238	74.268	±74.256	50.584	±50.576	749.631	±749.515	94.50
Rock elm	3,238	±3,238	51.802	±51.794	35.283	±35.278	1,186.447	±1,186.264	62.50
Total	**2,027,153**	**±479,555**	**17,662.956**	**±3,776.567**	**18,372.494**	**±4,488.921**	**439,744.489**	**±102,484.641**	**75.12**
Stratum: Residential									
Freeman maple	2,346	±2,345	13.047	±13.045	7.344	±7.342	221.151	±221.104	99.50
Paperbark maple	2,346	±2,345	1.484	±1.484	0.835	±0.835	28.071	±28.065	94.50
Boxelder	9,383	±4,532	192.541	±128.221	176.142	±117.300	2,004.957	±1,533.197	91.50
Black maple	4,692	±4,691	15.286	±15.283	8.604	±8.602	274.644	±274.585	88.50
Norway maple	16,421	±14,215	64.246	±52.524	34.677	±28.350	388.609	±306.179	98.07
Red maple	7,037	±3,971	48.738	±41.904	32.824	±28.222	749.799	±666.084	94.50
Sugar maple	321,378	±109,257	6,460.233	±2,389.439	3,891.941	±1,439.508	126,436.077	±47,567.885	88.22
Horse chestnut	2,346	±2,345	0.379	±0.379	0.265	±0.265	2.984	±2.983	62.50

Species	Trees Number	SE	Leaf Area (ha)	SE	Leaf Biomass (tonne)	SE	Tree Dry Weight Biomass (tonne)	SE	Average Condition (%)
Yellow birch	16,421	±9,466	117.369	±95.655	48.600	±39.609	8,209.376	±5,560.686	34.21
River birch	2,346	±2,345	6.761	±6.759	5.241	±5.239	31.783	±31.777	94.50
Paper birch	11,729	±6,025	200.352	±125.353	140.116	±87.666	10,421.115	±6,446.060	60.40
Bitternut hickory	7,037	±5,197	20.756	±15.027	13.048	±9.446	233.949	±168.891	94.50
Red hickory	9,383	±9,381	49.062	±49.052	32.956	±32.949	1,094.537	±1,094.304	94.50
Eastern redbud	4,692	±4,691	4.339	±4.338	2.779	±2.778	220.175	±220.128	47.25
Alternateleaf dogwood	16,421	±16,417	42.102	±42.093	28.070	±28.064	266.231	±266.175	67.64
Pear hawthorn	30,496	±30,489	17.898	±17.894	13.482	±13.479	1,748.728	±1,748.355	42.62
American beech	23,458	±12,950	307.641	±200.262	131.095	±85.338	7,337.024	±5,050.408	74.70
Ash spp.	16,421	±8,852	0.000	±0.000	0.000	±0.000	1,603.316	±937.502	0.00
White ash	63,337	±19,719	221.497	±74.408	125.858	±42.279	3,277.884	±1,151.346	61.69
Black ash	14,075	±14,072	11.206	±11.203	6.671	±6.669	323.865	±323.796	28.25
Green ash	23,458	±11,078	246.867	±165.967	161.024	±108.256	1,637.767	±899.254	70.45
Ginkgo	4,692	±4,691	2.983	±2.983	2.866	±2.865	18.339	±18.335	97.00
Honeylocust	2,346	±2,345	89.383	±89.364	93.605	±93.585	509.688	±509.580	94.50
Kentucky coffee tree	2,346	±2,345	0.693	±0.692	0.599	±0.598	5.521	±5.519	99.50
Black walnut	16,421	±10,587	283.470	±215.203	227.194	±172.480	2,434.593	±2,144.425	94.50
Eastern red cedar	7,037	±5,197	5.875	±4.389	16.324	±12.196	119.339	±98.488	94.50
Tamarack	2,346	±2,345	2.298	±2.298	1.486	±1.486	19.110	±19.106	82.50
Apple spp.	2,346	±2,345	0.928	±0.928	0.800	±0.800	10.813	±10.811	82.50
Hardwood	2,346	±2,345	0.000	±0.000	0.000	±0.000	189.701	±189.661	0.00

	Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
Species	**Number**	**SE**	**(ha)**	**SE**	**(tonne)**	**SE**	**(tonne)**	**SE**	**(%)**
Common apple	16,421	±14,215	203.809	±155.543	175.713	±134.100	33,647.812	±31,661.388	84.21
Eastern hophornbeam	105,562	±42,747	975.000	±450.916	636.506	±294.370	5,436.151	±2,755.085	87.89
Norway spruce	11,729	±6,025	359.008	±212.955	598.347	±354.926	3,798.244	±2,030.767	89.30
White spruce	145,441	±94,981	1,465.189	±654.649	2,353.717	±1,051.644	37,149.348	±23,981.385	53.73
Austrian pine	9,383	±7,367	245.316	±240.362	236.449	±231.674	2,706.249	±2,672.301	94.50
Blue spruce	18,767	±11,763	381.896	±343.225	635.857	±571.471	5,934.061	±5,218.903	94.00
Red pine	49,262	±35,443	469.540	±405.968	690.500	±597.011	9,423.994	±8,016.150	66.98
Eastern white pine	21,112	±16,974	119.123	±112.666	76.611	±72.459	783.798	±697.124	72.72
Scots pine	96,179	±55,024	1,095.522	±663.445	1,055.925	±639.465	20,299.494	±12,257.795	79.23
Swamp cottonwood	2,346	±2,345	3.896	±3.895	2.811	±2.811	13.275	±13.273	94.50
Quaking aspen	60,991	±47,146	299.327	±198.849	235.709	±156.586	4,350.949	±2,628.371	89.88
Sweet cherry	2,346	±2,345	1.742	±1.742	1.348	±1.348	23.980	±23.975	99.50
Black cherry	25,804	±11,706	153.876	±89.178	119.339	±69.163	8,093.186	±4,933.657	74.05
Common chokecherry	4,692	±3,280	5.296	±3.725	4.105	±2.888	149.863	±123.666	94.50
Callery pear	4,692	±4,691	31.446	±31.439	23.658	±23.653	1,063.937	±1,063.711	88.50
Pin oak	2,346	±2,345	23.020	±23.015	20.835	±20.830	296.831	±296.768	94.50
Northern red oak	56,300	±28,796	1,647.595	±978.996	1,312.825	±780.077	24,168.553	±14,272.057	87.50
European buckthorn	82,104	±44,004	157.847	±75.355	70.154	±33.491	4,498.706	±2,594.799	69.81
Staghorn sumac	28,150	±22,101	36.167	±28.324	32.140	±25.171	658.338	±567.486	82.17
Black locust	7,037	±5,197	105.039	±95.682	56.551	±51.514	1,625.467	±1,531.325	86.50
Japanese tree lilac	2,346	±2,345	0.463	±0.463	0.447	±0.447	7.467	±7.466	82.50

	Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
Species	**Number**	**SE**	**(ha)**	**SE**	**(tonne)**	**SE**	**(tonne)**	**SE**	**(%)**
Northern white cedar	241,620	±116,610	1,670.487	±917.943	3,212.475	±1,765.276	82,960.376	±48,772.559	84.59
American basswood	25,804	±11,215	299.806	±156.406	87.530	±45.663	5,358.226	±3,922.736	88.77
Littleleaf linden	2,346	±2,345	16.250	±16.247	12.174	±12.171	60.393	±60.381	94.50
Eastern hemlock	49,262	±23,879	549.899	±294.531	510.774	±273.575	7,759.762	±4,450.044	78.00
American elm	9,383	±5,637	63.219	±53.178	45.981	±38.677	394.021	±289.940	91.50
Siberian elm	7,037	±7,036	43.791	±43.782	29.826	±29.820	2,041.033	±2,040.598	62.50
Total	**1,733,562**	**±262,049**	**18,851.004**	**±3,289.388**	**17,442.753**	**±2,872.639**	**432,522.662**	**±81,021.442**	**77.77**
Stratum: Natural Cover – Open Space									
Boxelder	3,006	±3,005	3.458	±3.458	3.164	±3.163	29.836	±29.831	94.50
Red maple	18,034	±18,031	34.762	±34.756	23.412	±23.408	223.365	±223.328	85.17
Sugar maple	210,396	±96,552	5,878.788	±2,674.368	3,541.652	±1,611.162	103,473.180	±43,411.217	89.56
Yellow birch	3,006	±3,005	294.381	±294.332	121.897	±121.877	2,469.940	±2,469.529	94.50
Paper birch	6,011	±6,010	28.314	±28.309	19.801	±19.798	171.851	±171.823	82.50
Bitternut hickory	3,006	±3,005	48.002	±47.994	30.175	±30.170	527.411	±527.323	94.50
Alternateleaf dogwood	3,006	±3,005	1.700	±1.700	1.134	±1.133	20.691	±20.688	99.50
Dotted hawthorn	3,006	±3,005	10.269	±10.267	7.736	±7.734	252.266	±252.225	82.50
American beech	3,006	±3,005	17.691	±17.688	7.539	±7.537	42.463	±42.456	94.50
Ash spp.	15,028	±10,497	0.000	±0.000	0.000	±0.000	4,757.558	±3,577.437	0.00
White ash	33,062	±25,107	76.712	±58.805	43.589	±33.414	1,772.272	±1,218.436	47.64
Black ash	9,017	±9,015	0.000	±0.000	0.000	±0.000	772.437	±772.308	0.00
Green ash	30,057	±18,558	21.585	±21.443	14.080	±13.987	4,123.066	±2,747.755	10.75

	Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
Species	**Number**	**SE**	**(ha)**	**SE**	**(tonne)**	**SE**	**(tonne)**	**SE**	**(%)**
Eastern red cedar	3,006	±3,005	0.975	±0.975	2.710	±2.710	61.433	±61.423	82.50
Hardwood	3,006	±3,005	0.000	±0.000	0.000	±0.000	3,160.447	±3,159.921	0.00
Eastern hophornbeam	42,079	±27,367	381.122	±293.557	248.806	±191.642	2,250.464	±1,920.697	90.00
White spruce	45,085	±45,077	434.277	±434.204	697.633	±697.517	10,164.618	±10,162.927	94.50
Red pine	15,028	±15,026	147.098	±147.073	216.320	±216.284	3,615.730	±3,615.128	54.30
Eastern white pine	3,006	±3,005	6.009	±6.008	3.864	±3.864	72.729	±72.717	82.50
Scots pine	12,023	±12,021	34.711	±34.705	33.456	±33.451	1,495.197	±1,494.948	59.88
Quaking aspen	30,057	±20,993	154.071	±147.982	121.325	±116.530	4,204.970	±3,807.155	57.40
Black cherry	6,011	±6,010	7.835	±7.833	6.076	±6.075	258.717	±258.674	47.25
Northern red oak	12,023	±9,311	304.308	±208.226	242.476	±165.917	4,540.227	±3,232.834	94.50
European buckthorn	15,028	±15,026	170.668	±170.639	75.852	±75.840	2,774.159	±2,773.697	87.30
Staghorn sumac	51,096	±51,088	21.195	±21.191	18.835	±18.832	580.599	±580.502	66.35
Northern white cedar	18,034	±15,126	385.051	±384.025	740.482	±738.510	7,529.917	±7,351.023	76.92
American basswood	15,028	±10,497	251.018	±225.470	73.286	±65.827	4,190.704	±3,909.599	76.70
Eastern hemlock	18,034	±15,126	258.577	±242.760	240.179	±225.488	3,689.234	±3,597.329	83.83
Total	**628,183**	**±209,471**	**8,972.576**	**±3,176.371**	**6,535.479**	**±2,164.417**	**167,225.483**	**±54,142.151**	**73.92**
Stratum: Other Urban									
Balsam fir	12,032	±12,029	138.770	±138.741	144.552	±144.522	1,397.250	±1,396.960	58.00
Freeman maple	2,406	±2,406	122.490	±122.464	68.942	±68.928	3,167.865	±3,167.207	62.50
Boxelder	24,064	±21,682	32.871	±25.102	30.071	±22.964	210.390	±163.095	94.50
Norway maple	7,219	±3,982	82.014	±72.169	44.267	±38.954	502.886	±384.530	92.17

	Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
Species	**Number**	**SE**	**(ha)**	**SE**	**(tonne)**	**SE**	**(tonne)**	**SE**	**(%)**
Red maple	4,813	±4,812	22.398	±22.393	15.085	±15.082	4,172.925	±4,172.058	6.50
Silver maple	4,813	±4,812	284.975	±284.916	149.995	±149.964	11,706.716	±11,704.284	82.50
Sugar maple	12,032	±7,755	387.011	±301.939	233.153	±181.902	28,294.555	±18,525.502	66.80
Tree of heaven	2,406	±2,406	1.487	±1.486	2.287	±2.287	5.387	±5.386	99.50
Yellow birch	9,625	±9,623	141.076	±141.046	58.416	±58.404	1,974.279	±1,973.869	94.50
European hornbeam	2,406	±2,406	7.243	±7.241	4.363	±4.362	116.303	±116.279	94.50
Northern catalpa	4,813	±4,812	1.720	±1.720	1.047	±1.047	12.104	±12.102	97.00
Ginkgo	2,406	±2,406	22.400	±22.395	21.520	±21.515	73.498	±73.483	99.50
Black walnut	4,813	±3,328	109.039	±75.758	87.392	±60.718	401.800	±284.483	94.50
White spruce	12,032	±9,818	39.249	±33.284	63.051	±53.468	762.334	±712.816	96.10
Blue spruce	7,219	±7,218	7.338	±7.337	12.218	±12.216	128.817	±128.790	97.83
Scots pine	9,625	±9,623	53.962	±53.951	52.012	±52.001	848.517	±848.341	77.25
White poplar	2,406	±2,406	4.630	±4.629	4.026	±4.025	13.181	±13.179	94.50
Balsam poplar	21,657	±15,075	19.689	±17.711	14.206	±12.779	1,308.724	±1,243.043	31.44
Common chokecherry	4,813	±4,812	19.021	±19.017	14.745	±14.742	280.007	±279.949	99.50
European buckthorn	26,470	±20,260	82.499	±58.785	36.666	±26.127	1,165.908	±806.246	91.23
Northern white cedar	79,410	±69,756	203.731	±177.253	391.791	±340.871	6,630.048	±5,629.708	98.53
American basswood	12,032	±5,999	189.100	±114.036	55.208	±33.293	1,313.822	±715.435	89.70
Eastern hemlock	31,283	±31,276	514.792	±514.685	478.164	±478.065	5,785.140	±5,783.938	78.08
European white elm	2,406	±2,406	14.403	±14.400	9.810	±9.808	39.943	±39.935	94.50
Total	**303,203**	**±105,205**	**2,501.906**	**±1,100.107**	**1,992.989**	**±888.865**	**70,312.399**	**±27,019.333**	**84.23**

	Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
Species	Number	SE	(ha)	SE	(tonne)	SE	(tonne)	SE	(%)
Stratum: Other - Institutional									
Maple spp.	2,832	±2,832	0.000	±0.000	0.000	±0.000	1,171.466	±1,171.259	0.00
Freeman maple	19,824	±12,576	597.317	±413.542	336.194	±232.758	5,494.729	±3,906.667	92.79
Boxelder	59,473	±48,083	429.510	±244.624	392.928	±223.790	11,235.523	±7,034.255	81.31
Red maple	8,496	±6,215	221.253	±213.364	149.012	±143.699	5,569.131	±5,516.879	94.50
Sugar maple	300,196	±102,666	5,716.193	±2,955.464	3,443.697	±1,780.507	72,534.104	±47,207.974	90.74
Yellow birch	11,328	±11,326	255.005	±254.960	105.592	±105.574	2,987.681	±2,987.154	70.88
Flowering dogwood	2,832	±2,832	3.240	±3.240	2.518	±2.517	48.145	±48.136	94.50
Scarlet hawthorn	5,664	±3,912	23.854	±17.462	17.969	±13.154	513.476	±379.340	82.50
American beech	11,328	±5,263	145.905	±114.696	62.174	±48.875	816.268	±655.853	74.13
European beech	8,496	±8,495	2.845	±2.844	1.424	±1.423	60.188	±60.177	94.50
Ash spp.	19,824	±13,845	0.000	±0.000	0.000	±0.000	4,077.505	±3,807.140	0.00
White ash	45,313	±22,588	119.764	±61.002	68.052	±34.662	6,449.249	±5,125.600	44.25
Green ash	25,488	±16,244	14.371	±11.690	9.374	±7.625	5,953.277	±5,730.161	28.06
Honeylocust	5,664	±3,912	97.873	±91.423	102.496	±95.741	1,118.893	±1,060.457	88.50
Black walnut	16,992	±16,989	516.111	±516.020	413.650	±413.577	4,890.525	±4,889.662	90.50
Hardwood	14,160	±9,993	0.000	±0.000	0.000	±0.000	2,750.027	±1,935.841	0.00
Common apple	25,488	±22,701	50.372	±48.408	43.428	±41.735	5,071.064	±4,327.996	37.83
Eastern hophornbeam	39,649	±31,380	149.827	±106.083	97.811	±69.254	533.174	±373.527	62.54
Pine spp.	2,832	±2,832	0.000	±0.000	0.000	±0.000	1,468.350	±1,468.091	0.00
White spruce	14,160	±14,158	35.362	±35.356	56.807	±56.797	378.476	±378.409	94.50

Species	Trees Number	SE	Leaf Area (ha)	SE	Leaf Biomass (tonne)	SE	Tree Dry Weight Biomass (tonne)	SE	Average Condition (%)
Red pine	240,723	±114,015	1,688.687	±838.330	2,483.363	±1,232.838	49,154.928	±22,042.618	74.00
Eastern white pine	127,442	±63,625	1,017.997	±516.322	654.702	±332.061	11,954.989	±7,426.847	78.26
Scots pine	5,664	±3,912	18.100	±12.759	17.446	±12.297	148.834	±107.606	94.50
Bigtooth aspen	2,832	±2,832	3.036	±3.035	1.549	±1.549	32.356	±32.350	94.50
Quaking aspen	70,801	±62,218	132.880	±132.857	104.638	±104.620	14,753.536	±12,003.611	57.64
Black cherry	14,160	±7,040	62.849	±39.626	48.743	±30.732	1,038.681	±585.407	66.80
Northern red oak	14,160	±9,993	871.746	±604.981	694.618	±482.056	11,858.232	±8,620.058	80.90
European buckthorn	110,449	±85,634	250.659	±206.027	111.404	±91.567	3,036.098	±2,522.423	80.81
European mountain ash	5,664	±5,663	11.900	±11.898	9.444	±9.443	234.765	±234.724	88.50
Northern white cedar	124,610	±110,162	538.856	±464.139	1,036.261	±892.575	17,791.521	±15,524.453	57.33
American basswood	42,481	±39,614	828.675	±633.439	241.935	±184.935	7,530.529	±5,215.691	86.03
Eastern hemlock	2,832	±2,832	35.427	±35.420	32.906	±32.900	741.064	±740.933	94.50
American elm	5,664	±3,912	8.411	±8.410	6.118	±6.116	78.002	±58.557	47.25
Total	**1,407,522**	**±298,153**	**13,848.023**	**±3,476.106**	**10,746.252**	**±2,387.533**	**251,474.782**	**±57,792.049**	**73.15**
Study Area	**6,099,623**	**±665,195**	**61,836.465**	**±6,961.710**	**55,089.968**	**±6,291.070**	**1,361,279.816**	**±155,141.591**	**75.75**

Appendix E: Invasive Plants, Pests, and Diseases

Table 35. Invasive plant species by percentage of plots affected and average spread

Species		Agriculture		Residential		Natural Cover and Open Space		Other Urban		Other – Institutional		Whitchurch-Stouffville	
Common Name	Scientific Name	Percent of plots	Spread	Percent of plots	Spread	Percent of plots	Spread	Percent of plots	Spread	Percent of plots	Spread	Percent of plots	Spread
European Buckthorn	*Rhamnus cathartica*	23%	1.76	31%	1.80	18%	1.50	23%	2.17	24%	2.50	34%	1.89
Non-native honeysuckle	*Lonicera spp.*	6%	1.50	6%	1.75	5%	2.00	4%	2.00	6%	1.50	8%	1.64
Winged spindle-tree	*Euonymus alatus*	0%	N/A	2%	1.00	0%	N/A	4%	1.00	3%	1.00	2%	1.00
Tatarian honeysuckle	*Lonicera tatarica*	4%	2.25	8%	1.60	5%	2.00	8%	3.00	3%	2.00	7%	2.08
Dog-strangling vine	*Cynanchum rossicum*	6%	1.43	9%	2.00	9%	1.50	8%	1.00	6%	2.00	10%	1.63
Garlic mustard	*Alliaria petiolate*	0%	N/A	3%	2.00	0%	N/A	0%	N/A	3%	1.00	2%	1.67
Goutweed	*Aegopodium podagraria*	0%	N/A	0%	N/A	0%	N/A	4%	1.00	0%	N/A	1%	1.00
Periwinkle	*Vinca minor*	1%	2.00	3%	2.00	0%	N/A	4%	4.00	3%	3.00	3%	2.60
Phragmites	*Phragmites australis*	1%	2.00	2%	1.00	0%	N/A	12%	2.33	0%	N/A	3%	2.00

Species		Agriculture		Residential		Natural Cover and Open Space		Other Urban		Other – Institutional		Whitchurch-Stouffville	
Common Name	**Scientific Name**	**Percent of plots**	**Spread**	**Percent of plots**	**Spread**	**Percent of plots**	**Spread**	**Percent of plots**	**Spread**	**Percent of plots**	**Spread**	**Percent of plots**	**Spread**
Wild Parsnip	*Pastinaca sativa*	0%	N/A	3%	2.00	0%	N/A	0%	N/A	3%	1.00	2%	1.67
Wintercreeper Euonymus	*Euonymus fortune*	1%	2.00	3%	1.50	5%	2.00	0%	N/A	0%	N/A	2%	1.75
Black locust	*Robinia pseudoacacia*	0%	N/A	2%	1.00	0%	N/A	0%	N/A	0%	N/A	1%	1.00
Callery pear	*Pyrus calleryana*	0%	N/A	2%	1.00	0%	N/A	0%	N/A	0%	N/A	1%	1.00
Ivory silk lilac	*Syringa reticulata*	14%	1.87	12%	1.63	14%	1.33	15%	1.50	15%	1.80	19%	1.71
Manitoba maple	*Acer negundo*	1%	2.00	3%	1.50	0%	N/A	8%	1.00	0%	N/A	3%	1.40
Norway maple	*Acer platanoides*	23%	1.76	31%	1.80	18%	1.50	23%	2.17	24%	2.50	34%	1.89

Table 36. Invasive pest species (Emerald ash borer and Spongy moth) by percentage of plots affected and spread

Stratum	Emerald ash borer (*Agrilus planipennis*) Percent of Plots	Emerald ash borer (*Agrilus planipennis*) Mean Spread	Spongy moth (*Lymantria dispar dispar*) Percent of Plots	Spongy moth (*Lymantria dispar dispar*) Mean Spread
Agriculture	5.6%	1.17	4.6%	2.40
Residential	12.3%	1.25	9.2%	2.00
Natural Cover – Open Space	22.7%	2.20	9.1%	2.00
Other Urban	14.7%	1.80	17.7%	2.17
Other – Institutional	13.0%	1.54	10.0%	2.16
Whitchurch-Stouffville	**5.6%**	**1.17**	**4.6%**	**2.40**

Table 37. Diseases (Beech bark disease, Beech leaf disease and Dutch elm disease) by percentage of plots affected, average number of plants and spread

Stratum	Beech bark disease (caused by *Cryptococcus fagisuga*) Percent of Plots	Beech bark disease Mean Spread	Beach leaf disease (caused by *Litylenchus crenatae mccannii*) Percent of Plots	Beach leaf disease Mean Spread	Dutch elm disease (caused by *Ophiostoma spp.*) Percent of Plots	Dutch elm disease Mean Spread
Agriculture	1%	1.00	0%	N/A	1%	1.00
Residential	6%	1.00	2%	1.00	0%	N/A
Natural Cover – Open Space	0%	N/A	0%	N/A	0%	N/A
Other Urban	0%	N/A	0%	N/A	0%	N/A
Other – Institutional	3%	1.00	3%	1.00	0%	N/A
Whitchurch-Stouffville	**3%**	**1.54**	**1%**	**1.00**	**1%**	**1.41**

Appendix F: Leaf Area and Stem Count by Native or Non-Native

Table 38. Composition and structure by native species

Species		Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
Common Name	**Scientific Name**	**Number**	**SE**	**(ha)**	**SE**	**(tonne)**	**SE**	**(tonne)**	**SE**	**(%)**
Northern white cedar	*Thuja occidentalis*	1,127,518	±385,790	6,809.846	±2,148.044	13,095.857	±4,130.853	258,093.491	±84,262.960	77.12
Sugar maple	*Acer saccharum*	980,009	±187,166	22,129.343	±4,887.856	13,331.732	±2,944.669	410,186.270	±89,050.883	88.88
Red pine	*Pinus resinosa*	366,541	±128,873	2,631.853	±976.724	3,870.372	±1,436.359	68,848.795	±24,339.348	69.66
Quaking aspen	*Populus tremuloides*	288,141	±99,176	1,203.308	±428.031	947.56	±337.059	37,718.960	±15,818.874	74.48
White spruce	*Pice glauca*	236,147	±107,407	2,308.138	±816.932	3,707.851	±1,312.341	53,631.597	±26,307.991	69.28
Eastern white pine	*Pinus strobus*	235,755	±88,668	2,649.256	±1,267.191	1,703.811	±814.966	26,075.811	±12,410.768	81.58
Eastern hophornbeam	*Ostrya virginiana*	216,434	±61,938	1,697.705	±557.295	1,108.307	±363.817	10,266.246	±3,744.106	82.41
Eastern hemlock	*Tsuga canadensis*	208,274	±74,223	2,431.516	±1,030.616	2,258.514	±957.288	41,325.061	±21,560.638	82.44
White ash	*Fraxinus americana*	183,809	±43,573	495.07	±123.926	281.31	±70.416	17,222.756	±6,246.393	47.30
American basswood	*Tilia americana*	143,919	±51,465	2,242.477	±857.990	654.70	±250.494	27,084.787	±10,029.904	84.45
Green ash	*Fraxinus pennsilvanica*	91,956	±28,150	290.36	±167.923	189.39	±109.532	14,304.575	±6,678.266	32.59

Species		Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
Common Name	Scientific Name	Number	SE	(ha)	SE	(tonne)	SE	(tonne)	SE	(%)
Northern red oak	*Quercus rubra*	82,483	±31,871	2,823.649	±1,169.527	2,249.919	±931.894	40,567.012	±16,983.764	87.39
Staghorn sumac	*Rhus typhina*	79,246	±55,663	57.36	±35.374	50.98	±31.435	1,238.937	±811.802	71.97
Ash spp.	*Fraxinus spp.*	67,465	±22,216	0.00	±0.000	0.00	±0.000	13,179.216	±5,634.758	0.00
Yellow birch	*Betula alleghaniensis*	63,048	±22,682	958.15	±433.203	396.75	±179.380	22,391.995	±8,728.249	58.76
Alternateleaf dogwood	*Cornus alternifolia*	58,286	±29,209	81.34	±48.630	54.23	±32.422	998.97	±559.355	69.80
Black cherry	*Prunus serotina*	55,690	±15,916	349.63	±138.201	271.16	±107.183	29,772.669	±17,576.319	66.69
Black walnut	*Juglans nigra*	51,179	±21,261	979.75	±566.992	785.24	±454.430	8,420.163	±5,376.126	93.17
American elm	*Ulmus americana*	44,192	±19,104	164.38	±80.238	119.56	±58.359	8,141.215	±5,053.017	53.59
Dotted hawthorn	*Cretaegus punctata*	41,865	±35,845	64.74	±46.056	48.77	±34.694	1,234.887	±868.372	69.43
Red maple	*Acer rubrum*	38,380	±20,067	327.15	±221.336	220.33	±149.068	10,715.220	±6,952.378	79.08
American beech	*Fagus grandifolia*	37,792	±14,298	471.24	±231.458	200.81	±98.631	8,195.755	±5,092.991	76.10
American mountain ash	*Sorbus americana*	32,383	±29,276	119.78	±116.786	95.06	±92.687	3,130.723	±3,091.741	65.65
Paper birch	*Betula papyrifera*	30,693	±11,572	539.21	±221.204	377.10	±154.699	16,935.587	±7,560.715	74.05
Pear hawthorn	*Cretaegus calpodendron*	30,496	±30,489	17.90	±17.894	13.48	±13.479	1,748.728	±1,748.355	42.62
Black ash	*Fraxinus nigra*	29,568	±17,923	11.21	±11.203	6.67	±6.669	1,462.214	±913.868	13.45
Freeman maple	*Acer x freemanii*	27,815	±13,414	765.26	±432.706	430.72	±243.545	9,336.674	±5,054.425	89.53

Species		Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
Common Name	Scientific Name	Number	SE	(ha)	SE	(tonne)	SE	(tonne)	SE	(%)
Hardwood	*Magnoliopsida spp.*	22,750	±11,175	0.00	±0.000	0.00	±0.000	11,287.232	±6,376.974	0.00
Balsam fir	*Abies balsamea*	21,747	±15,461	173.73	±143.077	180.97	±149.038	2,854.489	±2,018.511	58.45
Balsam poplar	*Populus balsamifera*	21,657	±15,075	19.69	±17.711	14.21	±12.779	1,308.724	±1,243.043	31.44
Scarlet hawthorn	*Crataegus coccinea*	18,617	±8,763	62.23	±31.792	46.88	±23.949	1,371.244	±729.702	85.28
Bitternut hickory	*Carya cordiformis*	10,043	±6,004	68.76	±50.292	43.22	±31.614	761.36	±553.709	94.50
Eastern red cedar	*Juniperus virginiana*	10,043	±6,004	6.85	±4.496	19.03	±12.493	180.77	±116.072	90.91
Sweet crabapple	*Morus coronaria*	9,715	±9,713	28.45	±28.447	24.53	±24.525	1,303.104	±1,302.903	67.50
Common chokecherry	*Prunus virginiana*	9,504	±5,823	24.32	±19.378	18.85	±15.022	429.87	±306.047	97.03
Red hickory	*Carya glabra*	9,383	±9,381	49.06	±49.052	32.96	±32.949	1,094.537	±1,094.304	94.50
Honeylocust	*Gleditsia triacanthos*	8,010	±4,561	187.26	±127.844	196.10	±133.882	1,628.581	±1,176.537	90.26
Butternut	*Juglans cinerea*	6,477	±4,548	128.23	±109.702	70.84	±60.606	1,526.034	±1,361.662	72.50
Silver maple	*Acer saccharinum*	4,813	±4,812	284.98	±284.916	150.00	±149.964	11,706.716	±11,704.284	82.50
Northern catalpa	*Catalpa speciosa*	4,813	±4,812	1.72	±1.720	1.05	±1.047	12.10	±12.102	97.00
Black maple	*Acer nigrum*	4,692	±4,691	15.29	±15.283	8.60	±8.602	274.64	±274.585	88.50
Eastern redbud	*Cercis canadensis*	4,692	±4,691	4.34	±4.338	2.78	±2.778	220.18	±220.128	47.25

Species		Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
Common Name	Scientific Name	Number	SE	(ha)	SE	(tonne)	SE	(tonne)	SE	(%)
American hornbeam	*Carpinus caroliniana*	3,238	±3,238	21.55	±21.550	12.99	±12.983	138.40	±138.375	94.50
Black hawthorn	*Crataegus douglasii*	3,238	±3,238	5.69	±5.685	4.28	±4.283	47.32	±47.315	82.50
Cottonwood spp.	*Populus spp.*	3,238	±3,238	0.00	±0.000	0.00	±0.000	1,340.434	±1,340.227	0.00
Balm-of-gilead	*Populus balsamifera*	3,238	±3,238	177.21	±177.183	127.87	±127.847	2,144.436	±2,144.105	94.50
Wildgoose plum	*Prunus americana*	3,238	±3,238	0.41	±0.407	0.32	±0.315	38.16	±38.151	13.00
Rock elm	*Ulmus thomasii*	3,238	±3,238	51.80	±51.794	35.28	±35.278	1,186.447	±1,186.264	62.50
Maple spp.	*Acer spp.*	2,832	±2,832	0.00	±0.000	0.00	±0.000	1,171.466	±1,171.259	0.00
Flowering dogwood	*Cornus florida*	2,832	±2,832	3.24	±3.240	2.52	±2.517	48.15	±48.136	94.50
Pine spp.	*Pinus spp.*	2,832	±2,832	0.00	±0.000	0.00	±0.000	1,468.350	±1,468.091	0.00
Bigtooth aspen	*Populus grandidentata*	2,832	±2,832	3.04	±3.035	1.55	±1.549	32.36	±32.350	94.50
White poplar	*Populus alba*	2,406	±2,406	4.63	±4.629	4.03	±4.025	13.18	±13.179	94.50
Horse chestnut	*Aesculus hippocastanum*	2,346	±2,345	0.38	±0.379	0.27	±0.265	2.98	±2.983	62.50
River birch	*Betula nigra*	2,346	±2,345	6.76	±6.759	5.24	±5.239	31.78	±31.777	94.50
Kentucky coffee tree	*Gymnocladus dioicus*	2,346	±2,345	0.69	±0.692	0.60	±0.598	5.52	±5.519	99.50
Tamarack	*Larix laricina*	2,346	±2,345	2.30	±2.298	1.49	±1.486	19.11	±19.106	82.50

Species		Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
Common Name	Scientific Name	Number	SE	(ha)	SE	(tonne)	SE	(tonne)	SE	(%)
Apple spp.	*Morus spp.*	2,346	±2,345	0.93	±0.928	0.80	±0.800	10.81	±10.811	82.50
Swamp cottonwood	*Populus heterophylla*	2,346	±2,345	3.90	±3.895	2.81	±2.811	13.28	±13.273	94.50
Pin oak	*Quercus palustris*	2,346	±2,345	23.02	±23.015	20.84	±20.830	296.83	±296.768	94.50
Study Area		**5,065,624**	**±1,819,422**	**7,052.96**	**±18,231.59**	**6,174.70**	**±16,189.53**	**3,575.77**	**±428,941.85**	**69.00**

Table 39. Composition and structure by non-native species

Species		Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
Common Name	Scientific Name	Number	SE	(ha)	SE	(tonne)	SE	(tonne)	SE	(%)
European buckthorn	*Rhamnus cathartica*	376,535	±111,519	1,031.526	±326.797	458.46	±145.243	20,472.166	±6,469.547	77.32
Boxelder	*Acer negundo*	231,933	±82,404	2,764.251	±1,202.478	2,528.818	±1,100.062	57,004.861	±26,891.958	77.98
Scots pine	*Pinus sylvestris*	123,491	±57,272	1,202.295	±666.661	1,158.839	±642.565	22,792.041	±12,378.193	77.89
Common apple	*Morus domestica*	122,866	±79,187	567.05	±260.345	488.87	±224.455	43,023.497	±32,149.971	83.64
Blue spruce	*Picea pungens*	48,654	±24,013	1,008.943	±642.288	1,679.892	±1,069.411	15,927.092	±10,021.895	95.80
Norway maple	*Acer platanoides*	36,593	±17,941	201.91	±97.625	108.98	±52.693	1,409.433	±618.081	94.58
Black locust	*Robinia pseudoacacia*	13,514	±8,303	131.31	±99.222	70.69	±53.420	1,948.736	±1,565.064	91.53
Norway spruce	*Picea abies*	11,729	±6,025	359.01	±212.955	598.35	±354.926	3,798.244	±2,030.767	89.30

Species		Trees		Leaf Area		Leaf Biomass		Tree Dry Weight Biomass		Average Condition
Common Name	Scientific Name	Number	SE	(ha)	SE	(tonne)	SE	(tonne)	SE	(%)
Austrian pine	*Pinus nigra*	9,383	±7,367	245.32	±240.362	236.45	±231.674	2,706.249	±2,672.301	94.50
European mountain ash	*Sorbus aucuparia*	8,902	±6,523	67.11	±56.472	53.27	±44.819	625.79	±456.016	90.68
European beech	*Fagus sylvatica*	8,496	±8,495	2.85	±2.844	1.42	±1.423	60.19	±60.177	94.50
Ginkgo	*Ginkgo biloba*	7,098	±5,272	25.38	±22.593	24.39	±21.705	91.84	±75.736	97.85
Siberian elm	*Ulmus pumila*	7,037	±7,036	43.79	±43.782	29.83	±29.820	2,041.033	±2,040.598	62.50
European white elm	*Ulmus laevis*	5,645	±4,034	88.67	±75.640	60.39	±51.519	789.57	±750.578	94.50
Callery pear	*Pyrus calleryana*	4,692	±4,691	31.45	±31.439	23.66	±23.653	1,063.937	±1,063.711	88.50
Rowan Mountain Ash	*Sorbus discolor*	3,238	±3,238	56.89	±56.883	45.15	±45.145	1,086.627	±1,086.459	94.50
Tree of heaven	*Ailanthus altissima*	2,406	±2,406	1.49	±1.486	2.29	±2.287	5.39	±5.386	99.50
European hornbeam	*Carpinus betulus*	2,406	±2,406	7.24	±7.241	4.36	±4.362	116.30	±116.279	94.50
Paperbark maple	*Acer griseum*	2,346	±2,345	1.48	±1.484	0.84	±0.835	28.07	±28.065	94.50
Japanese tree lilac	*Syringa reticulata*	2,346	±2,345	0.46	±0.463	0.45	±0.447	7.47	±7.466	82.50
Sweet cherry	*Prunus avium*	2,346	±2,345	1.74	±1.742	1.35	±1.348	23.98	±23.975	99.50
Littleleaf linden	*Tilia cordata*	2,346	±2,345	16.25	±16.247	12.17	±12.171	60.39	±60.381	94.50
Study Area		**1,034,002**	**±445,167**	**1,849.39**	**±4,065.31**	**2,221.36**	**±4,112.64**	**1,808.99**	**±100,548.63**	**89.57**

Appendix G: Overview of additional (optional) tree health assessment

Field Data Collection

The field data collection procedure and ratings are outlined for each criterion below. However, some indicators listed here are not always indications of poor health as certain species naturally show these signs, for example, self-pruning limbs in spruce and silver maples. In such cases, relevant indicators were not given poor scores even if observed.

Trunk Integrity Indicator

- Rot/Cavities/Wounds in the Trunk
  - Rated from very poor (1) showing signs of advanced cankers or rot to good (4) being a perfect trunk with no indications of injury, rot or wounds.
- Lean
  - Rated for lean from very poor (1) tree showing signs of extreme lean, 45° from vertical or 90°, to good (4) with no/very minor signs of lean.
- Girdling Roots
  - Rated from girdled roots from very poor (1) to good (4), no signs of girdled roots.
- Root Damaged or Exposed
  - Rated with damage are rated from very poor (1), showing signs of root damage and/or exposed roots with signs of damage to good (4), with no signs of root damage and/or exposed roots
- Fruiting bodies/Conks
  - Rated as presence/absence along the stem

Canopy Structure

- Poor stem/branch attachment
  - Rated from very poor (1), V-shaped union present with integrated bark and/or split/failure of stems to good (4), branches properly attached
- Dead/broken branches
  - Rated from very poor (1), one or more large dead/broken major branches to good (4), no dead/broken branches (small branches excluded)
- Damaged crown
  - Rated as presence/absence if over 25% of the crown is missing due to weather event/extreme pruning etc.

- Unbalanced crown
    - Rated from very poor (1), crown is extremely unbalanced to good (4), health/balanced crown

Canopy Vigor

- Dieback
    - Rated from very poor (1), significant crown dieback of over 50%, to good (4), no signs of dieback
- Defoliation
    - Rated from very poor (1), high defoliation in crown of over 50%, to good (4), no signs of defoliation
- Chlorosis
    - Rated from very poor (1), majority of foliage is chlorotic to good (4), foliage shows no signs of chlorosis
- Weak Foliage
    - Rated from very poor (1), leaves are small or malformed to good (4), leaves are standard shape and size
- Foliage Abnormalities
    - Rated for presence for the following foliage abnormalities:
    - Mottling, spot or blotches
    - Marginal scorching
    - Interveinal scorching
    - White coating
    - Black coating
    - Stippling
    - Yellow/orange/white pustules
    - Foliage/twigs distorted or galls
    - Witches' broom
    - Other

Cases where there were more than 24 trees in a plot

To support data collection, a maximum of 24 trees were assessed per plot across all land uses. In natural forested areas, the field crew only assessed the health of trees that had a diameter of 5 cm or more, in line with the i-Tree Eco protocol.

Trees were selected in a manner to reduce bias. Trees were observed starting with the tree closest to north and moving clockwise. Every *x* number of trees was observed where *x* = 24 / number of trees per plot.

Dead Trees

Dead trees were included by giving the worst score for each option and commenting that the tree is dead.