CITY OF GUELPH URBAN FOREST STUDY REPORT

2019

PREPARED BY LALLEMAND INC./BIOFOREST
AND KBM RESOURCES GROUP

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City of Guelph

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Executive Summary

This report presents the results of the first comprehensive tree canopy study for the City of Guelph. Using proven methods developed in the United States (US) in 2006 (i-Tree)[1], studies of this kind have provided hundreds of cities around the world with reliable information to guide urban forest management decisions. Growing the urban forest and its associated benefits support the community's interests in building a livable, green City of Guelph, as identified in the 2019 Strategic Plan.

For the purposes of this study, the urban forest is broadly defined as all "trees, forests, greenspace and related abiotic, biotic and cultural components in areas extending from the urban core to the urban-rural fringe". That includes all individual trees, groups of trees or woodlands on both public and private property in Guelph. This is important, because the study shows that private landowners in Guelph play an important part in sustaining and growing the urban forest.

The study results show that Guelph has a reasonably diverse, healthy forest with a replacement value of $803 million. The City's high value population of street trees is in good condition. The forest as a whole produces $5.3 million per year in ecosystem services that benefit Guelph's residents, visitors and businesses. This includes reductions in air pollution, avoided stormwater runoff, energy savings in residential heating and cooling costs and carbon sequestration that helps mitigate climate change. This number could be increased, by encouraging the growth of larger trees whose higher crown leaf area provides the most benefits. There are various management strategies that could support more large trees in Guelph, like improved tree protection and management and/or maximizing planting of large stature shade trees on sites that can support their growth.

The data also reveals signs of stress in some parts of the forest. About half of the tree species found in Guelph's urban forest are native to southern Ontario, but invasive species (e.g. common buckthorn) have been colonizing natural areas over time. A high number of dead standing trees, many also in natural areas, may be a legacy of the emerald ash borer that has led to the removal of about 7,400 ash trees across the city. Maple species are found in high numbers and produce a significant amount of Guelph's urban forest benefits. However, the high amount of maple leaf area, particularly in the street tree population, makes the forest more vulnerable to pest threats like the Asian longhorned beetle.

[1] Since 2006, i-Tree has been a cooperative effort between the USDA Forest Service, Davey Tree Expert Company, The Arbor Day Foundation, Society of Municipal Arborists, International Society of Arboriculture, Casey Trees, and SUNY College of Environmental Science and Forestry.

The size distribution of the forest is skewed somewhat to the smaller and medium classes, with far fewer trees found in the largest size classes. Only 1per cent of trees are over 61 cm in diameter. This matters because large trees provide the most urban forest benefits and the best return on the planting investment. Another important finding is that over half of the urban forest is found on private land (53 per cent) (Table 1). This means that Guelph residents and business owners have an important role to play in protecting and growing the urban forest.

Table 1: Guelph urban study summary of findings.

Guelph Urban Forest Study Results	Findings
Total number of trees in Guelph	2,973,000
Structural (replacement) value of all trees	$803 million
Canopy cover (as a percentage of total land area)	23.3%
Land use with highest canopy cover	Vacant land (includes Natural Area and Open Space) at
Land use with lowest canopy cover	Industrial at 7.5%
Tree ownership	53% private, 47% public
Total number of tree species and varieties	106
Top three species by per cent of population (number of trees)	Eastern white cedar (20.8%) Common buckthorn (19.3%) Green ash (10.1%)
Top three species by per cent of leaf area (m^2)	Eastern white cedar (16.6%) Norway maple (9.1%) Sugar maple (8.9%)
Percentage of trees native to southern Ontario	48%
Percentage of trees in good or excellent condition	71.1%
Percentage of trees that are dead	16.7%
Percentage of trees in the smallest size class (7.6 cm diameter at breast height and under)	42.6%
Percentage of trees in the largest size classes (61 cm diameter at breast height and over)	1%
Annual dollar value of ecosystem services	$5.6 million
Annual energy savings	141,941 MBTUs (4,428 MWh), with a value of $1,882,502
Pollution removal	156 tonnes, with a value of $2,051,438

Guelph Urban Forest Study Results	Findings
Avoided Runoff	399,938 m³, with a value of $929,742
Gross Carbon Sequestration	6,455 tonnes, with a value of $741,515
Carbon storage	196,894 tonnes, with a value of $22.6 million

Street trees are a distinct and high value population under regular care by Forestry staff. To get a more detailed picture of the state of the City's street trees, the street tree inventory – representing 43,659 trees[2] – was input separately in i-Tree Eco. The results show that the street tree population is in good condition as a result of regular maintenance. Street trees are larger on average and deliver proportionately more urban forest benefits as a result. The number of trees in the smallest size class is somewhat lower than trees in the medium diameter classes, suggesting that the rate of street tree planting should be increased to sustain the population over time. The amount of maple leaf area is high in street trees and in the overall tree population as well, making the maple population vulnerable to threats from pests such as Asian longhorned beetle (Table 2).

Table 2: Street tree analysis summary of findings.

Street Tree Analysis Results	Finding
Total number of street trees	43,659
Per cent of total tree population	1.5%
Structural (replacement) value	$105.6 million
Per cent of total structural value of the urban forest	13%
Most abundant street tree	Norway maple (22.3% of street tree population)
Norway maple leaf area	40.9% of total leaf area
Street trees in excellent or good condition	84%
Street trees in small size class (under 15.2 cm)	36.6%
Street trees in medium-large size class (over 30.5 cm)	38.3%

The study findings as presented in this report lead to the following 29 recommendations (Table 3). Recommendations are based on the implications of the findings generated from the i-Tree models, the land cover classification and canopy

[2] After removing erroneous entries in the database.

feasibility analysis, the planting prioritization assessment and the findings of the literature review. These recommendations will be incorporated in the next five-year management plan to ensure progress toward Guelph's goal of achieving a healthy, resilient urban forest that supports many other sustainability objectives for the City of Guelph. Detailed methodologies, results and the rationale for the following recommendations can be found in the body of the report and related Appendices.

Table 3: Summary of recommendations.

Number	Recommendation
1	Use canopy cover maps with height models to support targeted and proactive outreach/ education to landowners with large/mature trees. (p 29)
2	Fund and implement an outreach campaign with landowners and community organizations in Guelph to build partnerships and expand the urban forest on private lands. (p 31)
3	Identify opportunities to increase hard surface planting in highly urbanized land use areas. (p 33)
4	Prioritize planting opportunities in and adjacent to the Natural Heritage System to enhance Natural Heritage System (NHS) function. (p 34)
5	Monitor forest and land cover change regularly using open source tools developed by the USDA Forest Service (i-Tree) or other proven methods. (p 37)
6	Identify options for improving the preservation of quality pervious growing space and soil resources in new residential and non-residential development. (p 38)
7	Ensure all future growing space designed for trees in new residential and non-residential development is high quality, including sufficient soil volume, quality and crown space to support long-term growth. (p 39)
8	Identify and implement best practices in zoning and urban design that maximize quality growing space on public and private land. (p 39)
9	Use the results of the canopy cover and plantable space analyses to develop canopy cover targets for implementation at the project or site level. Integrate targets into Guelph's policies, by-laws or built form guidelines or other guiding documents as appropriate. (p 39)
10	Work collaboratively with other forest managers to develop an invasive species monitoring and management strategy for the City of Guelph. (p 43)
11	Fund and implement invasive species management in high priority areas within and adjacent to the NHS. (p 43)
12	Review the effectiveness of current tree by-laws, protection policies and development review processes for protecting trees and promoting mature tree retention in Guelph. Identify options for promoting the retention of mature, heathy trees. (p 43)

Number	Recommendation
13	Increase outreach to and education for landowners to provide information about invasive species and options for stewardship on private lands. (p 46)
14	Include consideration of current species abundance and leaf area as well as vulnerability to pests in species selection as part of a comprehensive planting strategy. (p 48)
15	Develop suitable species lists for urban trees and natural areas and review lists annually as part of operational planning. Include as an Appendix to the Tree Technical Manual. (p 48)
16	Include an update on the status of major forest health threats as part of annual operational planning. (p 48)
17	Develop a forest monitoring program to support early detection and response to threats from pests, disease and invasive plant species. (p 48)
18	Document the contribution of trees in supporting net zero carbon by 2050 in future updates to the Community Energy Initiative and other climate resilience planning initiatives. (p 52)
19	Forestry should work with the City of Guelph Engineering Services to identify priority locations for planting trees in areas prone to high levels of runoff and flooding. (p 53)
20	Examine opportunities for extending stormwater credit calculations based on per cent hard surface to include per cent relative tree canopy to incentivize tree planting on industrial, commercial and institutional properties. (p 53)
21	Increase the rate of street tree planting to ensure a sustainable street tree population in the City. (p 57)
22	Identify populations of senescent street trees where underplanting would help maintain urban forest benefits and increase resilience to storm events. (p 57)
23	Implement proactive maintenance and inspection programs to optimize the services delivered by street trees, including maintenance and watering of newly planted trees. (p 57)
24	Compare i-Tree Storm estimates to current expenditures and use the information to forecast future resource requirements. (p 55)
25	Increase structural diversity in the forest through strategic planting and species mixes to improve resilience to extreme weather events. (p 62)
26	Extend the time horizon for achieving 40 per cent canopy to 50 years. (p 77)

Number	Recommendation
27	Use criteria and indicators to assess progress toward sustainable urban forest management goals as defined in the next Urban Forest Management Plan (UFMP). (p 77)
28	Use planting prioritization maps to inform tactical and operational planning for City tree planting programs. (p 82)
29	Use criteria in the Tree Technical Manual to evaluate and prioritize high quality planting sites in rights-of-way and other public lands. (p 82)

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Glossary

Ancillary data – Data from sources other than remote sensing used to assist in analysis and classification. Examples of ancillary data used in the study are roads, building footprints, etc.

Canopy cover – The amount of land area covered by trees and shrubs when viewed from above. Often expressed as a percentage of a city's total land area. For example, at 50 per cent canopy cover, half of the land area will be covered by tree or shrub canopies.

Crown condition – A measure used in i-Tree studies to provide some indication of the condition/health of a tree. Condition ratings are based on the percentage of dieback observed in a tree crown. The condition classes are Excellent (less than 1% crown dieback), Good (1-10% dieback), Fair (11-25% dieback), Poor (26-50% dieback), Critical (51-75% dieback), Dying (76-99% dieback), and Dead (100% dieback). Condition ratings do not consider stem defects or root damage.

Diameter at breast height (DBH) – The diameter of a tree's stem measured at a height of 1.37 metres from the ground.

Green infrastructure **-** The natural vegetative systems and green technologies that collectively provide society with a multitude of economic, environmental and social benefits[3].

Image (land cover) classification – The conversion of a remotely sensed image (e.g. satellite image) into land cover types that a computer can read.

Invasive – Refers to a non-native species that aggressively out-competes native species and comes to dominate ecosystems that would naturally be populated by native species.

Land cover – The physical surface cover on the ground, whether vegetation, water, bare soil or pavement. It does not describe the use of land.

Land use - Refers to the use of the land, for example, transportation, recreation (parks), commercial areas, agriculture. It does not describe the surface cover on the ground.

Leaf area – The total measure of area represented by the surface area of all living leaf tissue. Leaf area may be calculated for individual trees or for large populations

[3] Green Infrastructure Ontario.

of trees. Leaf area accounts for all overlapping leaf material, whereas canopy cover only accounts for the projection of tree or shrub canopy over land area.

Light Detection and Ranging (LiDAR) – LiDAR is a technology that uses lasers to collect geographic information, allowing for accurate horizontal and vertical measurements.

Native – A species living in a geographical area where it has been historically present and naturally self-sustaining. A native species is distinguished from a non-native species that has been introduced to a new area and become naturalized.

Normalized Difference Vegetation Index (NDVI) – NDVI is a method of analyzing the presence of chlorophyll in objects in a satellite or aerial photograph.

Non-native – Refers to a species introduced to an area outside of its native range. Synonymous with exotic species.

Potential canopy cover - A metric describing grass or other non-treed pervious land cover that is theoretically available for the establishment of tree canopy.

Shrub – In i-Tree Eco, a shrub is any woody plant that measures less than 2.5 cm DBH. Immature specimens of tree species may be included, provided they fall below the 2.5 cm DBH threshold.
In the land cover assessment methodology, assisted with LiDAR, a shrub is defined where maximum LiDAR height is less than or equal to 2.0 metres; LiDAR mean height less than 0.75 m and NDVI mean greater than -0.2.

Street tree – Generally, a tree that is located completely or partially on or immediately adjacent to the municipal property in the right-of-way and that is managed by municipal personnel. In Guelph, street trees include all trees located in right of ways and front yards and are classified as City, boundary (those located on the boundary of public and private property) and private trees. This reflects how they are managed by Forestry – for City and boundary trees, maintenance objectives are health (benefits) and safety (structure). For private trees, the maintenance objective is public safety and safety of right of way only. The City does not maintain private street trees unless they are an immediate danger as defined by the Municipal Act.

Structural value – The structural value of a tree is based on the trunk formula method developed by the Council of Tree and Landscape Appraisers (CTLA), an industry best practice for calculating tree value. It is based on the physical asset of the tree and is determined in part by the tree’s size, as well as its condition, species, and location. As such, it provides an estimate of the economic cost of theoretically replacing the tree. Structural value does not encompass the value of any ecosystem service or other benefits provided by trees.

Tree – In the i-Tree Eco protocol, a tree is any woody plant that measures at least 2.5 cm DBH.
In the land cover assessment methodology, assisted with LiDAR, a tree is defined where maximum LiDAR height is greater than or equal to 2.0 metres; LiDAR mean height greater than or equal to 0.75 m and NDVI mean greater than -0.2.

Tree Planting Prioritization Tool (TPPT) – A model developed for Peel Region that is used to assess priority tree planting locations, using land cover and other available datasets along with a set of benefit criteria to identify priority tree planting locations.

Introduction

STUDY BACKGROUND AND OBJECTIVES

The City of Guelph Official Plan (OP, 2018) recognizes the importance of the urban forest and supports its protection and enhancement through both public and private development. The OP provides direction for the protection of significant woodlands within the Natural Heritage System, including minimum buffer requirements, policies specific to cultural woodlands and plantations, policy supporting planting of native and non-invasive trees and shrubs, a canopy cover target of 40 per cent by 2031, and a commitment to a monitoring program for the urban forest. In the OP, the urban forest is defined rather narrowly as "plantations and smaller wooded areas less than one hectare, hedgerows and individual trees that are not included in the City's Natural Heritage System."[4]

In this study and in literature, the urban forest is often defined more broadly as all "trees, forests, greenspace and related abiotic, biotic and cultural components in areas extending from the urban core to the urban-rural fringe".[5] This is a more holistic view of the urban forest, recognizing that trees are part of an ecosystem that does not stop at the urban boundary. Taking this a step further, urban forests may be seen as a critical part of the larger urban infrastructure.[6]

Management of the urban forest should include all components included in this definition. In many municipalities, roles for different aspects of forest management are often divided between multiple city departments, leading to a patchwork of management approaches (e.g. street vs. park trees, natural areas, regulation of trees on private land). Achieving success in urban forestry programs relies on a coordinated effort across many disciplines and stakeholder groups, based on a solid foundation of ecology and science. A good urban forestry program should include not only foresters but also engineers, planners and landscape architects. In other words, all of the disciplines involved in building the urban landscape. [7]

Over the past decade, the City of Guelph has undertaken various projects to enhance urban forest management and work toward achieving the City's canopy cover goal of 40 per cent by 2031. The implementation of the City of Guelph's

[4] City of Guelph Official Plan, March 2018 Consolidation. Section 4.1.6.

[5] 2019-2024 Canadian Urban Forest Strategy, Tree Canada.

[6] Introduction: Building the Urban Forest. 2014. Published in: Scenario 04: Building the Urban Forest. Edited by Stephanie Carlisle, Nicholas Pevzner & Max Piana.

[7] Ibid.

Urban Forest Management Plan (UFMP) (2013-2032) was informed by several strategic goals, including:

- Improving understanding of urban forest assets;
- Fostering stewardship, awareness, and education;
- Transitioning to proactive management; and
- Increasing the resilience of the urban forest.

The first urban forest studies for the City of Guelph were completed in 2007 and 2011. A more recent analysis of Guelph's urban forest canopy cover and plantable spaces analysis was undertaken in 2015.[8] Since 2015, the City of Guelph, in partnership with the Ontario Ministry of Natural Resources and Forestry (OMNRF) and the University of Toronto, has also collected baseline field data at 207 permanent sample plots across the City. The City has also completed a municipal tree inventory, which includes information describing approximately 52,510 trees on streets and in parks.

To date, data about the urban forest has not provided a complete picture of the entire urban forest resource as it stands on both public and private land. As Guelph prepares to develop its second 5-year urban forest management plan, a sample-based inventory of the entire urban forest was identified as an information gap for developing the 2019-2023 UFMP.

The current study provides a detailed picture of the City's entire forest resource, including trees located on public and private lands. The study provides data to describe forest composition, structure, distribution as well as a valuation of ecosystem services that the forest provides. Using available provincial LiDAR data for southern Ontario along with high resolution satellite imagery, the study also includes a detailed map of land cover (including the location and distribution of canopy cover) for the City of Guelph, including potential height models. This data was used in conjunction with a Tree Planting Prioritization Tool[9] to map priority tree planting locations, based on a set of defined target benefits. All of this data provides information to support planning, as well as a baseline from which future assessments of progress toward Guelph's urban forest objectives can be made.

In this context, the main objectives of the study were defined by the City of Guelph as follows:

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[8] Brommer, J.L. 2015. City of Guelph Plantable Spaces Analysis. Completed in collaboration between the City of Guelph and the University of Guelph, with funding from the TD Green Streets grant program.

[9] Tree Planting Prioritization Tool – a model developed by Peel Region using land cover and other datasets along with a set of benefit criteria to identify priority tree planting locations in a given study area.

- Describe the current composition, structure and distribution of Guelph's urban forest;
- Quantify the ecological services and benefits provided by the urban forest;
- Identify opportunities for expanding the urban forest and enhancing forest health, resilience and sustainability;
- Establish baseline urban forest conditions and attributes for future comparison and evaluation to help measure progress toward achievement of the City's urban forest management goals and objectives;
- Assess the feasibility of achieving 40 per cent canopy cover in the City of Guelph; and
- Supplement and support the City's Urban Forest Management Plan and other City tree and Natural Heritage related policy.

This comprehensive urban forest study is an important component of the City of Guelph's efforts to improve urban forest resilience and vitality, and to enhance the social, ecological, and environmental benefits the urban forest provides to the City's residents.

STUDY SCOPE AND KEY CONCEPTS

CANOPY COVER VS. LEAF AREA

There are various terms in the literature that are used to describe the urban forest. These are often used interchangeably and can cause some confusion. These include terms like urban forest canopy, canopy cover, forest cover and tree canopy. For consistency with past plans and reports, the term 'canopy cover' will be used in referring to the City's goal of increasing canopy (tree) cover to 40 per cent by 2031.

As noted in the 2013 UFMP, canopy cover "is a two-dimensional measurement of the horizontal surface area of the forest as seen from a "birds-eye" view. It is a popular metric because it is readily understood, but it does not capture other important aspects of the urban forest, such as species diversity, urban forest structure (i.e., size and age ranges) or condition, etc."

Canopy cover can be communicated as a percentage of total city land cover or as an area measurement, commonly in hectares.

Leaf area (LA) is another way to describe the forest, which provides more information about forest structure beyond two dimensions. Leaf area describes the surface area of all the leaves found in every level of a tree crown. This makes it a much better measure to describe the value of a tree in terms of the potential ecosystem services a tree can deliver. An estimate of the total leaf area of the urban forest provides more information than simply an estimate of its canopy cover. A common way to use leaf area to describe the urban forest in more detail is leaf area index (LAI), which is the total leaf surface area per unit of land area.[10]

LAI recognizes differences in species and tree condition of the urban forest that canopy cover does not include. Some species may have the same two-dimensional crown area from above, but very different leaf area based on the crown attributes and condition. Both canopy cover and leaf area are used in the study to describe Guelph's urban forest.

POTENTIAL PLANTING AREA (AKA POTENTIAL URBAN TREE CANOPY)

In the study report, potential planting area (PPA) consists of two classes of land cover where it is possible to plant trees. In canopy assessments, PPA is often used as a proxy for potential future canopy and is used to calculate the "maximum potential canopy" within a given land area.

PPA includes pervious land cover types, comprised of areas of open soil and non-canopy vegetation. It also includes impervious land cover types (excluding buildings or transportation infrastructure) that could support tree growth by applying techniques for planting in hard surfaces, excluding buildings or transportation infrastructure with the exception of road rights-of-way.

The priority planting score map in this report focuses mainly on pervious land cover types, where exclusions have been identified to net down the available planting area. This is done in recognition of the fact that not all pervious area will be available for planting because of competing land uses like sports fields, hydro corridors and other factors that may limit opportunities to plant trees. Best efforts have been made using available data to identify areas potentially available for planting. Assessing planting feasibility at the site level is part of operational planning. This would include consideration of constraints such as soil volume and quality, presence of underground utilities and other conflicting infrastructure, light conditions, etc.

The recommendations in the report reflect those areas where the City has opportunities to influence outcomes in terms of future canopy cover growth. This will be part of developing a detailed Tree Planting Strategy for the City of Guelph.

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[10] Kenney W.A. (2008) Potential Leaf Area Index Analyses for the City of Toronto's Urban Forest. In: Carreiro M.M., Song YC., Wu J. (eds) Ecology, Planning, and Management of Urban Forests. Springer, New York, NY.

The purpose of developing PPA estimates are to provide a high-level understanding of where there are opportunities to increase canopy cover across the City.

LAND COVER VS. LAND USE

Part of this study included land and canopy cover mapping for the City of Guelph using the most recently available (2017)[11] leaf-on satellite imagery. For the study, land cover data describe how much of the urban area is made up of the following seven land cover types as seen from a top view looking down:

1) Canopy cover (tree canopy only)
2) Non-canopy vegetation[12]
3) Roads
4) Buildings
5) Other impervious surfaces (parking lots, driveways, patios, walkways, trails, etc.)
6) Water
7) Bare soil

Figure 1 shows a sample of the leaf-on Pleaides imagery used to derive land cover in Guelph as well as a sample of the final mapping.

Figure 1: Sample of Pleaides imagery and resulting land cover map.

The land cover data does not describe the full extent of physical land cover types in Guelph. This is because the land cover map has been derived from leaf-on satellite imagery that provides a top down view, which does not capture, for example, pavement under existing tree canopy. Nonetheless, the data provide a good picture

[11] 2017 was the most recent year of imagery with complete leaf-on coverage for the City of Guelph.

[12] Non-canopy vegetation is defined in the classification as maximum LiDAR height less than or equal to 2.0 m; LiDAR mean height less than 0.75 m and NDVI mean greater than -0.2.

of the general extent and distribution of land cover, and particularly canopy cover in the city.

Land use describes how people use different areas of the City. The land use map provided by the City of Guelph for this study has eight categories which include:

1. Commercial
2. Farm
3. Industrial
4. Institutional
5. Multi-Residential
6. Residential
7. Special and Exempt
8. Vacant (includes Natural Cover and Open Space)

The generalized land use types were derived using Municipal Property Assessment Corporation (MPAC) codes and are different from the City's land use designations. MPAC is an independent body that assigns codes to each property in the province that describe the property use. The MPAC codes were aggregated into broader (generalized) land use categories that are helpful for describing and understanding differences in the urban forest related to land use. The study uses MPAC codes as a basis for generalized land use categories because it allows for future comparison of the study sample plots, as well as opportunities to compare results across municipalities using the same approach. A second version of the map that breaks out some of these categories more finely was used to summarize statistics about land cover by land use (e.g. includes a "Transportation" category that consists of road rights-of-way).

Residential and Multi-Residential land use types are separated. This allows for a more detailed assessment of existing canopy cover as well as opportunities in specific land use classes of interest. The Residential land use tends to comprise the largest land area in most cities, and generally represents one of the greatest opportunities in terms of available growing space to increase canopy cover along with Natural Cover and Open Space.

FEASIBILITY OF ACHIEVING 40 PER CENT CANOPY COVER

Feasibility assessments look at how possible it is to achieve a target canopy goal in a given urban context. The approach uses detailed land cover data to assess the existing and maximum potential tree canopy at a parcel level, which can be aggregated at different geographic scales of interest. Maximum potential canopy cover consists of existing canopy cover plus the potential plantable area that could support additional tree canopy. It assumes that plantable area could achieve complete canopy cover in the future by establishing trees. The concept of 'feasibility' may be different in each municipal environment. Fundamentally, it looks at what the landscape can theoretically support with more detailed assessments of possible challenges and constraints at the site level occurring through operational planning. In this study, efforts have been made to use available city data to screen out known and competing land uses in Guelph in order to develop more realistic estimates of what is possible.

The feasibility of achieving a canopy cover goal also depends in part on the level of priority assigned to as well as related investments made to support goal achievement by a municipality. For example, there may be limitations on the amount of available pervious plantable areas on public land that could limit goal achievement when seen in isolation. However, there may be other opportunities to increase canopy cover that would require additional investments in regulatory or policy change and/or additional financial resources. Enabling tree planting on private property is one example, as is increasing planting in areas of impervious land cover like parking lots, school yards or road rights-of-way. A challenge for many municipalities is that the goal to increase canopy cover is set in a context of anticipated population growth and increasing urban density.

These challenges are being addressed by some cities by continually re-evaluating and improving on policy and regulatory tools that protect and support the integration of trees in the urban landscape. Examples of best practices in Ontario include:

- Implementing new and improved private and public tree by-laws to increase rates of healthy tree retention;
- Requirements for separate canopy cover plans as part of development applications under site plan control;
- Pro-active forest health monitoring programs that include invasive species monitoring;
- Regular funding for woodland renewal in conjunction with invasive species assessments;
- Outreach programs and partnerships to increase tree planting on private property as part of comprehensive municipal tree planting strategies; and
- Partnering with Business Improvement Associations to offset costs of hard surface tree planting in commercial areas, which can have economic benefits as well as mitigating the heat island effect.

STUDY SCOPE

The study uses assessment tools (specifically the i-Tree suite of tools, described in the Appendices) to develop metrics that describe the City's urban forest, including species composition, size class distribution, number of trees overall and by land use, tree condition, susceptibility to insect pests and other forest attributes. These tools have been rigorously tested and refined by the United States Department of Agriculture (USDA) Forest Service and its partners over the years. i-Tree studies generally use a sample-based approach that is associated with a known level of statistical accuracy. Due to limitations in the sample size (number of field plots), which are generally related to project cost, using the data to describe forest attributes at smaller geographic units of interest (like neighbourhoods) results in less statistical certainty due to the smaller sample sizes, unless plots are stratified for that purpose. In this study, plots were stratified by land use, which provides useful information on how different land uses and intensities affect forest structure and function across the city. In this study, a minimum of 20 field plots were assigned in each land use class, following the recommendations of the i-Tree Eco model specifications.

The study also uses data from a land cover classification along with analytical techniques to produce two important measures: a) the current extent and distribution of canopy cover in Guelph and b) a high-level estimate of the amount of potential future canopy cover and its distribution across the city. Canopy cover can vary depending on what methodology and what type of imagery is used to complete canopy cover estimates. For this reason, any future canopy studies undertaken by the City of Guelph should refer to previous methodologies when using the information for comparative purposes or to describe trends. These methodologies are included in the study appendices for future reference.

Important background information included the following documents, most of which can be found online at the City of Guelph website.

- Urban Forest Management Plan (2013-2032 UFMP)
- Tree Technical Manual (TTM)
- Tree By-law
- Street Tree Ownership and Tree Maintenance Protocol
- Natural Heritage Action Plan (NHAP)
- City of Guelph 2019-2023 Strategic Plan
- City of Guelph Official Plan (2018 Consolidation)
- Urban Design Standard

Urban Forest Management Context

CITY OF GUELPH - DEMOGRAPHICS[13]

The City of Guelph is a single-tier municipality with an area of just over 86 km^2. Guelph contains a mix of industrial, commercial and institutional land uses, as well as more than 2,000 hectares of park lands and natural areas. Guelph's urban forest is comprised of individual trees and all the treed areas that occur within its boundaries. These include treed natural areas, as well as individual or small groups of trees in parks, along roadways, and on residential, industrial, commercial and institutional properties.

Guelph has experienced a steady rate of growth in the past 25 years. New census data shows the population of the metropolitan area of Guelph outpaced the national growth rate over the last five years[14]. In 1986, the city's population was less than 80,000. By 2016, that number had risen to 131,794[15], and is projected to reach 169,000 by 2031, the same timeframe for meeting Guelph's 40 per cent canopy target. It is worth noting that the City's goal to increase tree canopy is set in a context of significant population pressure, increasing urban density, and greenfield development.

In the past, single detached dwellings were the predominant form of housing in the city of Guelph. Under the province's growth plan, which sets targets for increased density, the built form of housing and associated landscaping will change, potentially affecting available growing space for trees. The increased demand for housing puts more pressure on the City's municipal services, including roads, sewers, parks and natural areas. These pressures, combined with the already present and emerging threats of pests, pathogens, and environmental stresses associated with climate change, make maintaining and enhancing Guelph's urban forest challenging.

Another expected demographic change is an influx of newcomers. The ethnocultural diversity of the Guelph census metropolitan area (CMA)[16] is expected to change rapidly, with immigrants making up approximately 23 per cent of the population by

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[13] City of Guelph 2013 Urban Forest Management Plan

[14] Hamilton Spectator. New census data: Population of metropolitan area of Guelph outpaced national growth rate. February 8, 2017.

[15] Ibid.

[16] Includes Puslinch and Guelph-Eramosa

2036. Currently, visible minorities make up about 15 per cent of the Guelph area's population but over the next 20 years, that number is expected to double. The main countries of origin of these new Guelph residents are thought to include the Philippines, India, China, Vietnam and Pakistan[17]. For this reason, future urban forest programs will also need to consider how to engage effectively with newcomers to explore how culture might affect urban forest values and to develop approaches that promote social inclusion and environmental equity across the City of Guelph.

Addressing the tension between increasing urban density and urban forest expansion will require careful planning, active management, ongoing monitoring, and creative problem solving that make considerations related to trees a priority. Success requires strong internal support, including support from Council for innovative policy solutions, implementation funding, and a commitment to monitoring and adaptive management. Public support is also key, and this study will be used to engage with the public as the City continues to implement a sustainable urban forest plan.

COMMUNITY PRIORITIES

The City of Guelph recently completed public consultation to inform the City of Guelph Community and Strategic Plans. Residents were asked about their priorities for the City of Guelph for the next 10 years. Environmental quality ranked highest on the list, with twenty-seven per cent of Guelph's residents indicating that issues surrounding the environment, water, and waste should be the City's main focus (Figure 2).[18] Environmental consciousness and being a sustainable city also ranked high in responses to the question about what residents would like Guelph to be known for.

[17] Guelph Mercury. Guelph growth: Immigration to fuel future population increase. December 12, 2018.

[18] City of Guelph, Community Plan: Initial Findings. 2019.

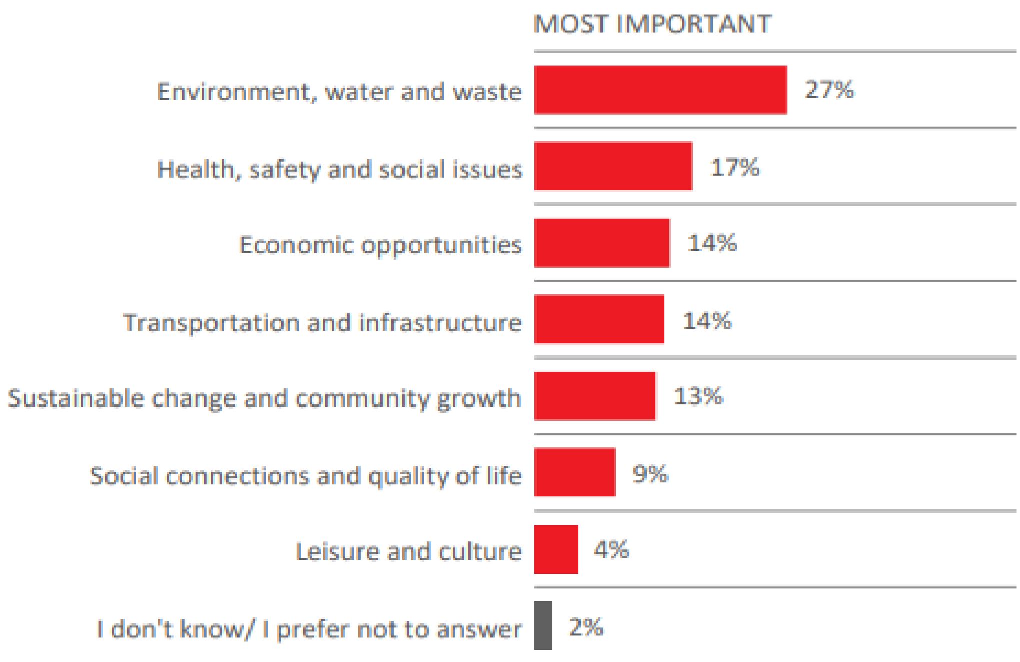


Figure 2: Resident response to a survey about ten-year priorities for the City of Guelph (Source: City of Guelph Community Plan, Initial Findings 2019).

ECOLOGICAL CONTEXT

Under Ontario's Ecological Land Classification (ELC) system, Guelph is situated within a Mixedwood Plains Ecozone (more specifically within Ecodistrict 6E-1 or Stratford Ecodistrict, Figure 3). ELC is a method for characterizing vegetation communities to provide a consistent way to identify, describe, name, and map vegetation communities or physiographic features on the landscape. ELC types help describe what vegetation communities can be expected on the landscape and provide insight into available habitat and species present. This information can be used to guide management or conservation activities in these communities.

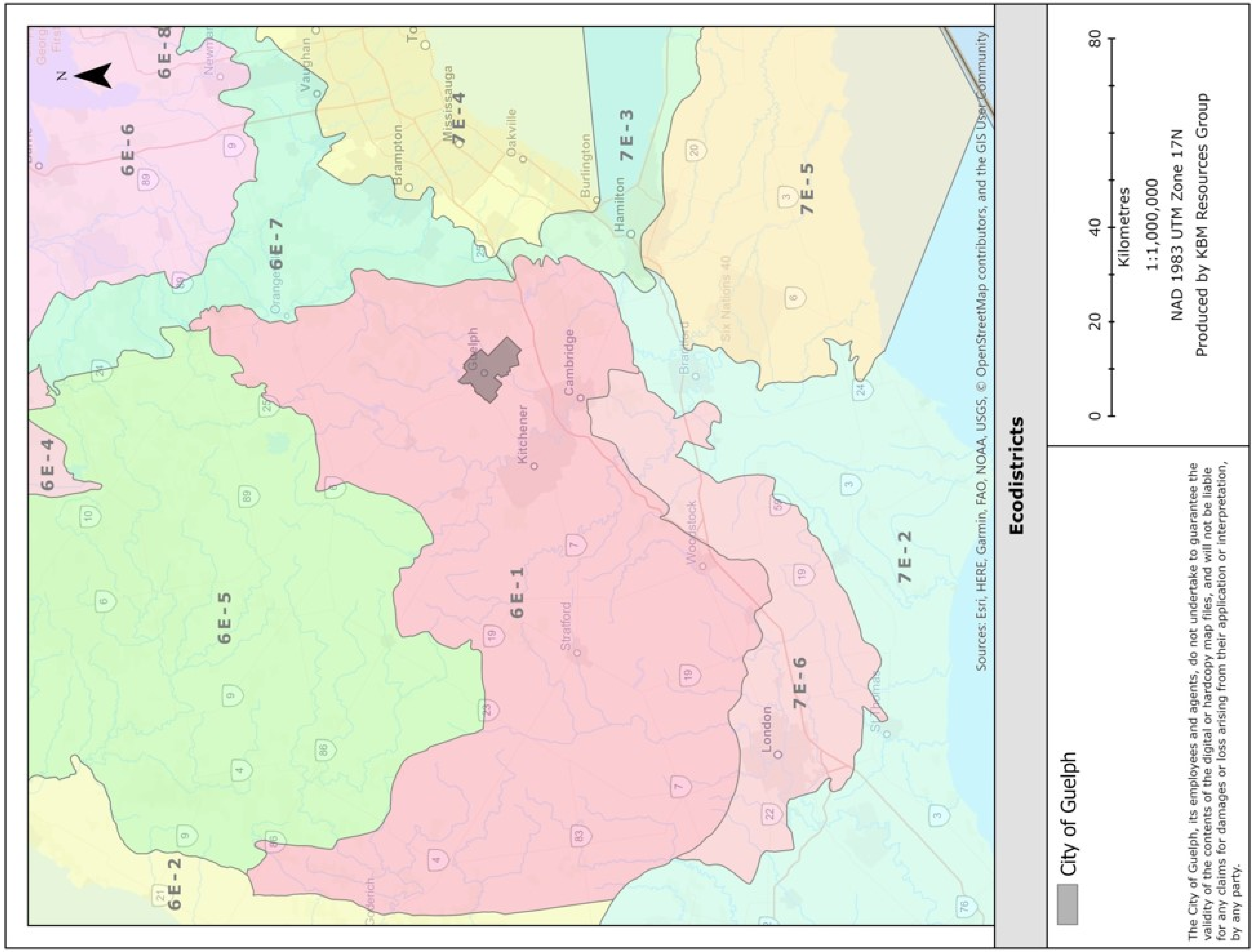


Figure 3. Guelph in Ecodistrict context (Source: Ontario Geohub, 2019).

The Stratford Ecodistrict is associated with the Eastern Temperate Deciduous Forest Vegetation Zone and the Huron-Ontario Section (L.1) of the Great Lakes-St. Lawrence Forest Region. The area has been predominately converted to pasture and cropland. Approximately one-fifth of the area is represented by natural or naturalized areas including forests, fen complexes, and marshes. Deciduous forests dominated by sugar maple, American beech, white ash, and oak species occur on dry to fresh sites, and yellow birch, red maple, silver maple, and ash species are found in wetter environments. Less common associates can include American elm, eastern hop-hornbeam, black maple, large-toothed aspen, butternut, and black cherry.[19]

According to the *Great Lakes Conservation Blueprint for Terrestrial Biodiversity* "…invasive plants and animals are now considered one of the most serious threats to global biodiversity. Invasive aliens can have a number of impacts upon a natural area and can contribute directly or indirectly to loss of native biodiversity. The most significant threat to the dominant forest ecosystems of northeastern North America continues to be the recurrent introduction of forest insect and fungal pathogens that target the dominant forest species of the Great Lakes region."

The emerald ash borer (EAB) is a recent example of an invasive insect pest that has decimated Ontario's ash populations. Currently, 114 species are federally listed as species at risk in the Ontario portion of the Great Lakes ecoregion, with the majority of these designations occurring as a result of habitat loss and human impacts.[20]

In Ecodistrict 6E-1, forest cover is currently at 13 per cent.[21] This is well below the 30 per cent minimum target recommended by Environment Canada, which in itself represents a high risk approach to maintaining a healthy watershed and at that level is likely to result in marginally healthy aquatic systems.[22] Other agencies, including the Grand River Conservation Authority (GRCA), are working at the watershed level to address some of these issues. Their work provides a landscape context for the management priorities within the City of Guelph. The GRCA Forestry Plan is consistent with the city's objectives to increase the amount and quality of forest cover in and around the city. GRCA sustainable watershed targets include:

- 30 per cent forest cover;

[19] The Ecosystems of Ontario, Part 2: Ecodistricts. 2018. Science and Research Technical Report TR-26, Ontario Ministry of Natural Resources, Science and Research Branch. URL:

[20] B.L. Henson, K.E. Brodribb, and J.L. Riley. 2005. Great Lakes Conservation Blueprint for Terrestrial Biodiversity. Nature Conservancy of Canada.

[21] https://files.ontario.ca/ecosystems-ontario-part2-03262019.pdf

[22] Environment Canada. 2013. How Much Habitat is Enough? Third Edition. Environment Canada, Toronto, Ontario.

- 75 per cent tree cover along streams;
- 40 per cent canopy cover in urban areas;
- No net loss of forests;
- Protection and enhancement of habitat for species at risk; and
- Reduction of invasive exotic plants.

POLICY CONTEXT

The Guelph 2013-2032 UFMP, Section 4 (*Planning for Trees: Legislation, Policies and Guidelines*) provides a comprehensive overview of the framework regulating urban trees under existing federal, provincial and municipal legislation, policy and guidelines. In Ontario cities, urban forests are managed largely by municipalities, who enact and enforce legislation regarding trees on both municipal and private land. Municipalities pass laws under the authority of enabling legislation from the province.[23]

In Ontario, the Provincial Policy Statement (2014) and the Planning Act include components that influence the practice of urban forestry in municipal environments. The Endangered Species Act also regulates any species at risk that are found within municipal boundaries. Federally, there is limited legislation that significantly influences urban forest management with the exception of protection for species at risk under the Species at Risk Act and other federal legislation like the Plant Protection Act that regulates matters related to the spread of invasive species, among other issues.[24]

The City of Guelph is surrounded by the County of Wellington, but is a single-tier municipality, so it does not need to defer to or be consistent with County policies. However, the City and County maintain an open dialogue and collaborate on tree-related issues for both planning and ecological reasons.

Since the 2013 UFMP, there have been several changes and/or updates to City policy regulations and guidelines that improve upon the urban forest management framework. Some of the key developments are as follows:

- Official Plan Updates, including - Official Plan Amendment 42 Natural Heritage System (approved by the Ontario Municipal Board, June 2014) and Official Plan Amendment 48 Final Phase of the Five-year Review (approved by the Ontario Municipal Board, October 2017, with the exception of one site specific appeal,

[23] Tree Canada. Enabling Legislation, Municipal By-laws and Regulations. URL: https://treecanada.ca/resources/canadian-urban-forest-compendium/5-enabling-legislation-municipal-bylaws-and-regulations/

[24] Ibid.

one policy appeal and a few policies that are still under appeal on a site specific basis)

  - In Guelph, the new NHS identifies Significant Natural Areas for long term permanent protection (i.e. Significant Areas of Natural and Scientific Interest, Significant Habitat for Endangered and Threatened Species, Significant Wetlands, Surface Water and Fish Habitat, Significant Woodlands, Significant Valleylands, Significant Landform, Significant Wildlife Habitat – including Ecological Linkages, and Restoration Areas) and their established buffers.

- Bill 168 (Modernizing Ontario's Municipal Legislation Act)
- Revisions to the City's Site Plan Procedures and Guidelines in 2015
- City of Guelph Guidelines for the Preparation of Environmental Impact Studies (June 2017)
- Urban design standards/manuals
- A new Tree Technical Manual, which consolidates and establishes guidelines, standards and specifications for the preservation, protection and operational activities involving trees on public and private land.
- A new 2019-2023 Strategic Plan
- Clair-Maltby Secondary Plan/Guelph Innovation District Secondary Plan
- Environmental implementation report guidelines (2018)
- New Built Form Standards (2019)

Investing in urban forest management supports several key aspects of the City's 2019-2023 Strategic Plan, including priorities related to "Investing in green infrastructure to prepare Guelph for the effects of climate change, increasing Guelph's tree canopy, planning and designing an increasingly sustainable city as Guelph grows and protecting the green infrastructure provided by woodlands, wetlands, watercourses and other elements of Guelph's natural heritage system".

Literature review

The study included a literature review to investigate recent science and best practices in urban forest management. The review looked at the following subject areas:

- Urban forest structure
- Urban forest function
- Modelling and forecasting
- Methodologies for assessing urban forest values (goods and services)
- Monitoring land cover change
- Costs of maintaining and not maintaining the urban forest
- Increasing the resilience of the urban forest to threats

    - Climate change
    - Storms and extreme weather events
    - Susceptibility to pests and disease and invasive species
    - Urbanization and development pressure
    - Invasive species
- Sustainable urban forest management – monitoring and adaptive management to achieve multiple/optimal benefits

Following are highlights and key findings of the review. The full literature review can be found in Appendix B.

URBAN FOREST STRUCTURE

Information about urban forest structure is essential for supporting planning and management. Urban forest structure attributes include tree species composition, height, tree density, size class and distribution, tree condition, etc. Structure is influenced by the urban landscape and built form, natural factors like soils, climate and existing vegetative communities as well as human management systems and development history. In turn, it influences many benefits and values provided by the urban forest, including biodiversity, ecological services, susceptibility to invasive plant establishment and even real estate values.

Structural information about the urban forest is generally derived through forest inventories, which can be complete inventories (e.g. street trees), sample-based inventories (across an entire municipality) or in some cases at the stand level in remnant woodlands or parks where more detail is required. There are some suggested guidelines for optimizing aspects of forest structure, including composition and target size class distribution – however, the process of applying these guidelines will need to take local context and management or environmental constraints into consideration.

URBAN FOREST FUNCTION

Healthy urban forests produce ecosystem functions, goods and services that benefit people and the environment. The functions and value of the urban forest have received increased attention in recent decades as urban ecology and ecosystem services have become prominent areas of research. Ecosystem services, or ecoservices, include energy conservation, air quality improvement, carbon storage, stormwater runoff reduction and wildlife habitat. Trees can raise property values, produce goods such as food and wood products, and provide social, economic, aesthetic and health benefits. Some of these are described in more detail in the following sections.

STORMWATER ATTENUATION

The interception and retention of stormwater by canopy can contribute to the protection of water quality by appreciably reducing the volume of stormwater runoff and by reducing soil erosion and pollutant washout. For example, infiltration of water into tree pits can reduce stormwater runoff from asphalt control plots by 62 per cent. A green infrastructure design that incorporates a mixture of plant functional types may be preferred for providing year-round cycling of stormwater volume inputs in urban landscapes.

AIR QUALITY

A recent and comprehensive literature review of the interaction of urban trees and air quality suggests that the interaction is complex. On the one hand, trees have been proven to contribute to direct improvements to air quality by intercepting particulate matter and producing oxygen. They also contribute to indirect improvements by reducing emissions related to heating and cooling through strategic planting around buildings. It is known that different tree species have different capacities for intercepting air pollution.

On the other hand, trees can also produce volatile organic compounds and in some situations could contribute to ground level pollution. For example, tall trees with thick canopies planted alongside busy roads can act like a roof, trapping pockets of polluted air at ground level. They can also exacerbate allergies through the distribution of pollen. The value for trees in improving air quality therefore varies with different urban form and context. For this reason, planners should carefully consider context when locating urban trees and green spaces to ensure the optimal contribution of trees to improving air quality in cities.

MODELLING AND FORECASTING

The most commonly used model types in urban forestry are the i-Tree toolset, ENVI-met, computational fluid dynamic models, and the Hedonic price model. Spatially explicit models are critically important for estimating ecosystem services as well as for environmental management. Linkages between urban forests and their social-psychological and health effects are less common due to subjectivity and uncertainty in expressing and quantifying human cultures, attitudes and behaviors. Vulnerability assessment modelling and analysis is another approach to gain insight into the processes of structural and functional change resulting from forest management interventions.

ASSESSING URBAN FOREST VALUES

Random sampling is generally applied as a cost-effective way to assess urban forest structure, function, and value for large-scale assessments. The USDA Forest Service has developed a specialized tool to perform such evaluations, the i-Tree Eco model. The i-Tree Eco model has been used in hundreds of cities across the globe to assess urban forest structure and its numerous ecosystem services using a standardized field sampling method.

The study of land use/land cover (LU/LC) changes is very important for proper planning and management of natural resources. Remote sensing has become an important tool for understanding the global, physical processes affecting the earth, including land cover change in cities. Each different approach to monitoring land cover and change has advantage and disadvantages in terms of reliability, accuracy and comparability over consecutive years of imagery. These limitations can be managed by having a sound understanding of how to verify the quality and accuracy of remote imagery assessments.

THE COSTS OF MAINTAINING AND NOT MAINTAINING THE URBAN FOREST

There are many studies quantifying the value of services provided by trees as well as the direct costs of maintaining the urban forest. Direct costs of maintaining the urban forest that are tracked by most cities include planting, pruning, removal, pest management and sometimes infrastructure repair - these numbers are fairly well understood. Other costs (like the opportunity costs associated with trees) are not tracked and are less well understood.

Literature looking at the cost of not maintaining the urban forest resource is scarce. However, some particular maintenance non-actions stand above the rest:

- Not caring for trees in early establishment (i.e., not watering)
- Not managing for diseases or pests, such as Dutch elm disease (DED) or emerald ash borer (EAB), and the subsequent loss of net benefits;
- Not maintaining the urban forest as a whole by not planting trees (and, again, the loss of net benefits resulting therefrom); and
- Instances where lack of tree care may result in decline in tree condition and/ or future liability issues.

Of these, points two and three are most clearly addressed in the literature.

INCREASING THE RESILIENCE OF THE URBAN FOREST TO THREATS

CLIMATE CHANGE

Future impacts of climate change on urban forests are uncertain. Exposures related to drought, heat stress, and wind, susceptibility of urban trees to insects and diseases, and the sensitivity of young trees and tree species with specific temperature and moisture requirements are the main concerns regarding the vulnerability of urban forests to climate change in three Canadian cities. Urban forest managers should complete quantitative and collaborative assessments of urban forest vulnerability. Vulnerability assessments can be used to inform future operational programming e.g. scheduling of hazard risk monitoring activities across the urban forest.

STORMS AND EXTREME WEATHER EVENTS

Climate change is expected to change the frequency and duration of extreme weather events. For urban forest managers, reactive management to storms is a challenging aspect of urban forest management, from a human resources and financial perspective. Some species and trees of certain sizes are more adversely affected by storm damage than others and have different radial growth responses, which affect their rates of recovery. For example, susceptible species include American basswood, elm and aspen. Resistant trees include white oak and several conifer species. Structural diversity can make urban forests more resilient to extreme weather events. Pruning and reduction of easily wind-damaged species can reduce the impact of future storms. Having sound emergency response plans in place is also a key part of managing extreme weather events in the urban forest.

PESTS AND DISEASE

An increase in susceptibility to pests and disease is an expected outcome of climate change, as trees experience more stress that affect their natural defenses. A city's susceptibility to certain pests may increase or decrease depending on the prevalence of certain species on the landscape. The legacy of invasive pests in North America has severely impacted forests and urban tree populations (most recently, emerald ash borer). The possibility of pest introductions into urban forests highlights the need for monitoring programs aimed at early detection. In cities, forest diversity is a crucial component to increasing urban forest resilience.

INVASIVE SPECIES

Existing invasive species management frameworks are often inadequate and still evolving in urban areas. Decision-support frameworks can assist managers in placing invasive species into management categories. Approaches to control of invasive species can include top-down implementation (e.g. regulation or public implementation) or design of policies or incentives to alter private behavior. Management of invasive species often requires making decisions about how to prioritize, rather than whether to manage or not. Interventions to mitigate the impacts of invasive species include reducing the rate of invasive species introduction (prevention), eradicating new invader populations, and reducing damages by slowing the spread of invasions across the landscape or adapting to an invader's presence through control or altered management practices. Monitoring and early detection are key to most invasion mitigation strategies.

URBANIZATION AND DEVELOPMENT PRESSURE

As cities grow and populations become more urbanized, both urban forests and forests adjacent to cities will be impacted by human activity and development. Specific effects of urbanization on forests include: deforestation, fragmentation, inappropriate forest management, habitat alteration, environmental deterioration, urban heat island effect and translocation (introduction) of alien species.

Solutions to counteract the effects of urbanization on forests include:

- Stopping deforestation (through stricter laws or better enforcement, or afforestation)
- Mitigating forest fragmentation by improving the quality of cooperation between forest managers and planners, among other departments
- Restructuring with respect to species composition and spatial structure
- Limiting habitat alteration and environmental degradation, education of society, appropriate legislation, and land-use planning
- Planting trees that are more resistant to pollution
- Defining and monitoring forest degradation
- Undertaking measures to eradicate or limit the expansion of problematic species
- Having appropriate infrastructure to direct recreational traffic

MONITORING AND ADAPTIVE MANAGEMENT

Adaptive management is a systematic process for continually improving management policies and practices by learning from the outcomes of programs. Adaptive management is important for handling the complex decision problems involving uncertainty and risk (e.g. effects of climate change on the urban forest). Characteristics of adaptive management include monitoring, analysis of the treatment outcomes in consideration of the original objectives and incorporation of the results into revised management decisions. Monitoring is a critical part of the adaptive management cycle – it helps managers assess the effectiveness of urban forest management approaches.

Indicators for urban forest monitoring should be relevant, credible, measurable, cost-effective, and have clear links to urban forestry. Many North American municipalities have adopted a framework developed by the USDA Forest Service and Davey Tree Ltd. - “A Sustainable Urban Forest Management Guide: A Step-by-Step Approach”. If available resources limit the scope of monitoring, it may be necessary to set priorities and focus monitoring on the highest priority areas or leverage partnerships with other agencies.

Study Approach and Methodologies

The study was completed in three phases, as follows:

Phase 1

- Production of a City-wide continuous land cover classification from 2017 leaf-on imagery to quantify the distribution and extent of urban canopy cover relative to other land cover classes;
- Accuracy assessment of land cover classification;
- Stakeholder tree planting survey; and
- Development of spatially explicit tree planting prioritization maps using the "Tree Planting Prioritization Tool" (TPPT) developed by the Region of Peel.[25]

Phase 2

- Completion of a 208-plot i-Tree Eco survey of public and private property and a comprehensive analysis of the results using i-Tree Eco v6 software;
- Analysis of street tree benefits, using the City of Guelph street tree inventory and i-Tree Eco v6; and
- Assessment of potential storm-related costs across Guelph's 6 wards using i-Tree Storm.
- There are some limitations of using the City street tree inventory as input data in terms of its comparability to the results derived from field plots, as each set of data has different parameters. Nonetheless, a separate street tree analysis provides more detail on that distinct population of trees within the City of Guelph, which supports the development of appropriate management strategies.

Phase 3

- Development of a detailed technical report of the project results generated in Phases 1 and 2, including a literature review with relevant analysis and management recommendations included.

The project team was made up of City of Guelph staff as well as a multi-disciplinary group of consultants and professionals from Lallemand Inc./Bioforest and KBM Resources Group, with extensive experience in urban forestry, natural resource management, policy development, i-Tree analysis and geomatics. A detailed description of the study methodologies can be found in Appendix A.

[25] Peel Region Tree Priority Planting Tool. 2015.

Study Results

LAND COVER

A continuous land cover classification completed using 2017 leaf-on Pleaides satellite imagery (0.5 metre resolution) and LiDAR data for the City of Guelph. These data provide information on the distribution of land cover in the City of Guelph (Figure 4), with an estimated overall accuracy of 87.3 per cent. The land cover data was cross-referenced with i-Tree field plot estimates for land cover, as an additional check to verify that the two datasets align. With some minor anomalies (expected with different methodologies), the two data sets show a similar distribution of land cover, providing another assurance that the results accurately reflect the situation across the City.

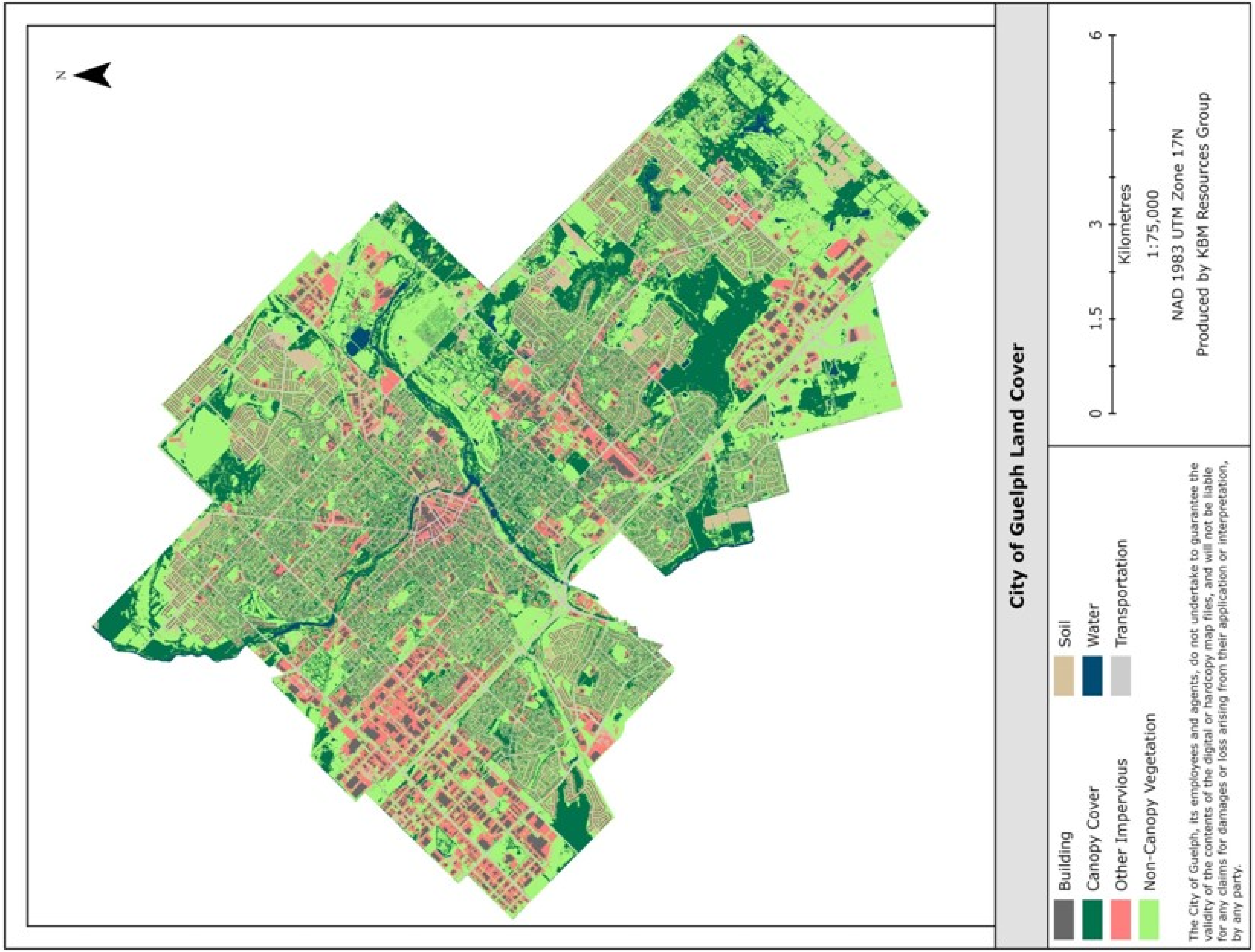


Figure 4: City of Guelph land cover map (Source: 2019 land cover data)

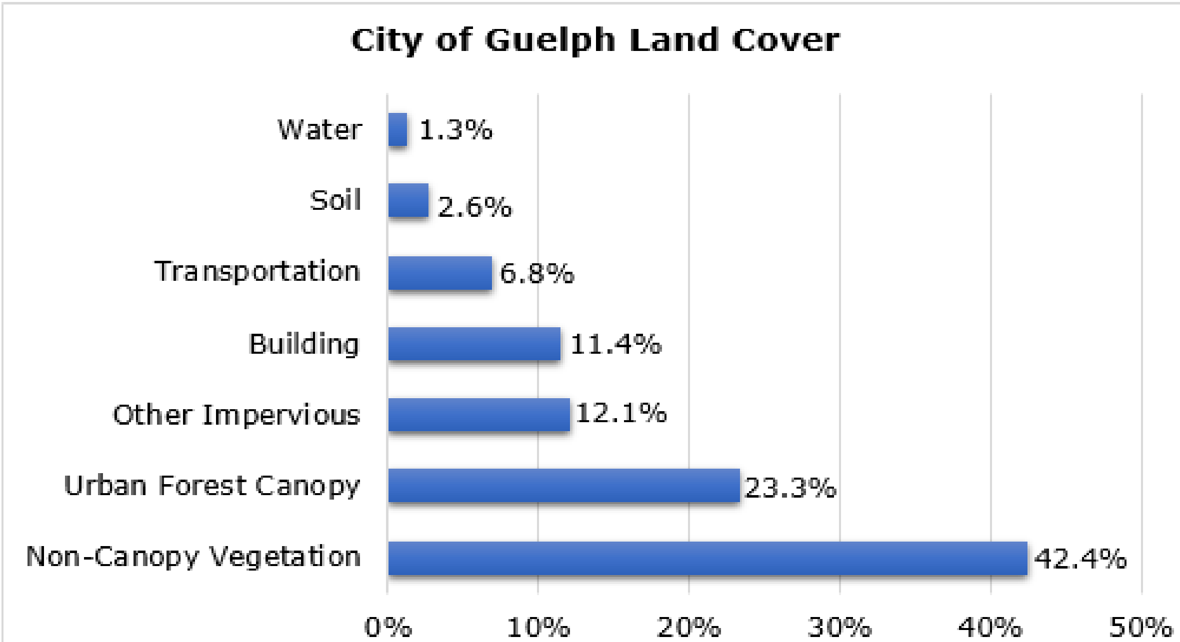


Figure 5: Land cover in the City of Guelph (Source: 2019 land cover classification)

Figure 5 shows the breakdown of land cover for seven land cover classes across the City of Guelph, as a percentage of total land area. At the time of assessment, canopy cover in Guelph was estimated at 23.3 per cent and represents the second most abundant land cover, following non-canopy vegetation (comprised of shrubs, herbaceous plants and grass at 42.4 per cent). There is a small percentage of bare earth (soil) in Guelph, which may represent agricultural areas, gardens or possibly active construction sites. These latter two categories are relevant because areas of soil and non-canopy vegetation (pervious land cover types) are a primary data input for developing estimates and maps of potential plantable area (PPA), which is used to calculate maximum potential canopy cover.

CANOPY COVER

Canopy cover represents 23.3 per cent or 1,976 hectares (ha) of the City's total land area (Appendix E). Figure 6 shows the distribution of canopy cover in Guelph as a percentage range at the parcel level, with areas of high canopy concentrated in woodlands and natural areas and some mature neighbourhoods in Guelph. The map also shows the location of "significant trees" in Guelph, which are defined here as trees with canopy heights over 20m (large/mature trees). This type of mapping may be useful for tracking the loss of mature canopy over time or for reaching out to landowners with mature trees on their properties.

Recommendation 1: Examine options for increasing the retention of healthy trees in Guelph on properties not subject to the Private Tree By-law.

Figure 6: Per cent canopy cover by parcel and areas of canopy height > 20m (Source: 2019 Urban Forest Study land cover map).

Mature trees are important in the urban forest because they have large crowns with more leaf area and therefore contribute substantially more to the provision of benefits, which include all of the ecosystem services that trees provide. Under Guelph's Tree current Tree By-law (Number 2010 – 19058), damage or destruction of any tree measuring at least 10 centimetres in diameter at 1.4 metres above the ground on lots larger than 0.2 hectares (0.5 acres) is prohibited without permission from the City.[26]

In 2014, the city stopped permitting removal of significant woodlands – a change that was outlined in the Guelph Official Plan. This is an area of progress that supports the City's goal of maintaining or increasing canopy cover. However, trees on lots 0.2 hectares or smaller are currently not regulated. Because protection of existing, healthy trees is an important aspect of maintaining and expanding sustainable canopy cover, the City should examine options and tools for improving the rates of private tree retention in the City of Guelph and increasing the proportion of large stature trees over time.

Compared to other municipalities in the region, Guelph's canopy cover is average at 23.3 per cent. Canopy cover for cities with estimates completed within the last 5-6 years range from a low of 19 per cent in Mississauga[27] to a high of 27.8 per cent in Oakville[28] and 28.4 per cent in Toronto[29] (Appendix D). Figure 7 shows the per cent canopy cover by neighbourhood – Dover Cliff has the highest canopy cover at 36.8 per cent and Non-Residential A has the lowest, at 5.7 per cent. This reflects in part the presence of green space as well as the predominant land uses in these areas. It also highlights the heterogeneous distribution of canopy cover across the city and reinforces the need for a multifaceted approach to urban forest management. A full series of neighbourhood maps can be found in Appendix F. These maps can be used to communicate with residents and businesses about the value of the urban forest and opportunities for tree planting on private property.

> Recommendation 2: Fund and implement an outreach campaign with landowners and community organizations in Guelph to build partnerships and expand the urban forest on private lands.

[26] The by-law includes exemptions for e.g. dead, injured hazardous trees and other specific situations as defined in the by-law.

[27] An Assessment of Urban Forest Canopy. 2014. Mississauga, Ontario.

[28] Growing Livability: A Comprehensive Study of Oakville's Urban Forest. 2015.

[29] Tree Canopy Study Ten-Year Update. 2018. City of Toronto.

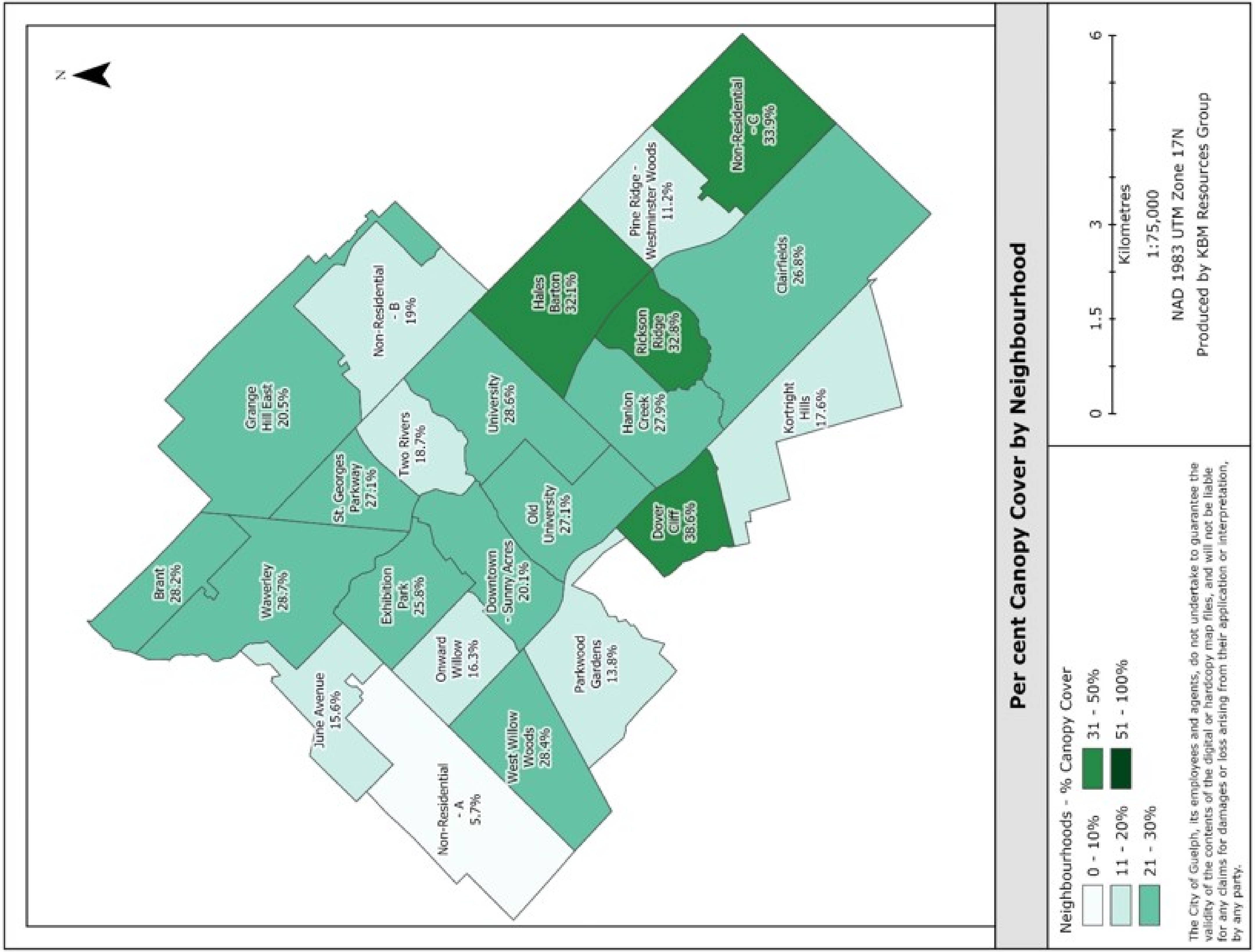


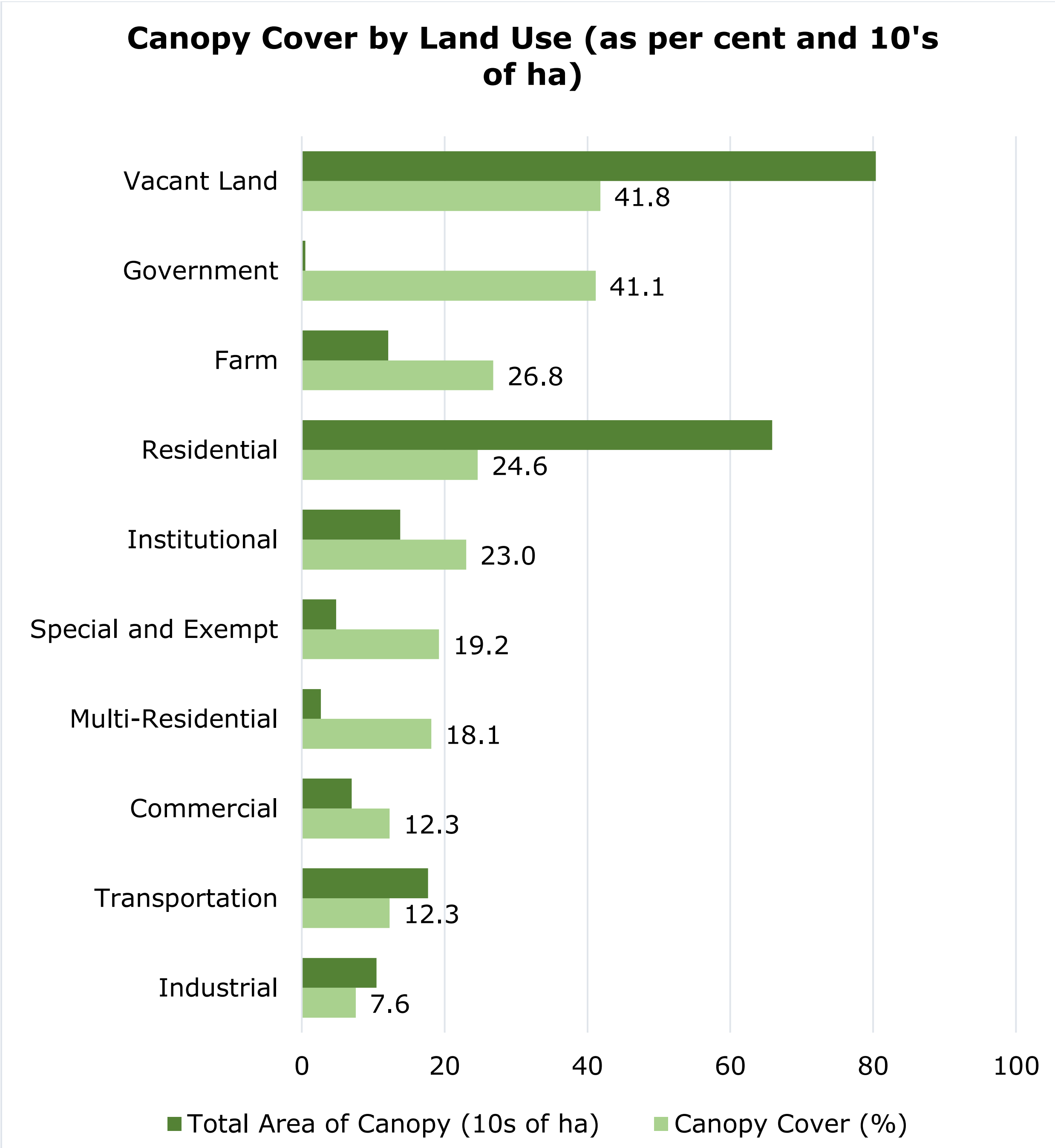
Figure 7: Per cent canopy cover by neighbourhood (Source: 2019 land cover data and neighbourhood map).

Canopy cover is highest in the Vacant land use (which includes Natural Cover and Open Space) at 41.8 per cent, and lowest in Industrial areas, at 7.6 per cent. This is consistent with patterns seen in many cities, where a higher intensity of land use is generally related to lower levels of canopy cover. The distribution of canopy cover is relevant, because the integrity and function of natural areas, including the NHS, is affected by the surrounding land use matrix.

Industrial and Commercial areas tend to have very little canopy cover and limited open space (soil) to plant trees, though this can be addressed in some areas through techniques for planting in hard surfaces. Improving the levels of canopy cover in low canopy areas has benefits for both the people and wildlife that occupy or pass through these areas.

> Recommendation 3: Identify opportunities to increase hard surface planting in highly urbanized land use areas.

Looking at the amount of canopy cover in hectares, the Vacant and Residential areas have the most area in hectares occupied by canopy cover because they represent some of the largest land uses areas in Guelph and also because they have higher canopy cover compared to other land uses. Figure 8 shows the per cent canopy cover and the area in hectares occupied by canopy cover in each land use.


Canopy Cover by Land Use (as per cent and 10's of ha)
Vacant Land
41.8
Government
41.1
Farm
26.8
Residential
24.6
Institutional
23.0
Special and Exempt
19.2
Multi-Residential
18.1
Commercial
12.3
Transportation
12.3
Industrial
7.6
0
20
40
60
80
100
Total Area of Canopy (10s of ha)
Canopy Cover (%)

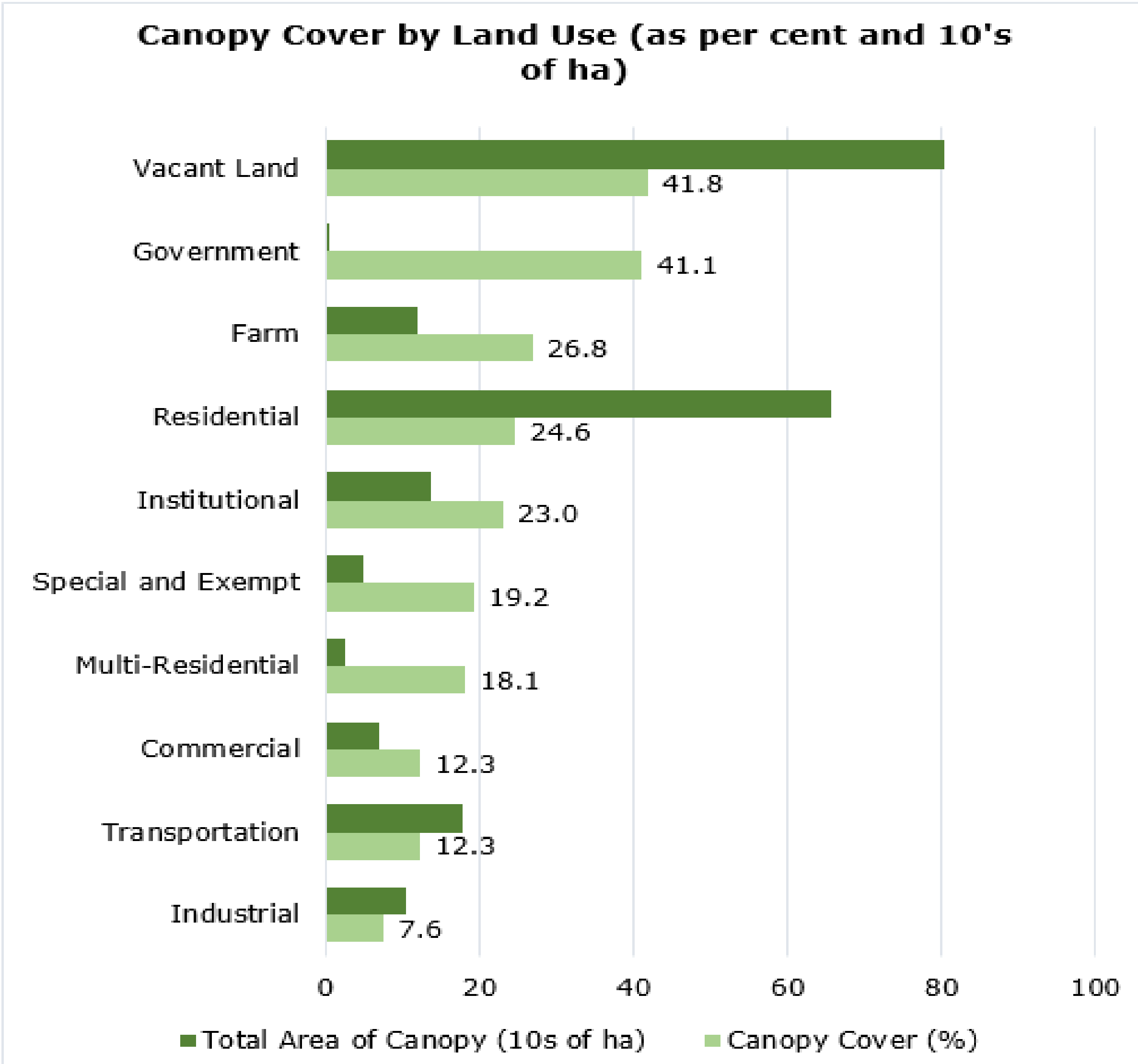


Figure 8: Canopy cover by land use as per cent and area in hectares (Source: 2019 land cover data and land use map).

The NHS contributes to enhancing the quality of life within the city by protecting a wide range of natural features and ecological services, while also providing natural and open spaces for leisure activities and enjoyment opportunities for residents of the City and visitors. A separate map of canopy cover in the NHS (Figure 9) shows the portion of the urban forest that is protected in the OP under specific NHS policies and is distinct in that respect from those areas outside the NHS. Canopy cover within the NHS is currently at about 60 per cent, and increasing those levels was identified as a priority by stakeholders to support NHS function in Guelph.

> Recommendation 4: Prioritize planting opportunities in and adjacent to the Natural Heritage System to enhance NHS function.

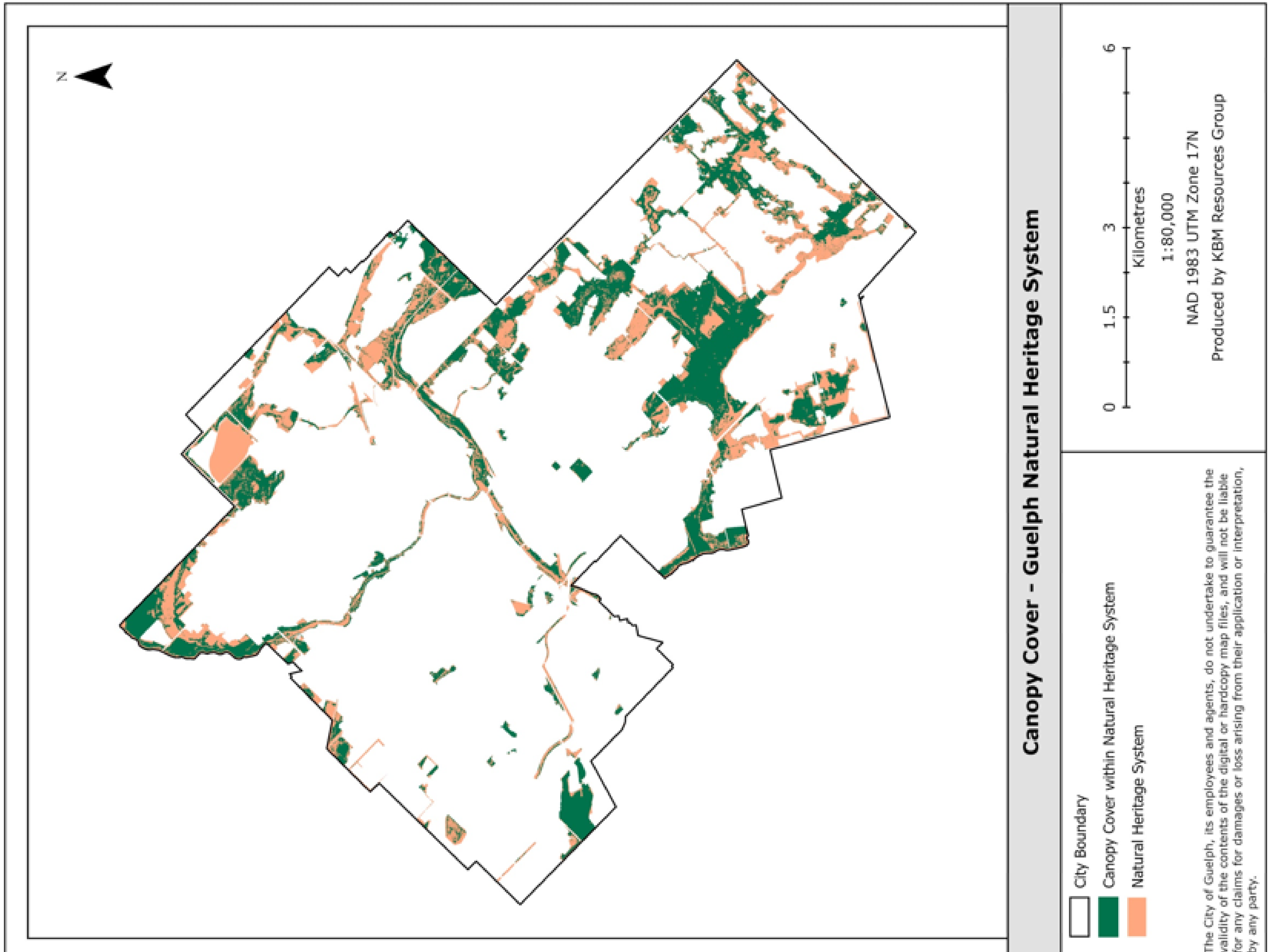


Figure 9: Distribution of canopy cover within the Natural Heritage System (Source: 2019 land cover)

LAND AND CANOPY COVER CHANGE

Measuring canopy cover change over time was not within the scope of this study. However, understanding trends in land cover and land use change provides useful context for understanding how urbanization is affecting the urban forest. Statistics Canada data show that the Guelph metropolitan area faces the same issues as other areas in the region where natural cover, including forests, is being lost to land conversion from natural or agricultural to urban land uses. The data quantifies this change over time, showing an increase in built-up area and a resulting decrease in natural cover (Figure 10). The Statistics Canada data does not provide information about specific changes within the City of Guelph, which is encompassed within the greater census metropolitan area. However, this trend of urbanization is reflected in the City's Stormwater Management Master Plan, which observes that infill and intensification are premised to lead to the potential for greater land coverage with hard surfaces. Change in built up area over time is a common finding of most municipal canopy studies, where land cover change is assessed as part of the environmental context for urban forestry.

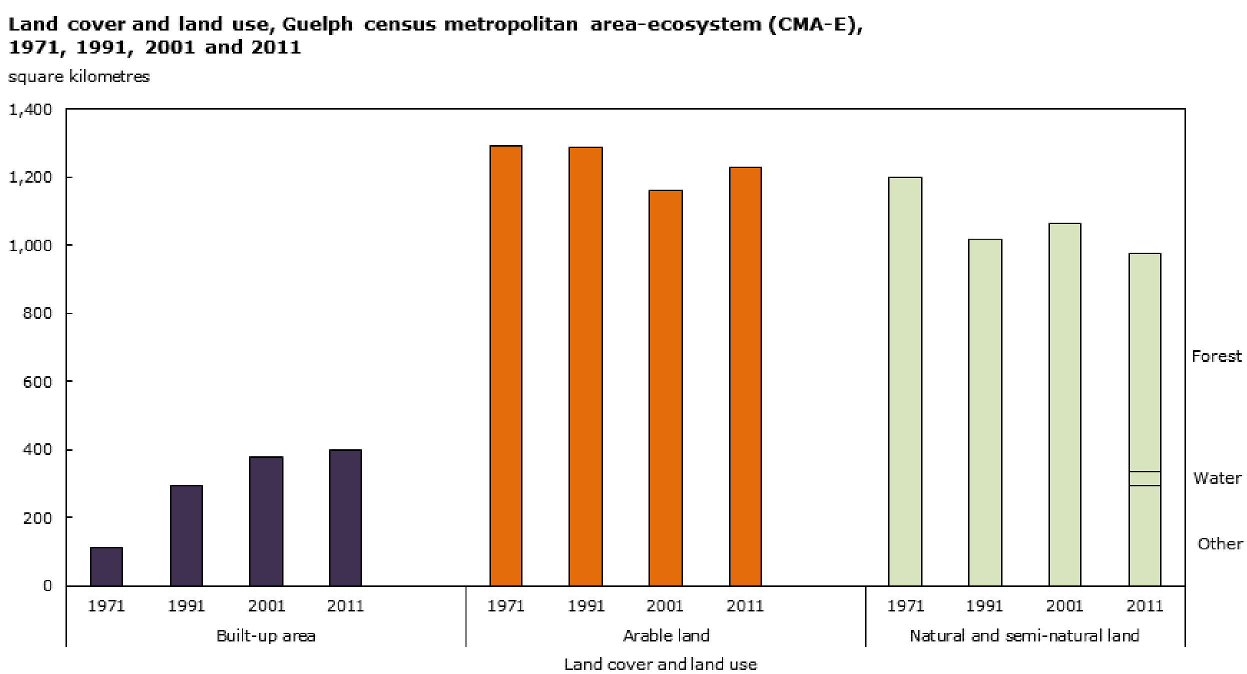


Figure 10: Land cover and land use change in the Guelph census metropolitan area – ecosystem (CMA-E) from 1971 to 2011 (Source: Statistics Canada, 2016).

This change is relevant to consider in view of the City's goals to increase canopy cover, which is happening in the context of loss of pervious growing space and soil quality as well as related increases in impervious land cover (hard surfaces). This highlights the need for increasing efforts to counteract the effects of urbanization on canopy cover as well as the importance of monitoring the effects, if any, of development and intensification on canopy cover and the health of the urban forest.

> Recommendation 5: Monitor land and canopy cover change regularly using available open-source tools developed by the USDA Forest Service (i-Tree) or other proven methods.

At this point in time, the City has a unique opportunity to design for the improved protection of pervious growing space and the associated soil resources as part of the development of new community and business areas. In light of Guelph's interest in building a more sustainable, climate resilient city, it should be considered that preserving existing vegetation, natural features, water and soil resources in situ wherever possible through good urban design may be more cost-effective and in line with the City's strategic environmental objectives than engineering green infrastructure into new developments after removing original natural features.

A forestry tour of Guelph that provided context for the urban forest study highlighted some of the challenges of new residential development. Site visits to recent subdivisions showed examples of limited growing space for trees on lots, poor soil quality, the effects of hydrological changes and the resulting impacts on the growth of planted trees and natural woodlands (Figure 11a and b). These factors all have long-term impacts on not only the amount but also the quality and health of the urban forest in Guelph.

Figure 11: a) Limited growing space and quality for front yard/street tree planting in a recent subdivision development and b) impacts of changes to local hydrology following subdivision development on a remnant woodland (extended flooding and tree dieback).

The tour also included specific examples of plantings and outcomes, comparing the condition of street trees planted under different conditions in road rights of way where differences in soil quality were most likely a key factor in the growth outcomes. Hard surface planting techniques (Silvacells) used in the downtown core provide adequate soil volume, quality and proper moisture conditions for trees to thrive in the challenging urban environment. In the latter case, the initial investment is higher up front but leads to better tree growth outcomes in the long term (Figure 12).

Figure 12: Examples of street tree planting outcomes in road rights-of-way (a) ROW in a recent subdivision, b) ROW planting using Silvacells in the downtown core.

In many cities, the lack of site-level canopy cover targets to translate the city-wide 40 per cent canopy cover goal to the individual project, land use or neighbourhood level during development means missed opportunities for realizing the City's urban forestry goals through incremental development. Some cities have set canopy cover targets by neighbourhood (Halifax) or land use (Oakville, London) to support planners in understanding and enforcing optimal levels of greening to support a city-wide canopy cover goal.

This leads to the following recommendations, which are aimed at improving planting outcomes and return on planting investments in the City.

Recommendations:

6. Identify options for improving the preservation of quality pervious growing space and soil resources in new residential and non-residential development.

7. Ensure all future growing space designated for trees in new residential and non-residential development is high quality, including sufficient soil volume, quality and crown space to support long-term growth.

8. Identify and implement best practices in zoning and urban design that maximize quality growing space on public and private land.

9. Use the results of the canopy cover and plantable space analyses to develop canopy cover targets for implementation at the project or site level. Integrate targets into Guelph's policies, by-laws or built form guidelines or other guiding documents as appropriate.

ASSESSING FOREST STRUCTURE, EFFECTS AND VALUES

Two separate i-Tree Eco analyses were completed in 2019:

1) A plot-based sample inventory of the entire City of Guelph; and
2) A complete inventory analysis of Guelph's street tree population.[30]

The results of the plot-based study provide insights into the characteristics, function, and value of the city's urban forest as a whole. The results of the street tree population analysis provide an in-depth analysis of the 43,659 street trees managed by the City of Guelph. Highlights from each analysis are presented in this section; a full technical report for the plot-based analysis may be found in Appendix J and another for the street tree analysis may be found in Appendix K.

GUELPH'S URBAN FOREST

OVERVIEW

The urban forest contains a diversity of forest types, land uses, ownership types, and ecosystems. Landscapes in Guelph's urban forest range from remnant woodlands in areas with a distinctly rural character to new developments and an older, densely built urban core with intensively managed trees planted in yards and along streets. The following results come from the 208 field plots measured across the City of Guelph, which capture all types of trees within the different land use classes across the City. The field plots capture some street trees, through the street

[30] Using existing data provided by the City of Guelph

tree population was evaluated separately, using the City's entire street tree inventory database and is described in a separate report section.

Guelph has a total tree population of approximately 2,973,000 with a structural value of about $803 million. Slightly more than half of the trees (53 per cent) are located on private property with the remaining 47 per cent located on public land. Guelph's urban forest has a canopy cover of 23.3 per cent, which represents a two-dimensional measure of tree cover relative to total land area in Guelph. This canopy cover contains 14,400 ha of leaf area, which describes the total surface area of all the leaves on Guelph's trees and shrubs.

Leaf area is used to calculate the leaf area index (LAI), which is commonly defined as total one-sided green leaf area (m^2) per unit ground surface area (m^2). Estimates of LAI rely on relationships between leaf area and e.g. stem diameter, tree height or crown base height.[31] LAI is a more informative measure to describe the urban forest than canopy cover and the i-Tree model uses LAI to produce the estimates of environmental services provided by trees. In short, canopy cover is the area of the tree population as viewed from above and leaf area is the total surface area of the living leaves. In the urban forest, this matters because more leaf area produces greater urban forest benefits.

The distribution of leaf area in Guelph illustrates the impact land use may have on the urban forest. For example, while Industrial lands make up 14.8 per cent of the land in Guelph, they represent only 5 per cent of the total leaf area, due to the nature of the landscape in those lands and the limited tree canopy supported there. By contrast, Vacant lands (including Natural Cover and Open Space) include many of the forested lands in Guelph and account for 25.7 per cent of land but 42.6 per cent of the total leaf area.

- **Total number of trees in Guelph: 2,973,000**
- **Structural (replacement) value of all trees: $803 million**
- **Canopy cover: 23.3 per cent**
- **Land use with highest canopy cover: Vacant Land, includes Natural Cover and Open Space (42.6 per cent)**
- **Land use with lowest canopy cover: Industrial (7.6 per cent)**
- **Tree ownership: 53** per cent **private, 47 per cent public**

[31] N.J.J. Breda. Ground-based measurements of leaf area index: a review of methods, instruments and current controversies. J. Exp. Bot., 54 (2003), pp. 2403-2417

FOREST COMPOSITION

A total of 106 species of trees[32] were recorded in Guelph in 2019. In terms of population, the three most abundant tree species are eastern white cedar (*Thuja occidentalis*), common buckthorn (*Rhamnus cathartica*), and green ash (*Fraxinus pennsylvanica*) (Figure 13). In many cities, an abundance of eastern white cedar points to widespread use of the species in hedges on residential properties. However, Guelph has many forested lands with substantial eastern white cedar components, which contribute significantly to its prominence in the tree population. Eastern white cedar comprises 20.8 per cent of Guelph's trees.

- **Total number of tree species: 106**
- **Top three species by population: Eastern white cedar, common buckthorn, green ash**
- **Top three species by leaf area: Eastern white cedar, Norway maple, sugar maple**
- **Tree species native to southern Ontario (per cent of population): 48 per cent**
- **Invasive common buckthorn (per cent of population): 19.3 per cent**

It is concerning that the second most abundant tree, the highly invasive common buckthorn, comprises 19.3 per cent of trees in Guelph and was found in each land use.

[32] i-Tree plots count trees, which are defined as any woody stem measuring 2.5 cm DBH or more.

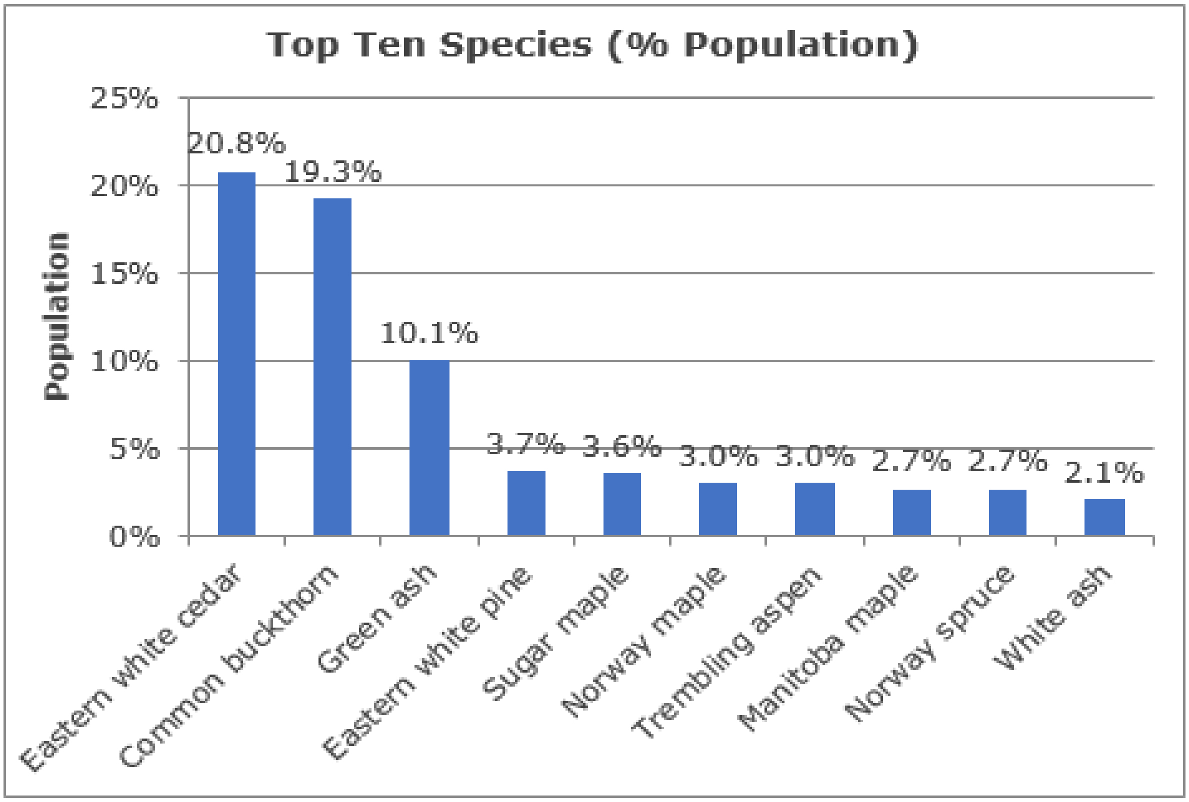


Figure 13: Top ten species by population in Guelph in 2019 (Source: 2019 i-Tree Eco plot-based analysis).

When ranked by leaf area, eastern white cedar is also dominant, comprising 16.6 per cent of the leaf area. This also suggests that Guelph's population of eastern white cedar is not merely made up of small trees in hedges but includes many mature trees in forested settings. Norway maple (*Acer platanoides*) ranks second in leaf area, followed by sugar maple (*Acer saccharum*). It is also notable that common buckthorn ranks sixth in leaf area, considering it typically has a fairly shrubby form and does not attain a large stature (Figure 14). This seems to suggest that Guelph's population of common buckthorn is not only fairly abundant, but that it also contains some fairly large specimens.

About 64 per cent of trees in Guelph are native to North America, though not all of these are native to Ontario. Approximately 48 per cent of trees in Guelph are native to southern Ontario, while the remaining 16 per cent of trees native to North America originate in another part of the continent.

The Commercial land use contains the highest proportion of trees native to North America, at 76.6 per cent, followed closely by Vacant lands, at 75.5 per cent. The Special and Exempt land use had the lowest proportion of trees native to North America, at 29.6 per cent, and the highest proportion of trees native to Europe, at 40.4 per cent.

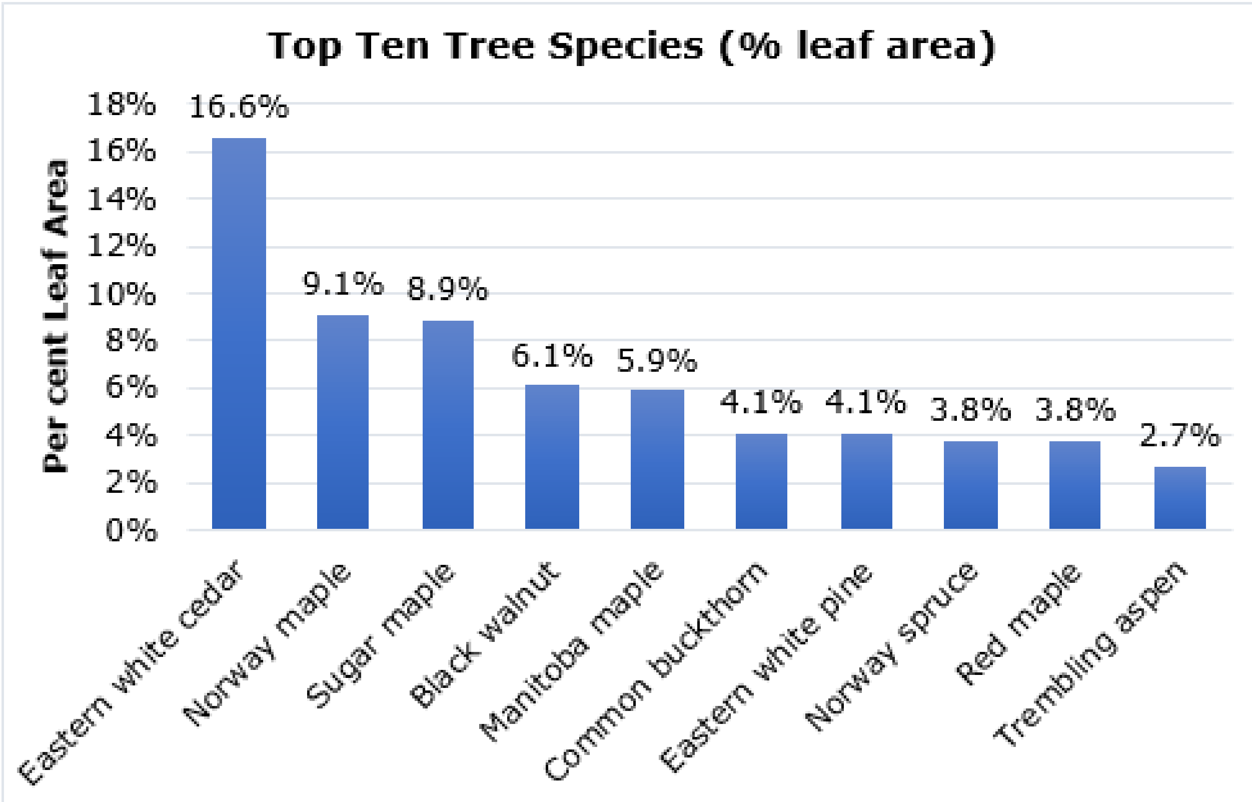


Figure 14: Top ten species by leaf area in Guelph in 2019 (Source: 2019 i-Tree Eco plot-based analysis)

Invasive species figure prominently in the shrub layer of Guelph's urban forest. The dominant shrub in Guelph is common buckthorn, comprising 23.7 per cent of the total shrub leaf area. About 57 per cent of the common buckthorn leaf area is found in the Farm and Vacant land uses, where the majority of the natural forests in Guelph are located.

Invasive species are problematic for several reasons – they threaten native biodiversity by displacing other species, they spread quickly, and they can degrade the recreational and aesthetic values of natural forests. Currently, the City does some but limited invasive species management in woodlands and natural areas. Prioritization is important to identify what level and type of management is appropriate in a given municipal context, and invasive species management plans can help managers allocate limited resources most effectively.

Recommendations:

10. Work collaboratively with other forest managers to develop an invasive species monitoring and management strategy for the City of Guelph.
11. Fund and implement invasive species management in high priority areas within and adjacent to the Natural Heritage System.

FOREST STRUCTURE AND CONDITION

42.6 per cent of Guelph's trees currently belong to the smallest diameter class (7.6 cm and under), while 7 per cent of trees measure more than 30.5 cm DBH, and only 1 per cent of trees measure more than 61 cm DBH (Figure 15**Error! Reference source not found.**). By land use, Multi-Residential lands have the lowest proportion of small-diameter trees with only 28.5 per cent of trees measuring less than 15.3 cm DBH, and the largest proportion of large diameter trees, with 31.4 per cent of trees measuring more than 30.5 cm DBH. The Residential land use had the second largest proportion of trees in the largest diameter classes (30.5 cm and above), with 9.3 per cent.

The size class of an urban forest is important, because it speaks to the sustainability and continuity of benefits the urban forest can provide. There are rules of thumb that provide guidance for what a sustainable size class looks like, with the smallest size classes comprising a relatively large cohort in order to replace trees as they mature and senesce, recognizing there will be some level in mortality in the young tree population. Large, healthy trees also provide the most urban forest benefits and best return on the planting investment. While the reason for the unevenness in the size class is unclear, it would be prudent for the City to review current policy and regulations that are meant to support tree protection in Guelph. This information can be used to propose improvements for increasing the number of large trees in Guelph's urban forest.

> Recommendation 12: Review the effectiveness of current tree by-laws, protection policies and development review processes for promoting trees and promoting mature tree retention in Guelph. Identify options for promoting the retention of mature, healthy trees.

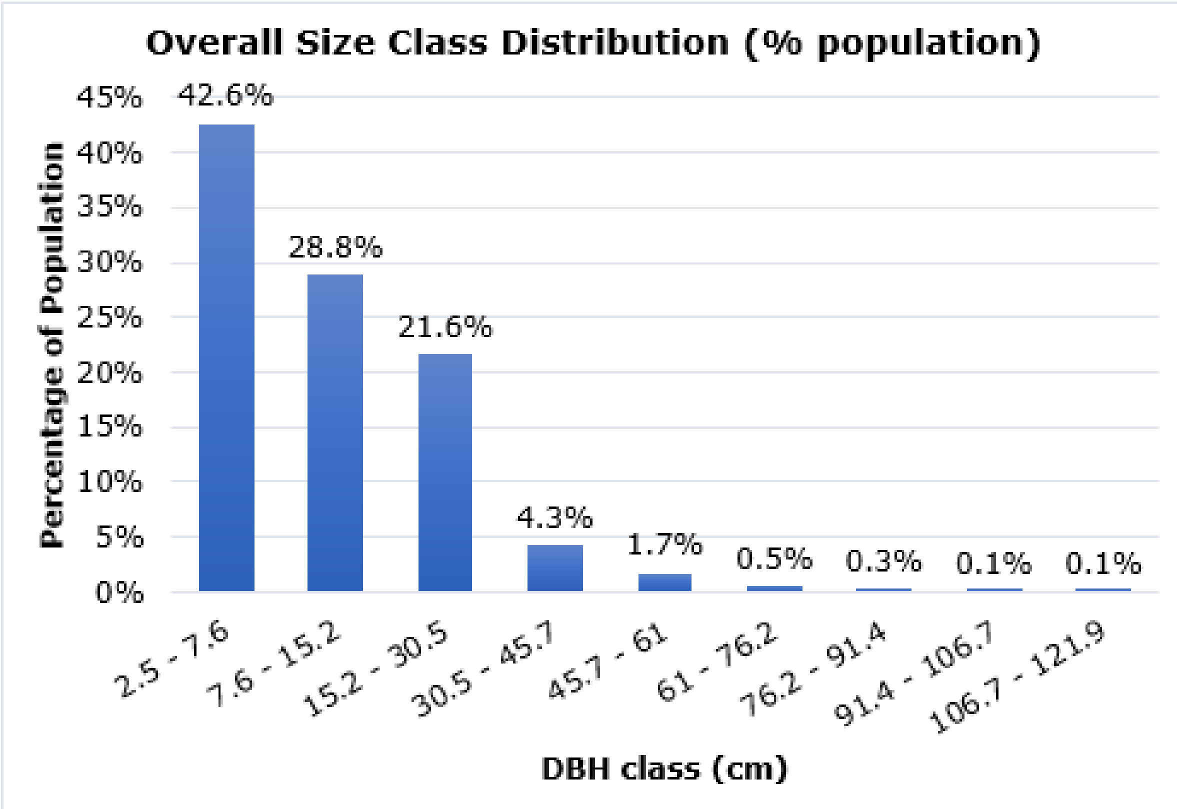


Figure 15: Distribution of Guelph's tree population by diameter class (cm) in 2019 (Source: 2019 i-Tree Eco plot-based analysis)

Approximately 71.1 per cent of trees were estimated to be in excellent or good condition (i.e. trees displayed less than 10 per cent dieback in the crown[33]). This is on the lower end of recent estimates in other municipalities, where 74.4 per cent in Toronto, 76.8 per cent in Oakville and 80 per cent of trees in Mississauga were rated in excellent or good condition.

Approximately 16.7 per cent of trees were found to be dead, which is an unusually high number, compared to the results of other urban forest studies[34] (Figure 16). Many of these dead trees were ash (*Fraxinus* spp.) of various species that had been killed by emerald ash borer (*Agrilus planipennis*) and remained standing in forests. For example, dead trees account for 45.8 per cent of the population of green ash, the third most abundant tree in Guelph.

[33] i-Tree uses per cent crown dieback to develop a rating of tree condition.

[34] Oakville 2015 – 6.6% dead trees, Toronto 2018 – 7% dead trees, Hamilton 2018 – 6.8% dead trees

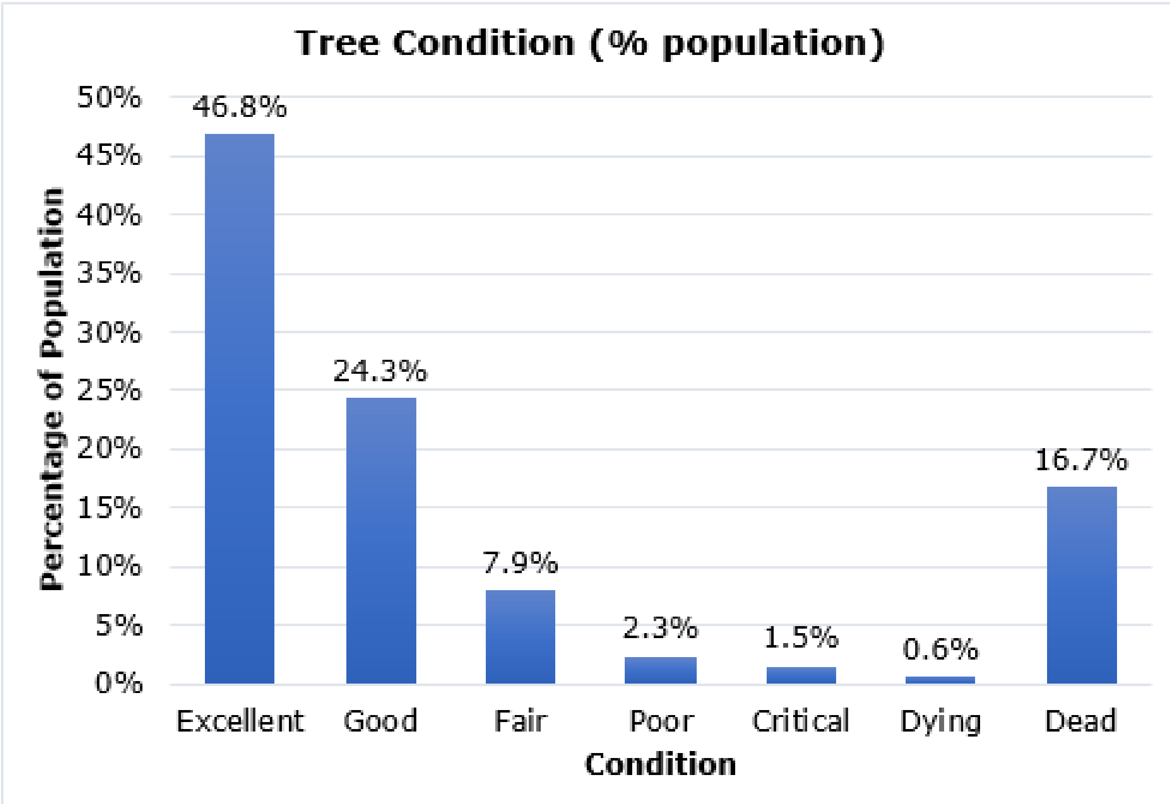


Figure 16: Distribution of tree population by tree condition rating in 2019 (Source: 2019 i-Tree Eco plot-based analysis)

The Commercial and Multi-Residential land uses were characterized by the best tree condition ratings, with 83 per cent and 82.9 per cent of trees rated as being in excellent or good condition, respectively. Trees in the Industrial and Residential land use categories were characterized by very good tree condition, with 78.7 per cent and 76.7 per cent of trees rated as being in excellent or good condition, respectively. The Farm land use category (representing the developable lands in Guelph) was characterized by the worst overall tree condition, with only 61.7 per cent of trees rated as being in excellent or good condition, and 24.7 per cent of trees recorded as being dead.

Experience suggests that ash dieback in woodlands without active forest renewal efforts can lead to site colonization by invasive species, including buckthorn. In the interest of early detection, the City of Guelph should increase efforts to do outreach and education about the impacts of invasive species on private lands, including the spread of unchecked invasions to adjacent public lands.

> Recommendation 13: Increase outreach to and education for landowners to provide information about invasive species and options for stewardship on private lands.

When considering the top ten species by leaf area, black walnut (*Juglans nigra*) and Norway spruce (*Picea abies*) were ranked highest in condition, with 95.2 per cent and 93.1 per cent of trees rated as being in excellent or good condition, respectively. Of the top ten species by leaf area, the population of eastern white cedar contained the highest percentage of dead trees, at 19.6 per cent.

- **Percentage of trees in the smallest size class (7.6 cm and under): 42.6 per cent**
- **Percentage of trees in the largest size classes (61 cm DBH and over): 1 per cent**
- **Percentage of trees in good or excellent condition: 71.1 per cent**
- **Percentage of dead trees: 16.7 per cent**
- **Tree species with best condition rating: Black walnut (95.2 per cent in good or excellent condition)**

FOREST PEST THREATS

The i-Tree results show that some of the most serious insect pests that threaten Guelph's urban forest include the invasive Asian longhorned beetle (*Anoplohora glabripennis* or ALHB), emerald ash borer (*Agrilus planipennis* or EAB), and European gypsy moth (*Lymantria dispar dispar* or GM). About 42 per cent of the leaf area in Guelph's urban forest is vulnerable to ALHB, which has been controlled in Ontario for the time being but still poses a potential threat.

Emerald ash borer (EAB) remains a threat to about 388,000 trees, but these trees only represent about 3 per cent of the leaf area in Guelph's urban forest. This suggests that the remaining population of ash is made up largely of small individuals and that the majority of mature ash trees have already succumbed to EAB. Since 2014, the City (under its EAB management program) has removed 2,400 individual street and park trees and an additional 5,000 trees from natural woodlands. About 1,570 of these trees have been replaced.[35]

About 357,000 of Guelph's trees are susceptible to damage by European gypsy moth (*Lymantria dispar dispar*). These trees represent about 18 per cent of Guelph's leaf area. However, unlike EAB and ALHB, gypsy moth infestations can be treated and are not fatal unless repeated years of defoliation occur. Figure 17 shows the number of trees and their replacement value in terms of susceptibility to various insect pests and pathogens for all trees in the City of Guelph.

[35]City of Guelph forestry data.

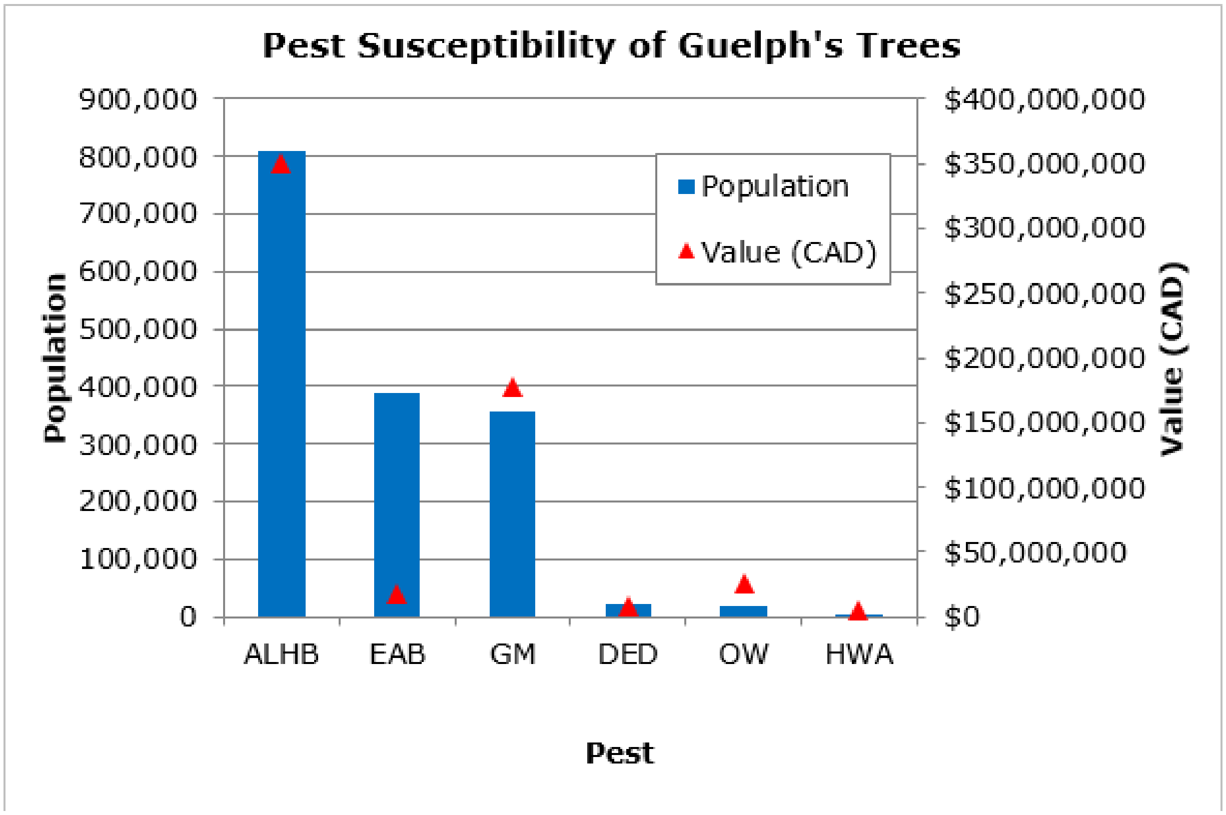


Figure 17: Susceptibility of Guelph's trees to major pests, with associated structural value in 2019. Illustrated here are values for Asian longhorned beetle (ALHB), emerald ash borer (EAB), gypsy moth (GM), Dutch elm disease (DED), oak wilt (OW), and hemlock woolly adelgid (HWA) (Source: 2019 i-Tree Eco plot-based analysis)

In order to minimize and mitigate forest health threats, the City should consider species vulnerability as part of a tree planting strategy that optimizes species selection in Guelph to maximize forest resilience. If ongoing monitoring is not occurring, the City should at minimum investigate and report on the status of forest health threats as part of annual operational planning. However, regular forest monitoring in urban and natural areas will assist the City in identifying and responding in the most cost-effective way to forest health threats from invasive and other species.

Recommendations:

14. Include consideration of current species abundance and leaf area as well as vulnerability to pests in species selection as part of a comprehensive planting strategy.
15. Develop suitable species lists for urban trees and natural areas and review these annually as part of operational planning. Include as Appendix to the Tree Technical Manual.

16. Include an update on the status of major forest health threats as part of annual operational planning.
17. Develop a forest monitoring program to support early detection and response to threats from pests, disease and invasive plant species.

URBAN FOREST ECOSYSTEM SERVICES

Each year, Guelph's trees deliver a range of benefits to the city's residents, workers, and visitors through their growth and natural processes. As trees grow, they store carbon over the long term in their woody tissue. Trees' leaves are responsible for sequestering atmospheric carbon, as well as intercepting particulate matter (air pollutants) and retaining rainfall, thereby helping to reduce runoff during rainstorms. While there is a host of social, economic, and ecological benefits provided by urban trees, only some of these prominent services listed above are easily quantified using the i-Tree models. According to the i-Tree Eco model, Guelph's trees are estimated to provide annual ecosystem services worth about $5.6 million as assessed in this study approach (carbon storage and sequestration, avoided stormwater runoff, interception of particulate matter, reduction in heating and cooling costs and related emissions). The study does not evaluate all possible ecological services but only key services as quantified by the i-Tree Eco software, for which data are readily available as inputs to the model. These are the standard suite of services needed to evaluate the benefits delivered by the urban forest.

- **Dollar value annual ecosystem services: $5.6 million**
    - **Annual energy savings: 141,941 MBTUs (4,428 MWh) with a value of $1,882,502**
    - **Pollution removal: 156 tonnes with a value of $2,051,438**
    - **Avoided Runoff: 399,938 m³ with a value of $929,742**
    - **Gross Carbon Sequestration: 6,455 tonnes with a value of $741,515**
- **Carbon storage: 196,894 tonnes with a value of $22.6 million**

These estimates do not reflect a comprehensive assessment of services provided by Guelph's trees and woodlands, but rather provide a starting point to quantify the dollar value of ecosystem services generated by the urban forest where data is often lacking. These estimates make up part of the picture of the total value of services provided by Guelph's natural assets, which are part of a larger natural asset assessment the City is undertaking.

Table 4 summarizes the annual benefits provided by trees as measured in this study and their associated value. These values are derived by the USDA Forest Service i-Tree Eco model (v6), which uses tree measurements and other data to estimate ecosystem services and structural characteristics of the urban forest. Eco is a complete package that provides:

- Sampling and data collection protocols - For plot-based sample projects, total population estimates and standard error of estimates are calculated based on sampling protocols. For complete inventories, eco calculates values for each tree.
- Automated processing - A central computing engine that makes estimates of the forest effects based on peer-reviewed scientific equations to predict environmental and economic benefits.

The filed data collected in the 208 sample plots provides the inputs from which the value of ecosystem services is derived. Full details on the model and its functionality can be found on the i-Tree website.

Table 4: Annual ecosystem services performed by Guelph's trees (Source: 2019 i-Tree Eco plot-based analysis)

Benefits	Total Units	Total (CAD)	CAD/tree	CAD/capita
Energy savings	141,941 MBTUs; 4,428 MWh	1,882,502	0.63	14.28
Gross Carbon Sequestration	6,455 tonnes	741,515	0.25	5.62
Pollution Removal	156 tonnes	2,051,438	0.69	15.56
Avoided Runoff	399,938 m^3	929,742	0.31	7.05
Total Annual Benefits	**N/A**	**5,605,197**	**1.88**	**42.51**

CARBON STORAGE AND SEQUESTRATION

Forests play an important part in the global carbon cycle, both storing and releasing carbon in an ongoing process of growth, decay, disturbance and renewal. Trees and forests help maintain Earth's carbon balance. Carbon is absorbed from the atmosphere through photosynthesis and becomes deposited (stored) in forest biomass (that is, trunks, branches, roots, leaves, litter and dead wood). The process of carbon absorption and deposition is known as carbon sequestration.[36] As of 2019, Guelph's trees store a total of 196,894 tonnes of carbon. The total value of carbon storage by Guelph's urban forest in 2019 is about $22.6 million. Large trees on average store more carbon in their trunks and branches compared to small trees, due to the larger amount of woody tissue in large trees. Stored carbon is gradually released when trees die and decay naturally. If a population of trees is in

[36] Natural Resources Canada, Forest Carbon.

particularly poor health, or there is a high mortality rate, it can emit more carbon than it sequesters.

Sugar maple stores the most carbon in Guelph, accounting for 13.4 per cent of carbon stored by Guelph's urban forest, followed by eastern white cedar, which stores 8.8 per cent of the carbon stored by Guelph's urban forest. Guelph's trees are estimated to sequester about 6,455 gross tonnes of carbon annually, which has an annual value of $741,500. After accounting for loss of carbon through mortality and decay, Guelph's trees sequester about 4,201 net tonnes of carbon annually. Sugar maple sequesters the most carbon annually, in gross and net amounts (699.7 tonnes and 483.6 tonnes, respectively). Eastern white cedar sequesters the second most amount of carbon in gross but is fourth in annual net carbon sequestration behind Norway maple and common buckthorn. Sugar maple sequesters 11.5 per cent of all net carbon annually sequestered by trees in Guelph (Figure 18).

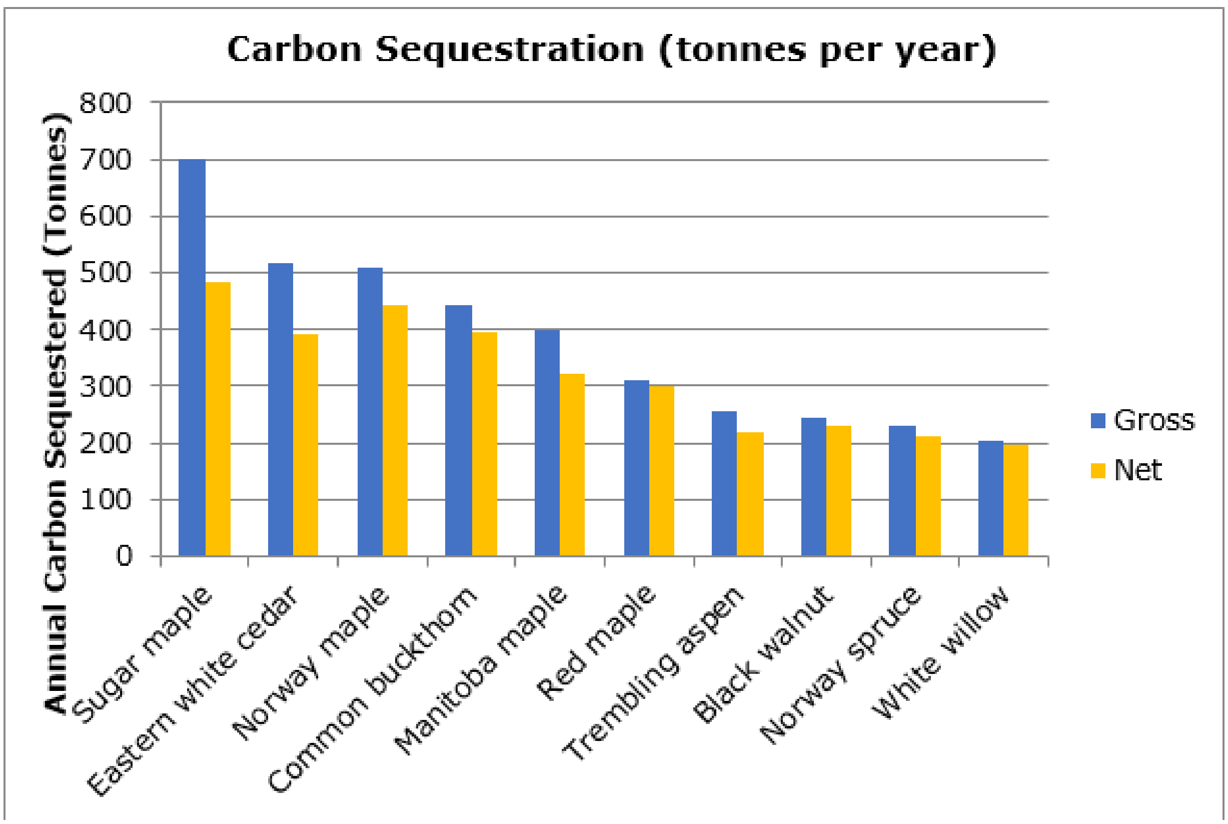


Figure 18: Annual carbon sequestration rates of top ten species by amount of carbon sequestered in 2019 (Source: 2019 i-Tree Eco plot-based analysis)

The trees in the Vacant land use are responsible for about 53 per cent of the net annual carbon sequestration performed by Guelph's urban forest. This is disproportionately higher than the population of trees in that land use, which represents about 49.1 per cent of the city's trees and 42.6 per cent of the leaf area. Trees in the Residential land use are responsible for about 26.5 per cent of the net annual carbon sequestration performed by Guelph's urban forest. The high density of trees in the Vacant land use means that it ranks highest in gross rates of carbon sequestration per unit of area, at 1,521.75 kilograms per hectare per year (kg/ha/yr). The annual gross carbon sequestration rate per unit of area for the City of Guelph as a whole is 870.85 kg/ha/yr, which is slightly above the rate for the Residential land use (701.42 kg/ha/yr).

POLLUTION REMOVAL

As with atmospheric carbon, trees remove pollution from the air by direct absorption through the leaf stomata as well as by capturing particulate matter on and in plant tissue. In doing so, trees can mitigate air pollution to some extent and possibly have beneficial effects on human health. Guelph's trees are estimated to remove about 156.4 tonnes of pollution per year. The total annual value of pollution removal performed by Guelph's trees is estimated at about $2.05 million. This ecosystem service includes the removal of atmospheric ozone (Guelph's urban forest removed ozone (O_3) at higher levels than any other pollutant), nitrogen dioxide, sulphur dioxide, carbon monoxide, and small particulate matter (under 2.5 microns).

RESIDENTIAL ENERGY SAVINGS

When properly placed, the presence of trees on residential properties helps to lower home energy costs. In summer, trees that shade the residence contribute to lower cooling costs, and in winter, evergreen trees can help to block cold winds, thus lowering the cost of home heating. By lowering home energy demands, trees help to reduce carbon emissions that result from energy use as well. These benefits are enhanced as the size and leaf area of the trees increase. Guelph's trees save homeowners about $1.88 million each year through reduced energy consumption.[37] As a result of this reduced energy consumption, trees prevent the emission of about 3,450 tonnes of carbon, which has an additional annual value of $396,300. Given the value of trees for reducing energy-related emissions, their role in contributing to the City's goal of net zero carbon by 2050 should be acknowledged.

[37] The i-Tree Eco models only residential energy savings and does not account for potential energy savings for commercial, government or institutional buildings.

Recommendation 18: Document the contribution of trees in supporting net zero carbon by 2050 in future updates to the Community Energy Initiative and other climate resilience planning initiatives.

STORMWATER MITIGATION

Guelph's trees also help to intercept rainfall and prevent stormwater runoff, which reduces the burden on municipal stormwater infrastructure. Guelph's trees prevent approximately 399,938 cubic metres of runoff annually, which has an equivalent annual value of about $929,742. Trees in the Vacant land use prevent the most runoff – more than 170,000 m^3 per year, with an equivalent annual value of more than $395,800. This accounts for 42.6 per cent of the avoided runoff performed by Guelph's urban forest and aligns with the large tree population and leaf area present in the Vacant land use. Eastern white cedar prevents more runoff than any other species, accounting for 16.6 per cent of the avoided runoff performed by Guelph's urban forest. Norway maple and sugar maple also contribute significantly to the avoided runoff service provided by Guelph's urban forest. The City's ongoing natural asset assessment will also be calculating their value for stormwater management using a different methodology. This will provide another perspective on the value of ecosystem services produced by the City's urban forest and other natural assets.

The City of Guelph currently calculates stormwater fees and credits[38] for businesses based on the amount of hard surface on industrial, commercial and institutional properties. Given the benefits of trees for attenuating stormwater runoff, the City should examine options for including the amount of tree canopy cover on property to calculate stormwater credits and incentivize tree planting in these land use areas in Guelph.

Recommendations:

19. Forestry should work with the City of Guelph Engineering Services to identify priority locations for planting trees in areas prone to high levels of runoff and flooding.
20. Examine opportunities for extending stormwater credit calculations based on per cent hard surface to include per cent relative tree canopy to incentivize tree planting on industrial, commercial and institutional properties.

GUELPH'S STREET TREES

[38] City of Guelph Stormwater Service Fees, Credits and Rebates.

Street trees comprise an important element of the urban forest. They enhance neighbourhood aesthetics and provide shade and valuable ecosystem services in residential and commercial areas, forming a publicly controlled grid across the urban landscape. In densely built areas with limited potential for planting, street trees represent valuable green infrastructure. Street trees have positive impacts on human mental and physical health in urban areas and provide a suite of ecosystem services.

In Guelph, street trees include all trees located in rights-of-way and front yards and are classified as City, boundary (those located on the boundary of public and private property) and private trees. This is relevant for how they are managed by Forestry – for City and boundary trees, maintenance objectives are health (benefits) and safety (structure). For private trees, the maintenance objective is public safety and safety of right of way only. The City does not maintain private street trees unless they are an immediate danger as defined by the Municipal Act.

Due to their location along roadways, street trees are also subject to some of the harshest growing conditions and are therefore predisposed to a number of stress factors that can inhibit their growth and performance. The use of road salt in winter can negatively impact the soil chemistry where street trees grow, which negatively affects tree health.[39] Street trees are often planted in confined growing spaces with limited soil volume, and foot traffic can further harm tree health by compacting soil. Sidewalk repair and conflicts with utilities can also cause damage to the root zone of street trees. Street trees may also be more vulnerable to injury than other trees, such as by vandalism or impacts from vehicles or snowplows.

Some engineered solutions such as modular paving systems are employed to enhance street tree growing space and water infiltration and reduce stress. However, these systems are expensive for municipalities to deploy widely, so their use may be limited to certain areas. As municipal assets, management of street trees is generally undertaken by municipal forestry crews. As such, their health is partly a reflection of the resources a municipality is able to devote to their management.

STREET TREE POPULATION COMPOSITION AND STRUCTURE

- **Total number of street trees: 43,659**
- **Number of species and varieties: 148**
- **Per cent of total tree population: 1.5 per cent**

[39] Camilo Ordóñez-Baronaa, Vadim Sabetski, Andrew A. Millward, James Steenberg. 2018. De-icing salt contamination reduces urban tree performance in structural soil cell. Environmental Pollution 234: 562-571.

- **Structural (replacement) value: $105.6 million**
- **Per cent of total structural value of the urban forest: 13 per cent**
- **Most abundant street tree: Norway maple (22.3 per cent of population)**
- **Norway maple leaf area: 40.9 per cent of total street tree leaf area**
- **Per cent of street trees in small size class (< 15.2 cm DBH): 36.6 per cent**
- **Per cent of street trees in medium-large age class (>30.5 cm): 38.3 per cent**
- **Street trees in excellent or good condition: 84 per cent**

Guelph has a street tree population of 43,659 trees[40] with a structural (replacement) value of approximately $105.6 million. Street trees make up about 1.5 per cent of Guelph's total tree population, but their structural value represents about 13 per cent of the total structural value of Guelph's trees.

Guelph has 148 species and varieties of street trees.[41] Norway maple (*Acer platanoides*) is the most abundant street tree species in Guelph, comprising about 18.5 per cent of the street tree population. However, it should be noted that the top ten species of street tree by population also contains Crimson King Norway maple, which comprises an additional 3.8 per cent of the total street tree population. When totaled together, it may be said that Norway maple makes up 22.3 per cent of Guelph's street trees. Sugar maple (*Acer saccharum*) is also abundant in the street tree population, comprising about 11.8 per cent of the street tree population (Figure 19).

[40] Represents the number of street tree records input to the i-Tree model after removing unusable data

[41] There are more species identified in the street tree inventory than the sample-based field plots because it represents the entire population. A sample by its nature does not capture the full range of species in the urban forest but provides a good representation of the overall forest composition.

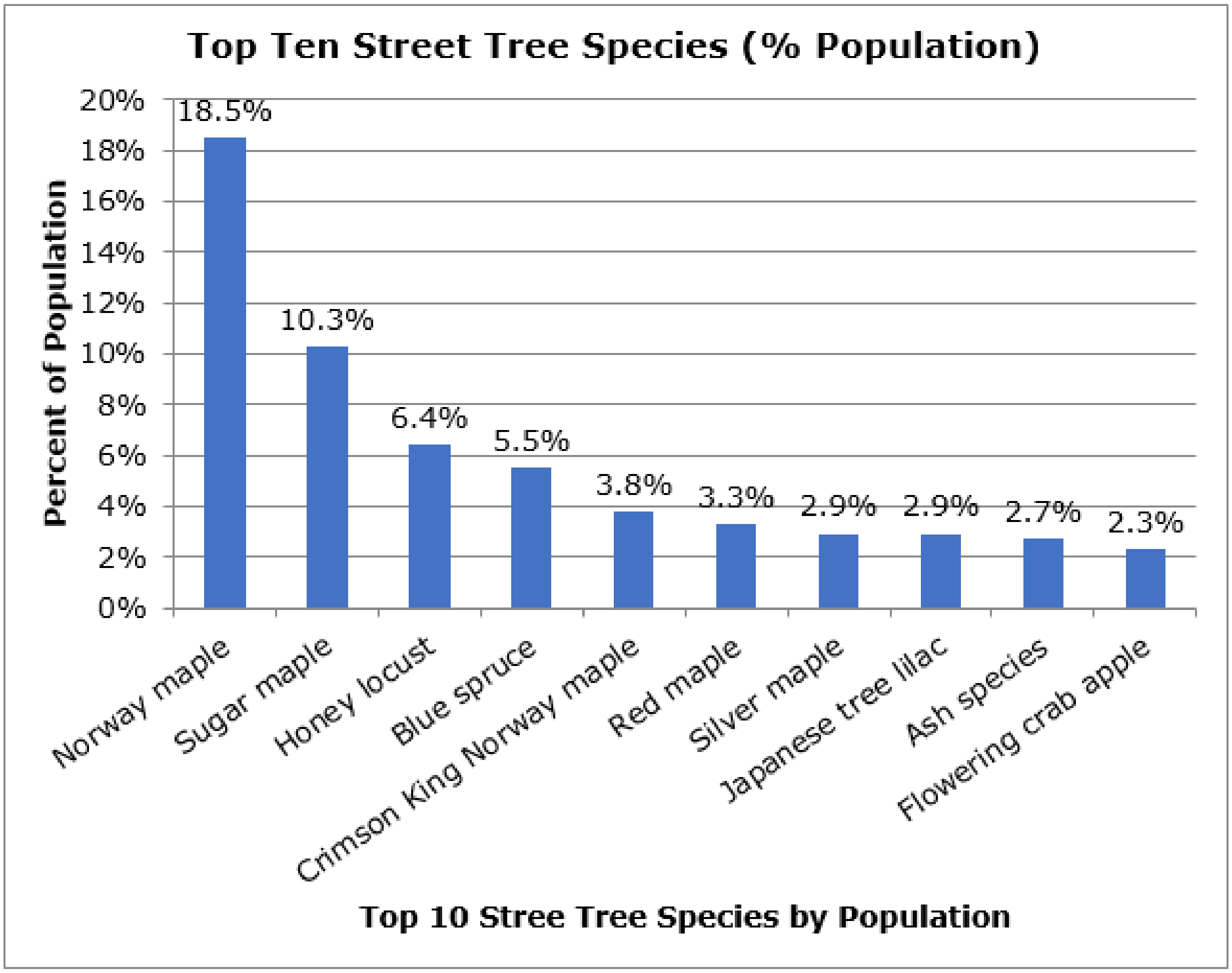


Figure 19: Top ten species of street trees by population in 2019 (Source: i-Tree Eco analysis of Guelph street tree inventory)

Norway maple is also dominant among street trees in terms of the leaf area it represents. Norway maple contributes about 35.5 per cent of the leaf area of all of Guelph’s street trees. When combined with Crimson King Norway maple, which comprises 5.4 per cent of street tree leaf area, the species accounts for 40.9 per cent of the leaf area represented by Guelph’s street trees. As with population, sugar maple is the second most abundant street tree in terms of leaf area (Figure 20).

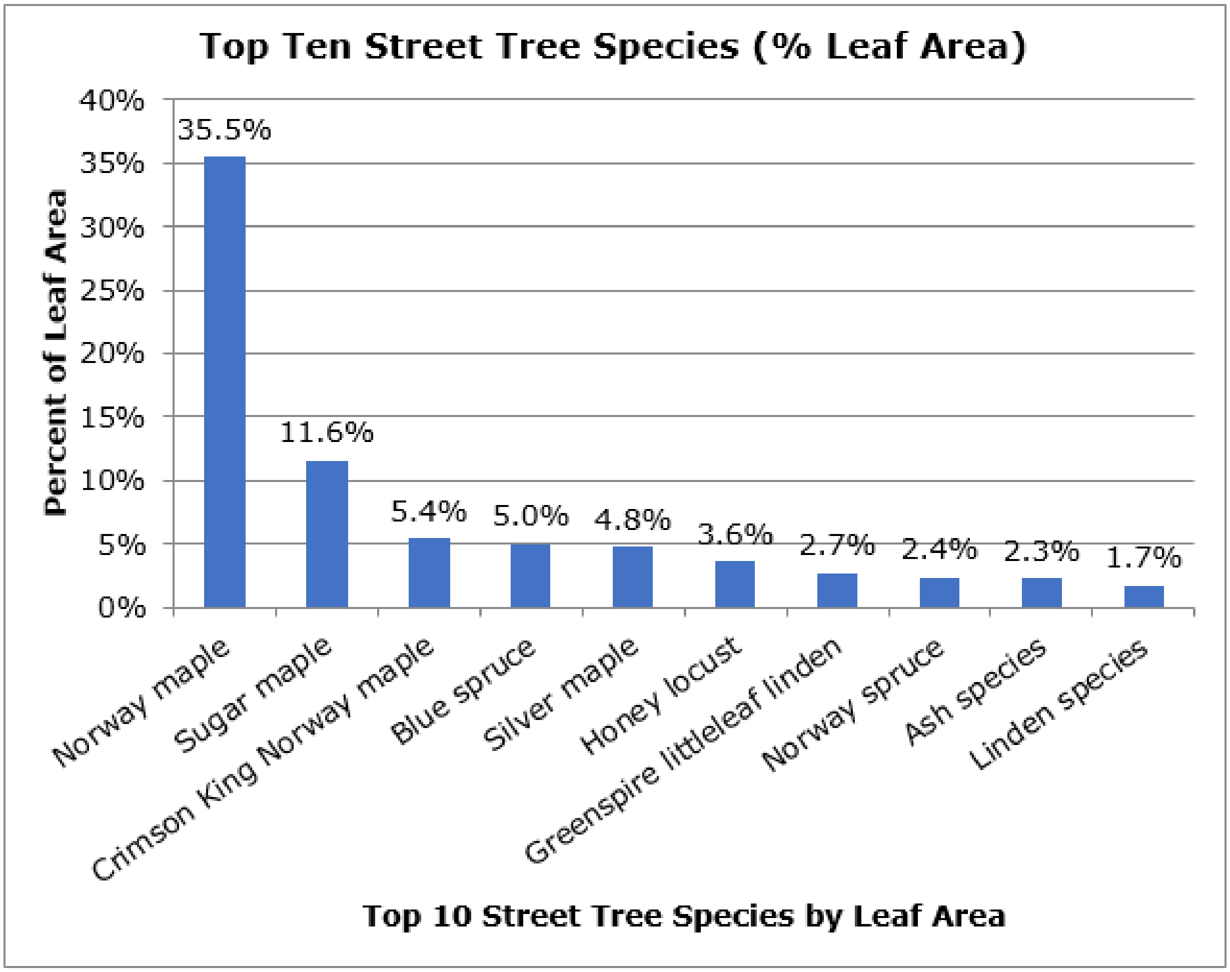


Figure 20: Top ten species of street trees by leaf area in 2019 (Source: i-Tree Eco analysis of Guelph street tree inventory)

The size class distribution of Guelph's street trees raises some concern about the rate of replacement planting in the City's rights-of-way (ROWs). Ideally, the size class distribution curve would show a higher number of small/young trees to replace mid- and large-sized trees and to balance expected mortality in the population.

As of 2019, about 36.6 per cent of street trees measure 15.2 cm or less in diameter. About 38.3 per cent of street trees now measure more than 30.5 cm in diameter, which suggests that Guelph's street tree population has a fairly sizable component of mature street trees (Figure 21). While these mature street trees deliver important ecosystem services to Guelph's residents, it will be important to continue to plant new street trees at a pace that will ensure sufficient numbers of street trees are able to replace senescent and dying trees in the future.

Recommendations:

21. Increase the rate of street tree planting to ensure a sustainable street tree population in the City.

22. Identify populations of senescent street trees where underplanting would help maintain urban forest benefits and increase resilience to storm events.

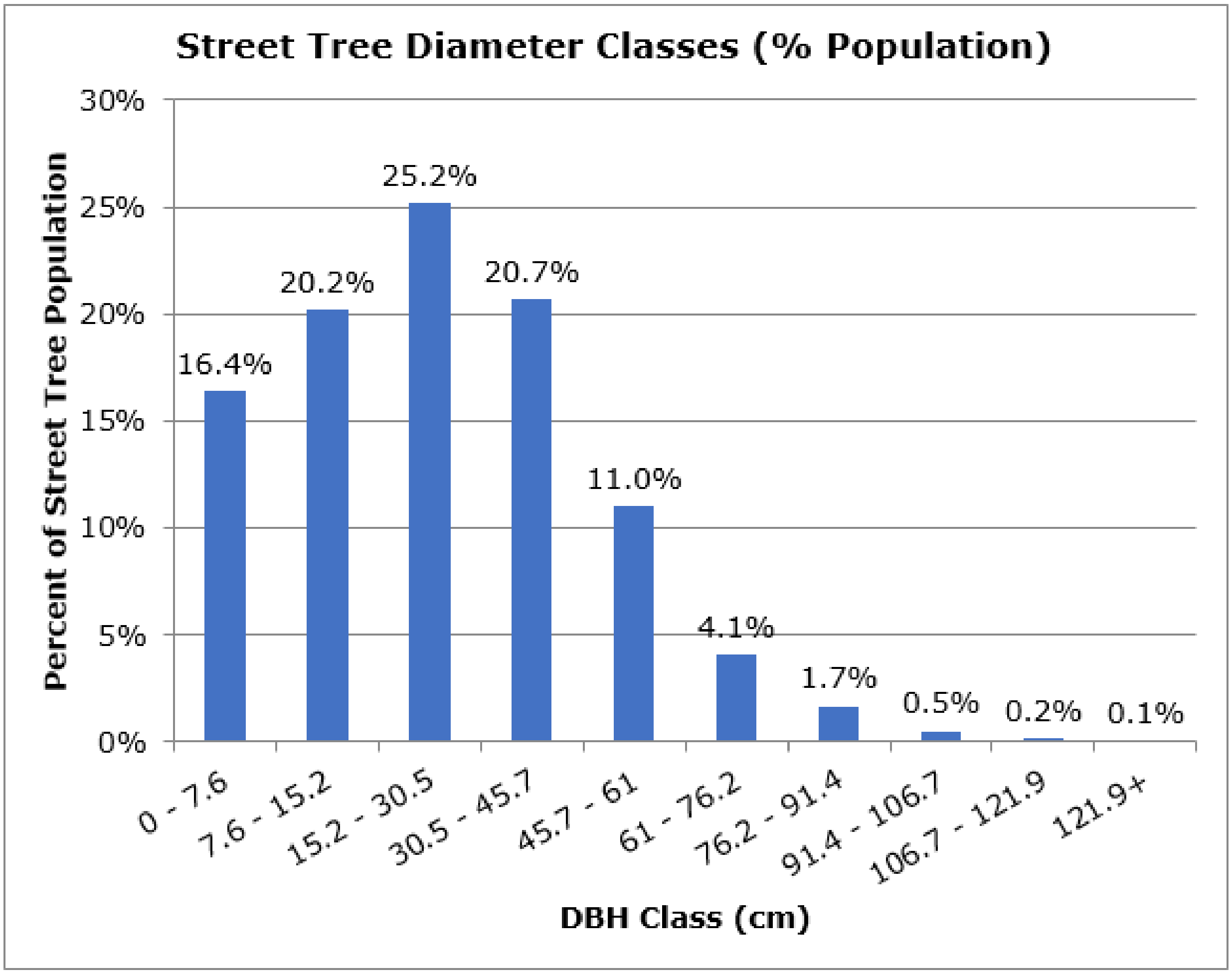


Figure 21: Distribution of Guelph's street tree population by diameter class (cm) in 2019 (Source: i-Tree Eco analysis of Guelph street tree inventory)

The health of Guelph's street trees is relatively good, based on the condition ratings assigned to the trees in the city's inventory. About 84 per cent of Guelph's street trees are reported to be in excellent or good condition, while dead trees make up only 0.5 per cent of the street tree population (Figure 22). This suggests that regular pruning and care are maintaining the good condition of the street tree population. It may also point to the suitability of species selected for planting in Guelph's street tree population. As the urban forest expands, the City will need to ensure that adequate resources are available to continue the care and maintenance of all street trees, including the care and watering of newly planted trees.

Recommendation 23: Implement proactive maintenance and inspection programs to optimize the services delivered by street trees, including maintenance and watering of newly planted trees.

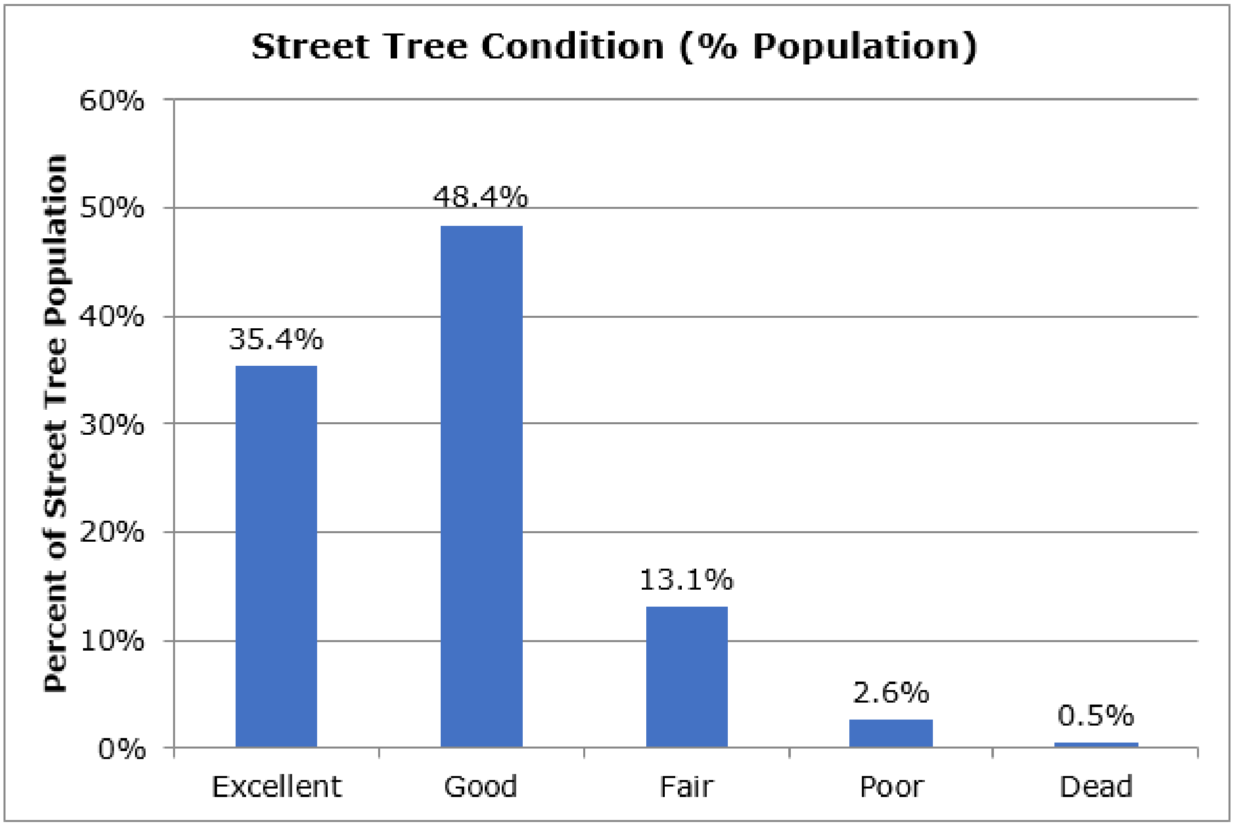


Figure 22: Street tree condition as per cent of population in 2019 (Source: i-Tree Eco analysis of Guelph street tree inventory)

ECOSYSTEM SERVICES – STREET TREES

Street trees provide annual ecosystem services with an approximate net value of $199,750. These include annual carbon sequestration, pollution removal, and avoided runoff.

Annual carbon sequestration by street trees totals 287.9 tonnes, with an associated value of $33,066. This represents about 4.5 per cent of the annual carbon sequestration performed by all of Guelph’s trees. Annual pollution removal by street trees totals 8.5 tonnes, with an associated value of about $105,820. This represents about 5.4 per cent of the total annual pollution removal performed by all of Guelph’s trees. Annual avoided runoff by street trees totals 26,184 m^3, with an associated value of $60,870. This represents about 6.5 per cent of the total annual avoided runoff performed by all of Guelph’s trees.

In terms of annual carbon sequestration, Norway maple is again the dominant species, sequestering 83.53 tonnes of carbon annually. When combined with Crimson King Norway maple, the total amount of carbon sequestered annually by this species is 97.2 tonnes (Figure 23). This combined amount is equivalent to 33.8 per cent of annual carbon sequestration performed by street trees. Sugar maple sequesters the second largest amount of carbon annually, at 42.63 tonnes, or 14.8 per cent of annual carbon sequestration by street trees.

While the maple species contribute substantially to carbon sequestration and storage, the City will need to balance those benefits with the advantages and resilience of a more diverse street tree population to ensure its sustainability in the future.

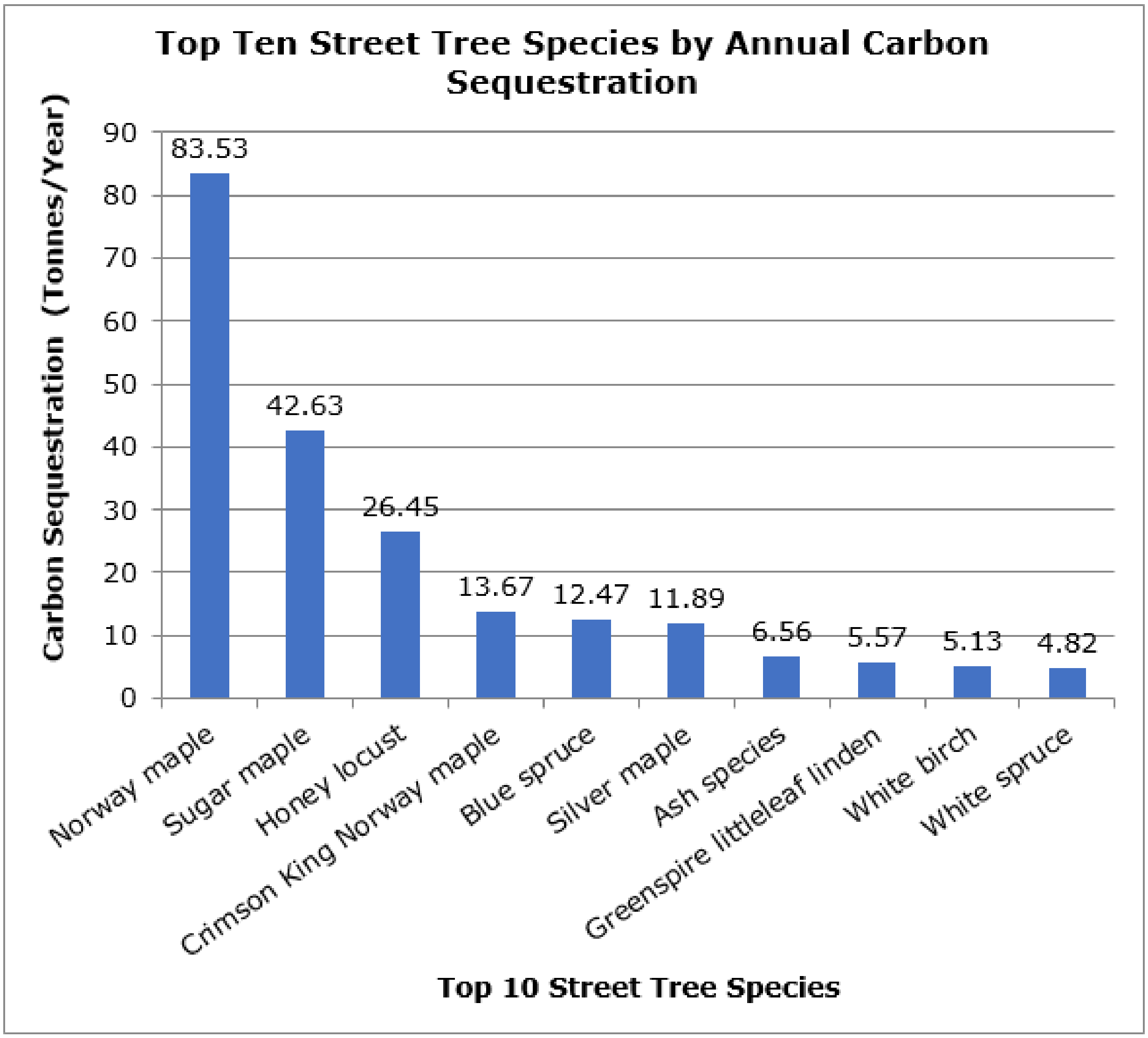


Figure 23: Top ten species of street trees by annual rates of carbon sequestration in 2019 (Source: i-Tree Eco analysis of Guelph street tree inventory)

CARBON STORAGE

Norway maple also dominates street trees in terms of total carbon storage, accounting for 30.6 per cent of the carbon stored by street trees. When combined with Crimson King Norway maple, the total for the species accounts for 34.9 per cent of carbon stored by street trees. Sugar maple stores the second largest amount, accounting for 17.6 per cent of carbon stored by street trees (Figure 24). Guelph's street trees store a total of 15,411.9 tonnes of carbon, which has an equivalent value of about $1,770,362.

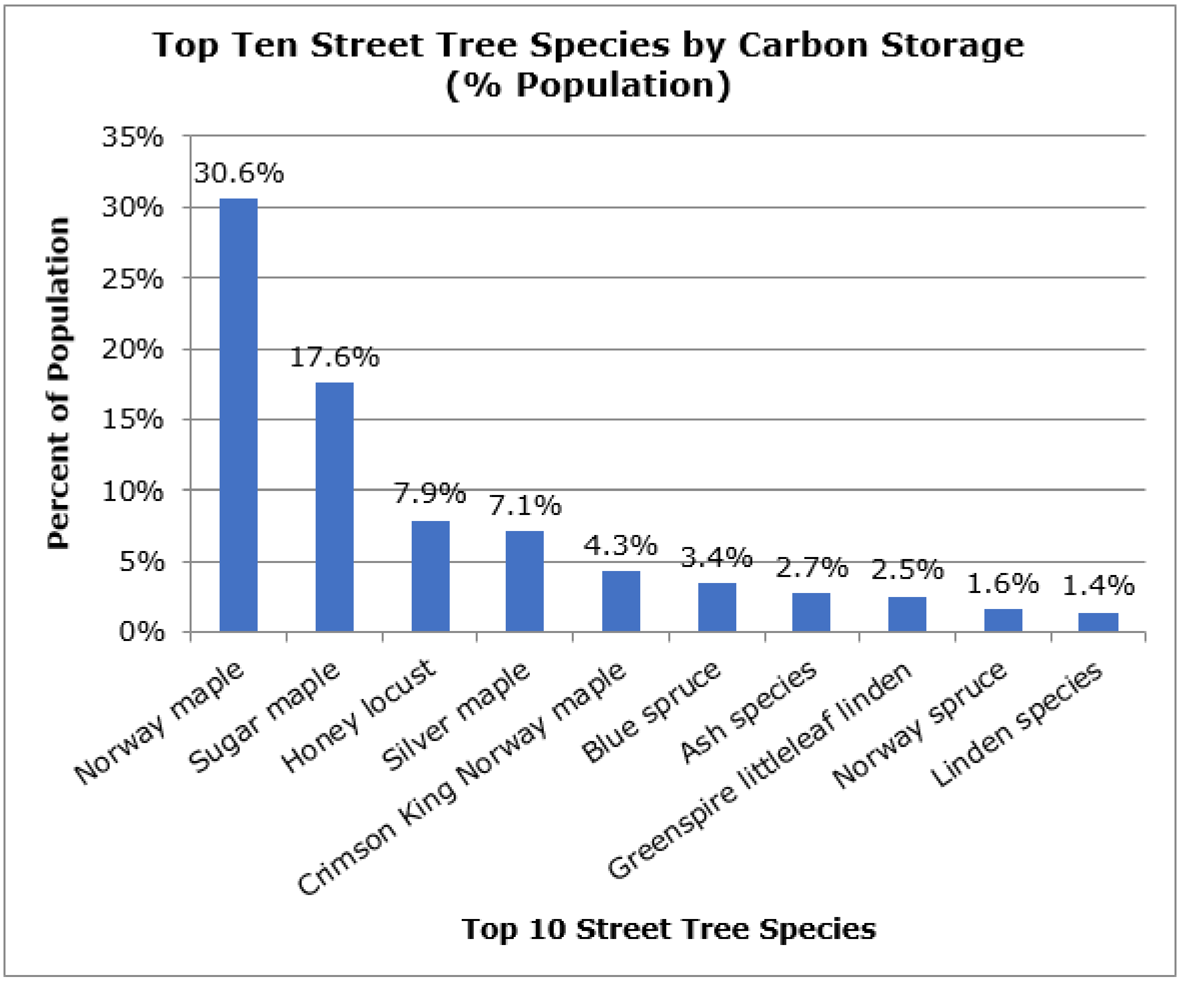


Figure 24: Top ten species of street trees by total carbon storage in 2019 (Source: i-Tree Eco analysis of Guelph street tree inventory)

FOREST HEALTH THREATS TO STREET TREES

The most significant pest threat to Guelph's street trees is Asian longhorned beetle (ALHB). This is primarily due to the dominance of maples in Guelph's street tree population, although other genera, such as birch (*Betula* spp.) and poplar (*Populus* spp.) are susceptible as well. About 49 per cent of Guelph's street trees (a total of 21,328 trees) are susceptible to infestation by ALHB. The structural value of these trees is about $64.3 million (Figure 25). The most recent infestation of ALHB was discovered in Mississauga, Ontario in 2013. Eradication and quarantine efforts are currently in place to control its spread and prevent another potential outbreak.[42]

Only about 2.8 per cent of Guelph's street trees are susceptible to emerald ash borer (EAB) – a total of 1,229 trees. EAB has reduced the ash population on Guelph's streets, with about 2,400 individual street and park trees removed under the EAB program, although it is unknown what this represents in terms of canopy cover lost. The remaining ash planted on Guelph's streets has a structural value of about $2.8 million.

About 13.2 per cent of Guelph's street trees are susceptible to gypsy moth – a total of 5,772 trees that span a range of genera. The structural value of these trees is about $9.1 million. However, it should be noted that it is unlikely that gypsy moth infestation will result in tree loss, except under extremely severe and prolonged defoliation scenarios.

[42] Forest Invasives Canada.

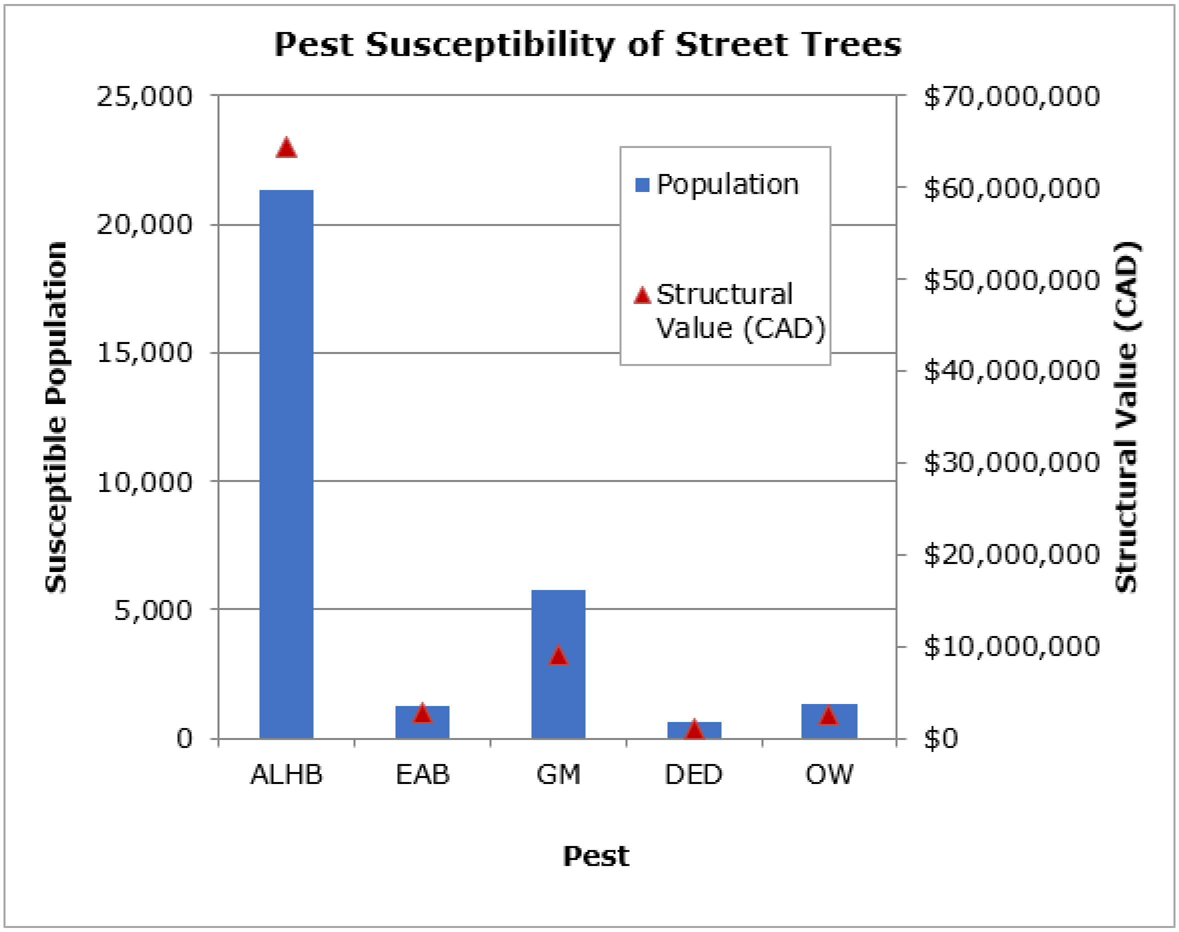


Figure 25: Susceptibility of Guelph's street trees to major pests in 2019 (Asian longhorned beetle (ALHB), emerald ash borer (EAB), gypsy moth (GM), Dutch elm disease (DED), and oak wilt (OW)) (Source: i-Tree Eco analysis of Guelph street tree inventory)

This analysis of Guelph's street tree population reveals several issues that should be addressed in the coming years. Guelph has a notable proportion of mature street trees, which deliver valuable ecosystem services and store carbon, but it will be important to plant sufficient numbers of new street trees to take the place of the mature trees once they senesce and die. This will help to ensure that Guelph maintains its street tree population and does not forego valuable benefits in the future. Guelph's street tree population contains a large amount of maples, with Norway maple dominating. Increasing species diversity in new street tree plantings will help to add resilience to the street tree population and decrease vulnerability to host-specific pests, such as Asian longhorned beetle. This could be accomplished in the context of Recommendation 22, where underplantings of diverse species could be implemented in areas that are dominated by mature specimens with low species diversity.

I-TREE STORM

Proactive management helps municipalities to develop tools and strategies to address issues before they arise. By using a knowledge-based approach to developing proactive management strategies, municipalities increase their operational efficiency and can more successfully minimize negative outcomes. Storm preparedness is an important component of proactive management, particularly in the event of severe storms and the effects of climate change.

In the event of a severe storm that affects the entire City of Guelph, the clean up of trees that fall into municipal roads could total as much as $9.7 million. The estimated clean up costs vary by ward but range from about $1.35 million for Ward 4 to $1.99 million for Ward 3. These costs include expenses related to tree removal, tree pruning, and brush removal from roads and sidewalks. The details for the methodology to develop these estimates are found in Appendix A. It is worth noting that the cost of storm clean up does not negate the values provided by the urban forest. The forest has a structural value estimated at $803 million dollars and provides ongoing goods and services to all residents that far outweigh the cost of storm clean up.

> Recommendation 24: Compare i-Tree Storm estimates to current expenditures and use the information to forecast future resource requirements.

The literature review revealed some management approaches to make the forest more resilient to storm events, including species selection, regular maintenance and increasing local structural diversity to mitigate the effects of extreme weather.

> Recommendation 25: Increase structural diversity in the forest through strategic planting and species mixes to improve resilience to extreme weather events.

Table 5 displays the breakdown of estimated potential hours and costs associated with clean up following a severe storm event in Guelph. Estimates reflect the costs associated with maximum potential damage from one severe storm.

Table 5: Pre-Storm estimates for major storm damage in Guelph's six wards. Costs are presented in Canadian dollars (Source: i-Tree Storm Pre-Storm analysis)

Estimate components	Ward 1	Ward 2	Ward 3	Ward 4	Ward 5	Ward 6
Removal Hours	8,030.61	8,726.56	12,286.37	6,656.81	11,221.65	7,457.44
Removal Cost	$619,610.43	$673,307.50	$947,968.17	$513,613.16	$865,818.91	$575,387.00
Pruning Hours	4,765.18	5,018.47	6,855.96	3,994.08	6,510.27	4,474.46
Pruning Cost	$367,662.88	$387,205.59	$528,979.08	$308,167.89	$502,307.16	$345,232.20
Brush cubic yards	22,668.86	23,312.97	26,014.64	26,590.48	29,014.80	26,873.74
Brush Cost	$449,779.01	$462,558.89	$516,163.47	$527,588.90	$575,690.38	$533,209.07
Total Cost	**$1,437,052.32**	**$1,523,071.98**	**$1,993,110.73**	**$1,349,369.95**	**$1,943,816.45**	**$1,453,828.27**

POTENTIAL CANOPY FEASIBILITY ANALYSIS

A key question the land cover data from the study helps to answer is whether it is feasible to achieve 40 per cent canopy cover in Guelph. In an approach developed by the USDA forest service (UTC assessment), land cover data is used to assess both existing canopy cover and potential future canopy cover. The measure of maximum potential canopy is determined by looking at existing plus potential canopy cover, where possible plantable area (PPA) is used as a proxy for potential canopy cover.

CURRENT CONDITIONS

Currently, at 23.3 per cent canopy cover Guelph is just over halfway to its overall canopy cover goal of 40 per cent. In order to understand where the planting opportunities are to increase and maximize canopy cover, potential planting area (PPA) is commonly used as a proxy for future canopy cover. PPA is determined by identifying all areas consisting of soil and non-canopy pervious land cover types (where trees could theoretically be planted) and removing areas with known land use constraints to get an estimate of potentially available planting area and use it to calculate maximum potential canopy for the City of Guelph. It is important to note that this estimate considers pervious land cover types only and does not include the potential for other types of planting in hard surfaces. Planting in hard surfaces can offer further opportunities to increase the amount of canopy cover in Guelph.

Figure 26 shows all properties in Guelph according to a per cent range of pervious potential plantable area (PPA), where PPA consists of all soil and non-canopy land cover types (minus areas with known land use constraints).

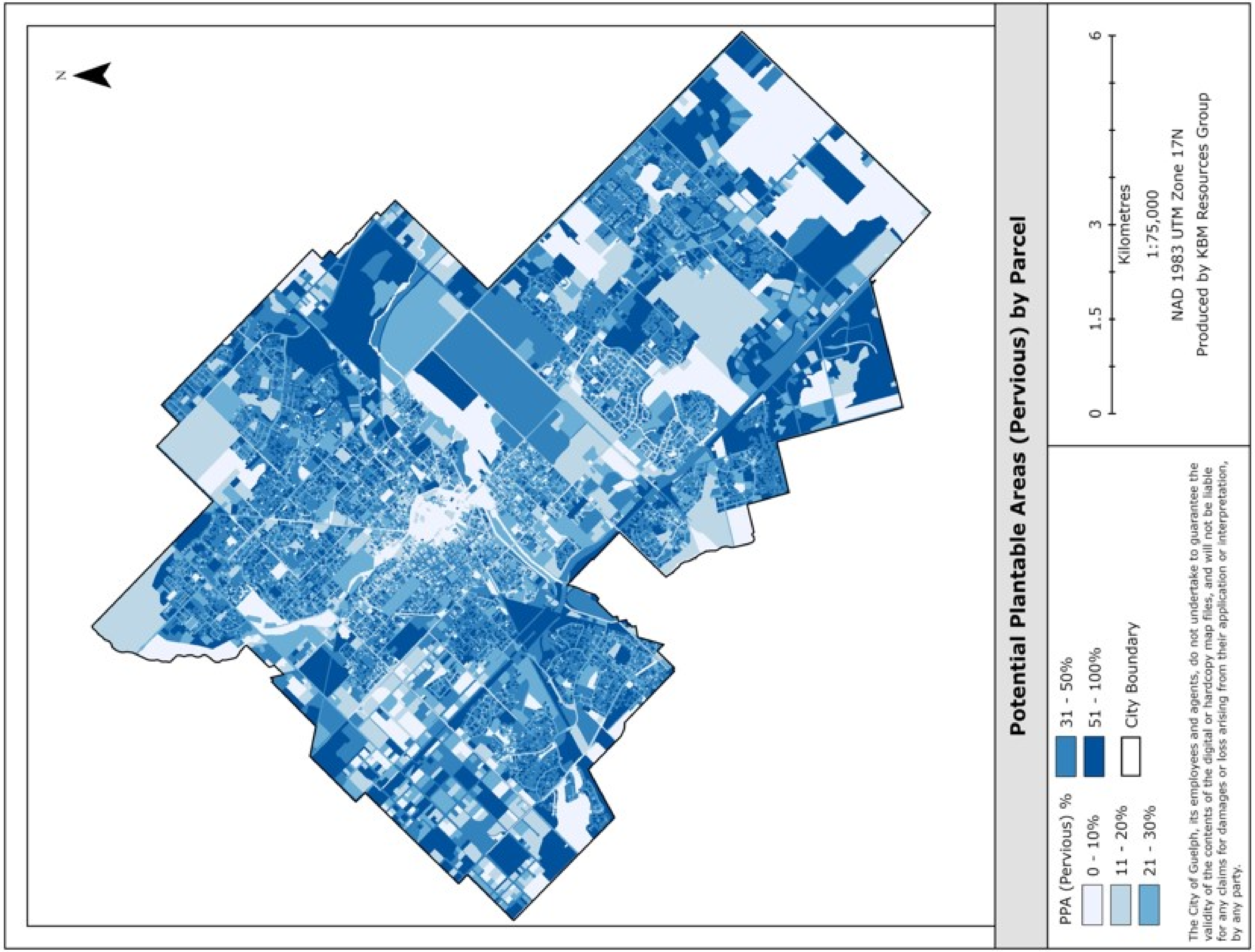


Figure 26: Potential plantable areas (pervious) by parcel (Source: 2019 land cover and parcel data)

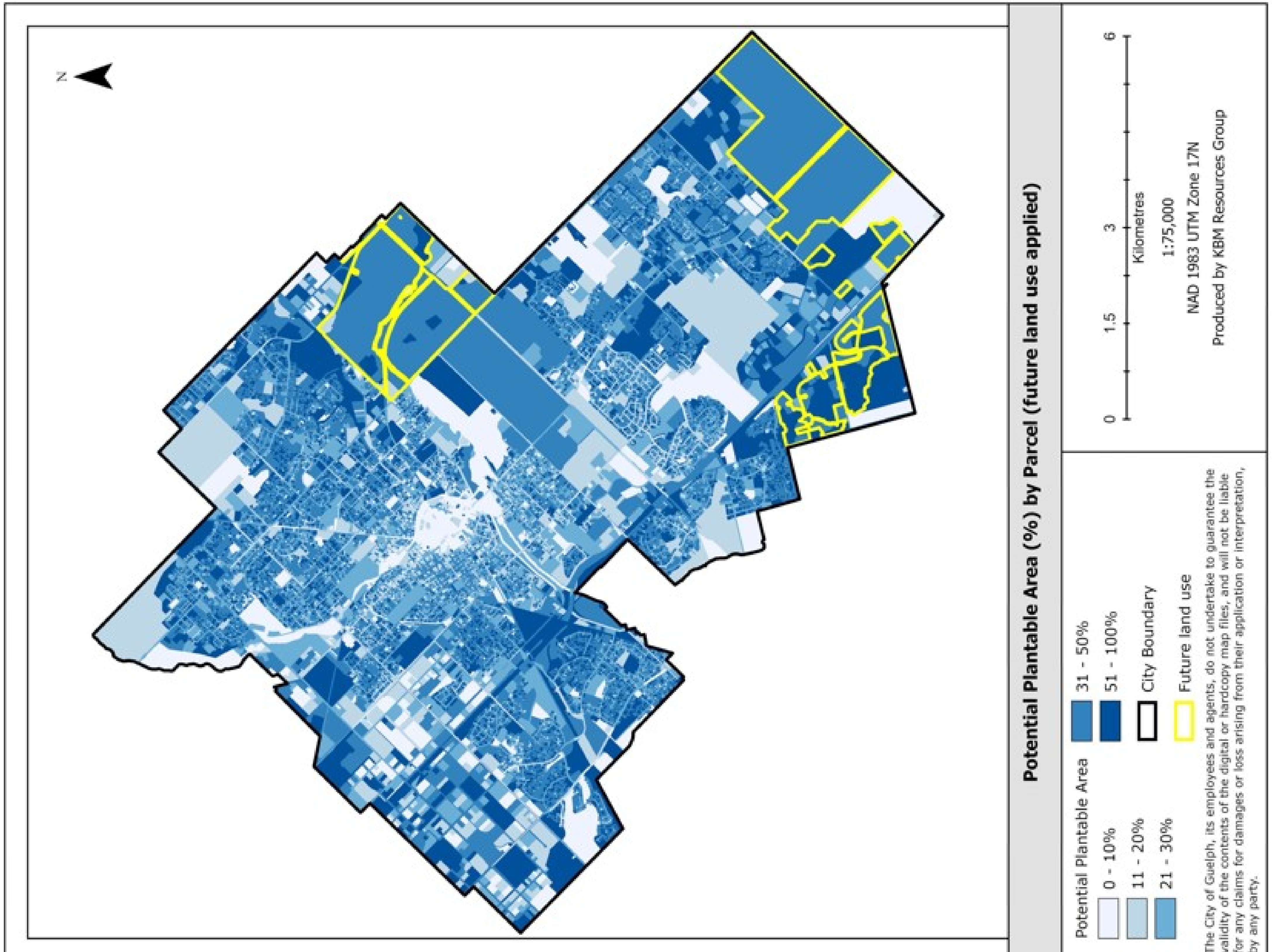


Figure 27: Potential plantable area by parcel, with future land use applied (Source: 2019 land cover and land use data, City of Guelph).

Recognizing that there are known future land uses in some areas of Guelph, a second map looked at PPA by land use, applying known future land use areas and averaging the PPA in these areas from similar land uses across the City. This provides a more realistic picture of PPA in Guelph, based on known and impending land use change (Figure 27).

Figure 28 shows areas where trees could be planted in hard surfaces. These areas consist of all land cover in the "Other Impervious" class which can include parking lots, schoolyards, courtyards and other impervious land cover that is not occupied by buildings, roads or other transportation infrastructure. Some municipalities have developed or are developing guidelines for greening surface parking, in an effort to capitalize on opportunities to add canopy cover in areas that have traditionally not supported trees. Toronto has developed a best practices manual for planting in hard surfaces, which provide specifications for different types of hard surface planting conditions.

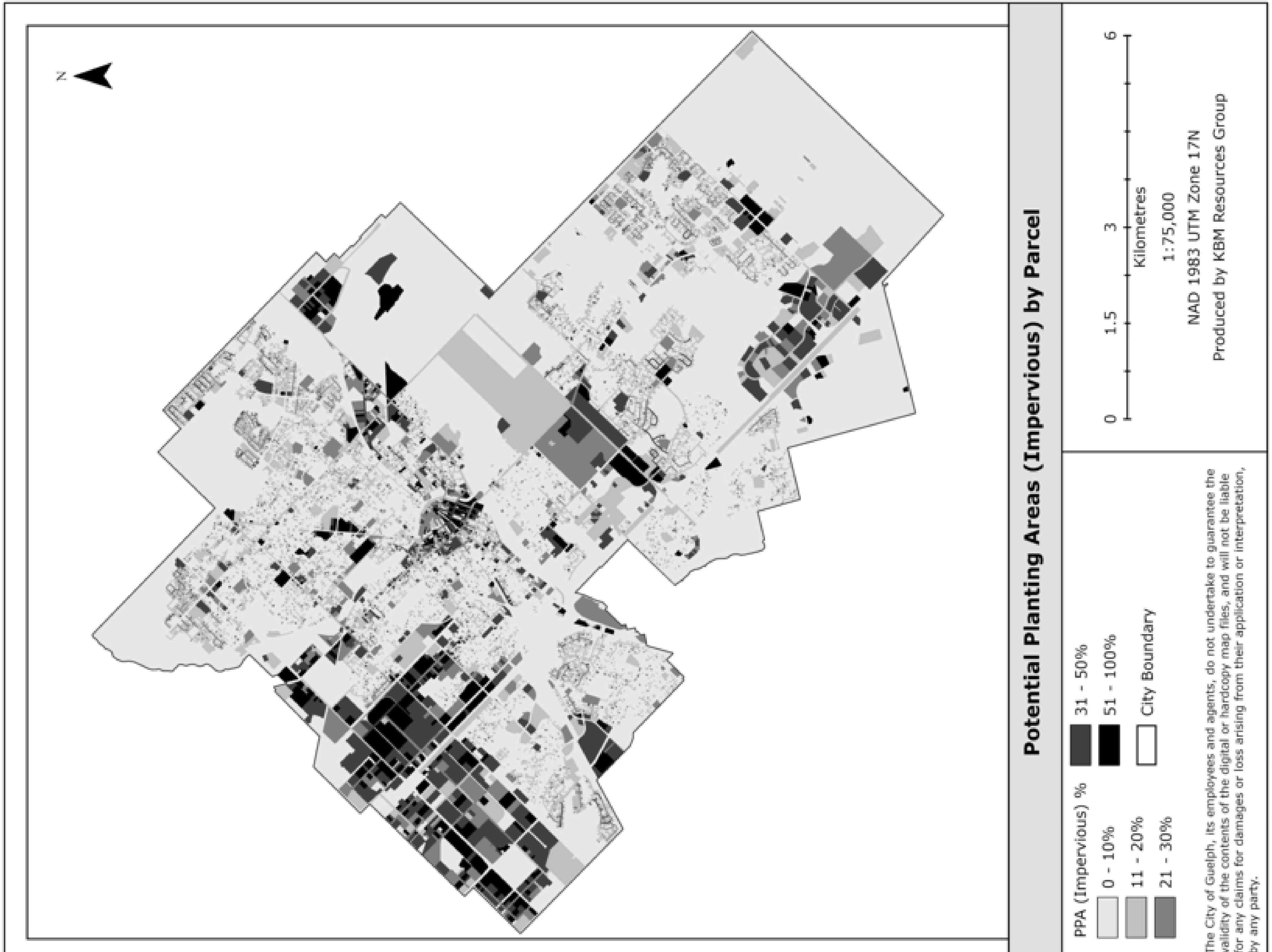


Figure 28: Potential plantable areas (impervious) by parcel – current conditions (Source: 2019 land cover and parcel data)

POTENTIAL CANOPY COVER

Maximum potential canopy cover is calculated by adding existing canopy and potential planting area (aka potential canopy cover) to determine the maximum level of canopy that can be achieved assuming full stocking and canopy closure.

The data show that under a completely optimal planting scenario where all available area in the City is planted, Guelph could achieve a maximum total canopy cover of 57 per cent. Table 6 shows the breakdown of maximum potential canopy cover by land ownership in Guelph. The data demonstrate that the most canopy gains to be made would be in private land ownership. These are lands over which the City has some, but limited jurisdiction, through existing regulatory and policy tools when it comes to urban forestry (e.g. Planning Act, Site Plan and Urban Design Guidelines, etc.).

Table 6: Maximum potential compared to current canopy cover by land ownership in hectares and per cent (Source: 2019 land cover data)

Land Ownership	Pervious PPA (ha)	Existing canopy (ha)	Maximum potential canopy (ha)
City Of Guelph	776	534	1,310
Government Of Canada	0	0	0
Grand River Conservation Authority	75	322	397
Private	1,812	995	2,807
Province Of Ontario	165	71	236
School Board	51	14	65
University Of Guelph	126	118	244
Total	**3,005**	**2,055**	**5,060**

At a high level, it seems that achieving the 40 per cent canopy cover goal under optimal planting scenarios is theoretically feasible (e.g. 57 per cent maximum canopy cover at full stocking of all available lands and ownerships). However, the data do not shed light on how reasonable these targets are given that achieving 100 per cent stocking on every property is unlikely.

Figure 29 shows maximum potential canopy cover by parcel, giving an indication of where canopy cover could be maximized across the City. It is clear from the map that certain areas of the City have higher canopy potential than others.

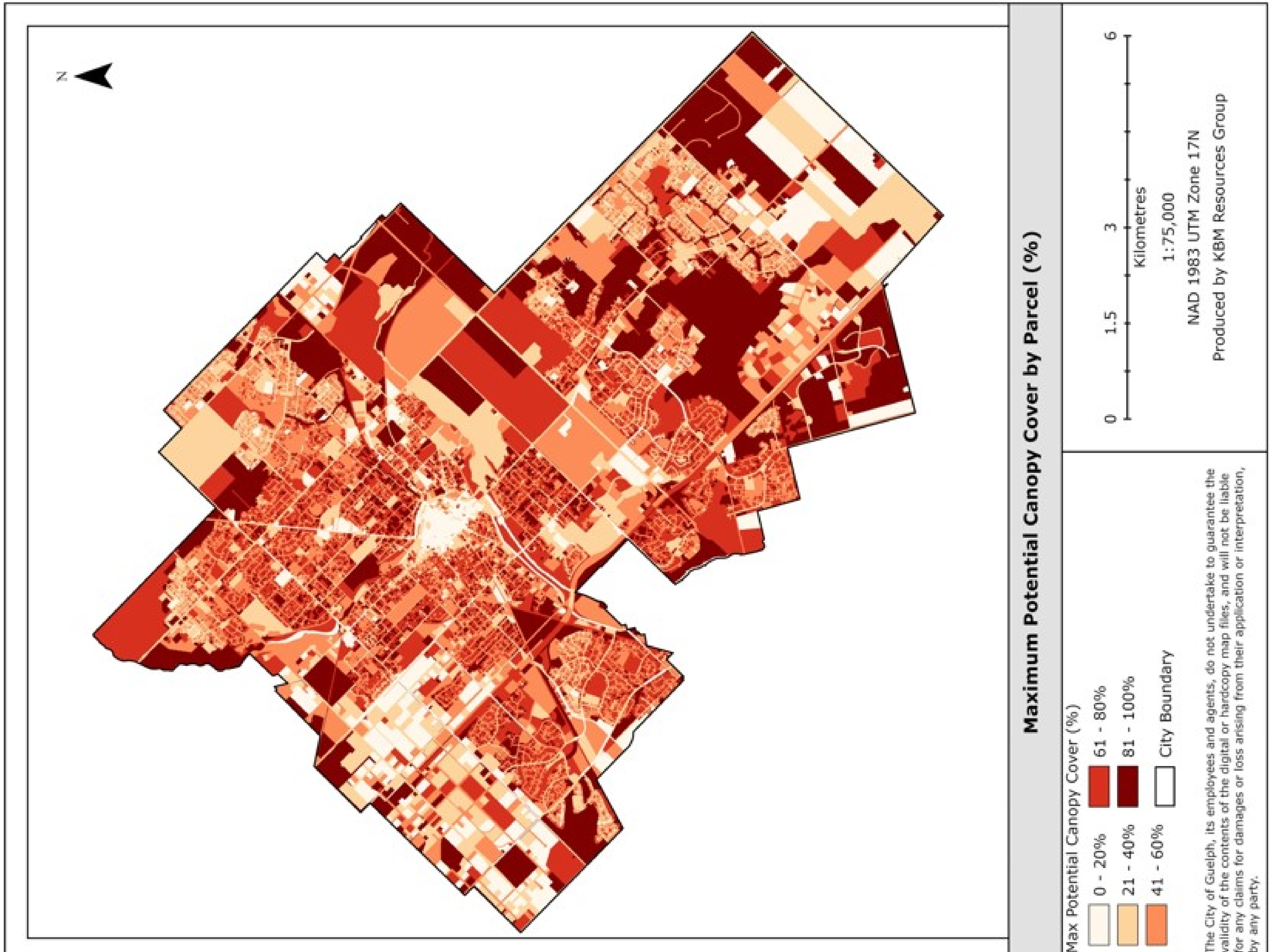


Figure 29: Maximum potential canopy cover by parcel (Source: 2019 land cover and parcel data)

In terms of the contributions the City can make to the overall canopy goal, the data show that City of Guelph lands would contribute about a maximum of 15 per cent to the overall 40 per cent goal, assuming all pervious PPA areas, including rights-of-way, were fully planted.

If all public lands had maximum canopy cover, it would contribute 22 per cent toward the overall 40 per cent canopy goal. It is clear from the data that private land in Guelph has an important role to play in supporting goal achievement (Table 7).

Table 7: Maximum contribution of each land ownership type to City 40 per cent canopy cover goal (Source: PPA and canopy cover as calculated from 2019 land cover).

Land Ownership	Contribution to 40% Goal
City Of Guelph	15
Government Of Canada	0
Grand River Conservation Authority	4
Private	32
Province Of Ontario	3
School Board	1
University Of Guelph	3

The results highlight the importance of private lands for increasing canopy cover, as even full stocking of all public lands in Guelph would achieve a maximum of 22 per cent canopy cover. With full stocking of all public lands and 50 per cent achievement on private lands, this would bring the City to 38 per cent canopy cover, still falling somewhat short of the overall 40 per cent goal. This may suggest that adjusting the canopy cover goal to 35 per cent may provide a more reasonable goal for the City of Guelph under a business as usual scenario. On the other hand, the data do not suggest conclusively at this point that 40 per cent is unachievable.

It is important to note that this assessment does not consider additional canopy cover gains related to:

- The growth of existing trees;
- The fact that tree canopies can extend well beyond the physical soil area in which they are planted (pervious PPA, which is being used as a proxy for potential canopy cover); and
- Increasing tree planting in hard surfaces, which will be important in future efforts to contribute to livability and climate resilience in Guelph.

The study results suggest that 40 per cent is an ambitious but feasible goal for the City at this point in time if expansion of trees and woodlands for the benefits they provide is a high priority under the new Strategic Plan. In terms of how many trees would be required to meet 40 per cent canopy cover, the following (high level) estimates are provided. Again, these estimates do not account for many factors that influence tree growth, including mortality rates, the mix of species and crown area, the site conditions, or the time it takes trees to reach mature size.

The numbers in Table 8 merely indicate how many trees (small, medium or large stature with a defined crown size at maturity) would be needed to fill the area required (1,492 ha) to meet a 40 per cent target, assuming that there is no change to existing canopy cover.

Table 8: High level estimates of number of trees required to meet land area requirement for 40 per cent canopy cover.

Tree Size	Crown Diameter (m)	Crown Size (m2)	# Trees to Reach 40% Canopy Cover*	# of Trees Per Year for 50 Years
Small Stature	3	7	2,131,429	42,628
Medium Stature	10	78.5	190,064	3,801
Large Stature	14	154	96,883	1,938

*Area of additional canopy required to reach 40 per cent potential canopy cover is 1,492 ha or 14,920,000 m^2

FEASIBILITY OF TIMELINE

A second factor of interest for Guelph is the timeframe in which canopy cover targets can be achieved. Guelph's Official Plan sets a target of achieving 40 per cent canopy cover by 2031, which requires almost doubling the current canopy from its present level at 23.3 per cent in 11 years.

Based on recent examples from other cities, it is unlikely that Guelph can achieve 40 per cent canopy cover by 2031. Other cities have set longer time horizons to meet similar canopy targets, with Oakville aiming for 40 per cent by the year 2051 and starting at a slightly higher baseline level of canopy cover in 2005, at 26.5 per cent. A 2015 study[43] for the Town of Oakville reported that canopy increased by 1.3 percentage points over the 10 year period between 2005 and 2015.

Similarly, Toronto aims to achieve 40 per cent canopy by the year 2054, with a starting point of 26.6 per cent [44]. A 2013 study[45] for Toronto showed the same rate of canopy increase (1.3 percentage points) for the 10-year period between 1999 and 2009. The most recent update for Toronto suggests that canopy cover increased by 1.8 percentage points for the 2008-2018 period (from 26.6 per cent to 28.4 per cent).[46] These increases are positive findings, in light of the stress on the urban forest resource over that time period. These have included a severe ice storm, thousands of tree removals from emerald ash borer and ongoing urban development. What is not clear is whether invasive species have a role in that expansion of canopy cover, which is identified as an area of investigation in future studies.

In terms of what is a realistic rate of growth to expect, both Toronto and Oakville have made substantial investments in policy changes and programs that enhance the protection and growth of the urban tree canopy by implementing recommendations and action plans outlined in both canopy studies and subsequent forest management plans. Some of these actions have included:

- Developing, implementing and improving comprehensive public and private tree by-laws;
- Development of a city-wide tree planting strategy and hiring supporting staff (Toronto);
- Outreach and incentives for tree planting on private property (Oakville and Toronto);
- Active invasive species and natural areas management (Toronto and Oakville);
- Detailed planting specifications for implementation across all City departments (Toronto, Oakville);
- Development of a Best Practices Manual for Tree Planting Solutions in Hard Boulevard Surfaces (Toronto); and
- Requirements for separate canopy cover plans in developments under site plan control, with canopy targets by land use (Oakville);

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[43] Growing Livability: A Comprehensive Study of Oakville's Urban Forest. 2016. https://www.oakville.ca/assets/general%20-%20culture%20recreation/itree-growing-livability-report.pdf

[44] Toronto's Parks and Recreation 2004 "Our Common Ground" report set a 40% canopy target to achieve in 50 years.

[45] Assessing Urban Forest Effects and Values: Toronto's Urban Forest. 2013.

[46] City of Toronto. Tree Canopy Study. 2019.

These are just some of the improvements that have been made to support canopy cover growth and a healthy urban forest – more details can be found in the available study reports for Toronto and Oakville.

Relatively few cities in Ontario have completed a re-assessment of baseline studies, so it is difficult to comment on broader trends in canopy cover in Ontario municipalities.

Because canopy cover change assessment was not within the scope of this study, it is not possible to comment on rates of gain or loss in Guelph's urban forest and how it compares to other cities. Without baseline data to compare against, it is also not possible to comment at this time on whether the current approach to management is supporting progress toward the City's forestry goals. This highlights the importance of ongoing monitoring, which helps identify what is working as well as program gaps.

SUMMARY

Looking at planting opportunities by land use, the most opportunity in terms of available area for increasing canopy cover is in the Residential land use, followed by Vacant land (which includes parks and open space in the City). There is also an opportunity to increase canopy cover in city rights-of-way, which are captured in the Transportation land use. Figure 30 shows the relative canopy cover by parcel, with light areas representing properties where canopy cover is low relative to the maximum potential cover.

Figure 30: Relative canopy cover by parcel (Source: 2019 land cover and land use data).

In reality, substantially increasing canopy cover in an urban area has many challenges and is not a short-term undertaking. It requires that many pieces fall in place across all City departments. Planting more trees is only one of many factors that go into growing a sustainable urban canopy. Protection and maintenance of the existing resource have a large part to play. There are systemic policy barriers to be addressed (land tenure, zoning, site plan review processes, protection of private trees) as well as logistical challenges to solve practical conflicts between trees and other infrastructure. Staff need appropriate tools to be able to take a city-wide target and implement it at a site level in both private and City infrastructure and development projects.

Real considerations and challenges include tree mortality, loss of trees to pests, diseases and storm events, climate change effects, the need to accommodate ongoing development, and associated servicing, and resource constraints that limit the proactive management of the existing urban forest.

Monitoring canopy growth is a key part of the feedback loops required to gain a level of confidence in the ability of Guelph to meet a 40 per cent canopy cover target.

Effective urban forest management and canopy growth requires an ongoing commitment to managing trees in all phases of their life cycle, as well as strategic planning to bolster the resilience of the overall urban forest against the numerous stressors it may be subjected to. While canopy targets provide a measurable objective for cities, the next phase of the UFMP should steadily move the City forward in support of a truly sustainable urban forest.

Recommendations:

26. Extend the time horizon for achieving 40 per cent canopy to 50 years, consistent with other city strategies.
27. Use criteria and indicators to assess progress toward sustainable urban forest management goals as defined in the next Urban Forest Management Plan.

DEVELOPING A PLANTING PRIORITY INDEX

A main aspect of the City’s forestry work is to undertake replacement planting for trees that are removed as well as plant additional trees in support of the City’s canopy cover goal of 40 per cent. One of the challenges faced by all municipalities is accessing detailed information about potential planting sites in Guelph to support operational planning and budgeting for tree planting in the city.

In light of the City's strategic goals, including climate resiliency and building healthy communities, it is also important to understand where to focus tree planting efforts for optimal results. For this reason, completing a tree planting priority mapping was included in the scope of this study.

The approach used a GIS tool (the Tree Planting Prioritization Tool or TPPT) developed by the Region of Peel, that prioritizes tree planting locations based on eight "Overall Benefits" (further divided into 12 Target Benefits) that urban trees provide as described in the literature. These include:

1. Mitigating Air Pollution
2. Mitigating Urban Heat Island Effect
3. Contributing to Management of Surface Water Quantity and Quality
4. Maintaining and Enhancing Natural Heritage
5. Enhancing Economic Value
6. Providing Direct Cost Savings (reduced energy use)
7. Supporting Improved Physical Health and Emotional Wellbeing
8. Strengthening Communities and Enhancing Social Equity

The framework developed for the TPPT consists of five nested components, as shown in Figure 31. Tier 1 (Sustainability Theme) consists of three components, including criteria for Environmental, Economic and Social Sustainability. Each of these themes includes at least two Overall Benefits to help identify tree planting priority areas related to that theme.

Tier 2 (Overall Benefits) refers to the category of urban forest benefits (or function) that relates to one of the three Sustainability Themes an reflects a priority within the City of Guelph that can be addressed, at least in part, by tree planting. Examples are mitigating heat island effect, stormwater runoff, etc.

Tier 3 (Target Benefits) describes the specific benefits being targeted through the TPPT as identified through scientific, technical and practical considerations such as data availability, as week as input from consultations.

Tier 4 (Opportunity Zones) are areas of geographic space related to each Target Benefit based on defined parameters.

Tier 5 (Opportunity Zone Categories) sub-divides Opportunity Zones into two or three sub-categories (primary, secondary, tertiary) where relevant. The categories divide the Target Benefit into 'sub-zones' that define where the most benefits are achieved through planting (e.g., primary zone for air pollution mitigation is 0-133m from provincial highways, secondary zone is 334-500m from provincial highways, etc.) While tree planting anywhere in Guelph will create overall benefits, the TPPT allows for prioritizing areas based on themes of interest to the City and residents of Guelph.

Further detail on "Target Benefits" for Guelph and the "Opportunity Zones" that help prioritize tree planting locations are found in Appendix G.

Figure 31: Diagram of the nested TPPT framework.

A stakeholder survey (with respondents including forest practitioners, local experts, planners, developers and municipal staff and Council) identified the top two highest priorities for tree planting as follows:

1. Areas within or adjacent to the Natural Heritage System, to support NHS function and biodiversity;
2. Areas with low canopy cover within the city (defined as parcels with canopy cover of less than or equal to 23.3 per cent)

Other priorities identified had relatively equal or lower weighting by survey respondents. Other valuable comments from stakeholders to inform future tree planting strategies highlighted the following issues:

- The critical importance of planting the "right tree on the right site" to ensure planting success;
- The importance of preserving existing canopy as well as planting new trees;

- The challenges associated with maintenance of newly planted trees (identified as the main challenges for successful planting outcomes by all stakeholders);
- The need to consider/reduce potential conflicts between trees and other infrastructure;
- A suggestion to use incentives instead of new regulatory approaches to encourage tree planting;
- The need to develop processes that 'force' consideration for trees earlier in the planning process;
- Using more non-native, non-invasive trees as well as native species in planting (in light of climate change and other pressures on trees);
- Increasing the use of evergreens for screening/aesthetics and fencing (which has been well-received in new developments);
- Using smaller stock to get more trees in the ground at less cost than caliper trees.

Running the TPPT to produce priority planting indices does not support a weighting function in terms of assigning higher priorities within the list of 12 Target Benefits. However, it does allow users to turn layers on or off to highlight areas of interest that have been identified as high priority by stakeholders in Guelph. The model also produces individual benefit maps that show the priority areas for each benefit identified in the analysis, if a particular benefit is of interest (Appendix I).

HOW THE MODEL WORKS

The TPPT uses a variety of data inputs to produce two key maps that highlight priority areas for increasing canopy cover based on an assigned benefit score. The model takes the 12 defined benefits, and essentially overlaps the data layers to rank priority areas based on where the most benefits from increasing canopy cover would be achieved. Inputs include defined criteria and opportunity zones, where the level of priority may change. For example, air pollution mitigation inputs include major trucking routes and roads in Guelph, with 'opportunity zones' prioritized based on the distance from the identified source of pollution (roads). In the example of a target benefit with opportunity zone presented in Table 9, the priority decreases with distance from the road.

Table 9: Example of a target benefit with opportunity zone.

Overall Benefit	Target Benefit	Opportunity Zones
Mitigating Air Pollution	Air Pollution Mitigation Near High Traffic Roads	Primary Zone 0-333m from provincial highways, 0-67m from major roads, 68-133m from major roads that are truck routes Secondary Zone 334-500m from provincial highways, 68-133m from major roads, 134-200m from major roads that are truck routes Tertiary Zone 134-200m from major roads, 0-200m from other truck routes

OVERALL BENEFIT AND PRIORITY PLANTING AREAS

The TPPT produced the following map products:

1. An overall canopy cover benefit map for Guelph
    - This map shows areas where adding canopy cover would optimize outcomes for the twelve defined target benefits. This map does not consider the availability of planting space in identifying priority areas but rather describes where the most benefit could be achieved by adding canopy cover. For example, it identifies areas with extensive impervious (paved) surfaces as a high priority due to high surface temperatures that could be mitigated by canopy cover. This can include land uses like parking lots and commercial areas.
2. A planting score map for Guelph (Figure 32)
    - This map shows areas where the City could actually plant trees to optimize the twelve target benefits. These areas are identified by including consideration for potential planting area (PPA), which is defined as areas of available pervious land cover (soil and non-canopy vegetation) that exclude known land use constraints like sports fields, railway beds, etc.). It assumes that pervious areas without known land use constraints would be available for planting and includes both public and private lands.

Figure 33 is the overall benefit map, which identifies the highest priority areas for increasing canopy cover in Guelph, without considering whether or not there is available planting area. The planting locations are refined in the planting score map (Figure 32), which adds data to describe where trees could be planted, and produces a priority ranking for actual potential planting locations. The highest priority areas are those where the most criteria intersect. These maps can be used by City staff to develop a more comprehensive tree planting strategy for the City, based on which benefits are of the most interest to the City and its residents.

Three things are important to note about these maps and their purpose:

1. The maps provide a high-level view. Best efforts were made to screen out unsuitable areas with incompatible land uses, but there will be other factors identified at the site level which may exclude further areas that are identified as plantable in the map.
2. Priority mapping highlights potential areas of new canopy only to support canopy targets. It excludes ecological restoration areas with existing canopy. However, these results do not suggest that identified areas on the map are the only opportunities for tree planting.
3. An area that is identified as high priority in the map does not mean it is scheduled for planting. The City will not infringe on private property based on this study but rather look at current policies and how they can be more effective in achieving canopy cover targets, protecting natural heritage and guiding the city in planning and designing sustainably (refer to Sustaining our future in the Strategic Plan).

These maps will be used as inputs to the development of a comprehensive tree planting strategy for the City of Guelph. A full set of maps showing priority scores for each of 12 Target Benefits separately is included in Appendix H. Based on the prioritization analysis, feedback from stakeholders, key findings from the literature review as well as a scan of the background information the findings lead to the following recommendations.

Recommendations:

28. Use planting priority maps to inform tactical and operational planning for City of Guelph tree planting programs. Share the maps with other agencies, departments and groups planting trees in the City of Guelph.

29. Use criteria in Tree Technical Manual to evaluate and prioritize high quality planting sites in ROWs and other public lands.

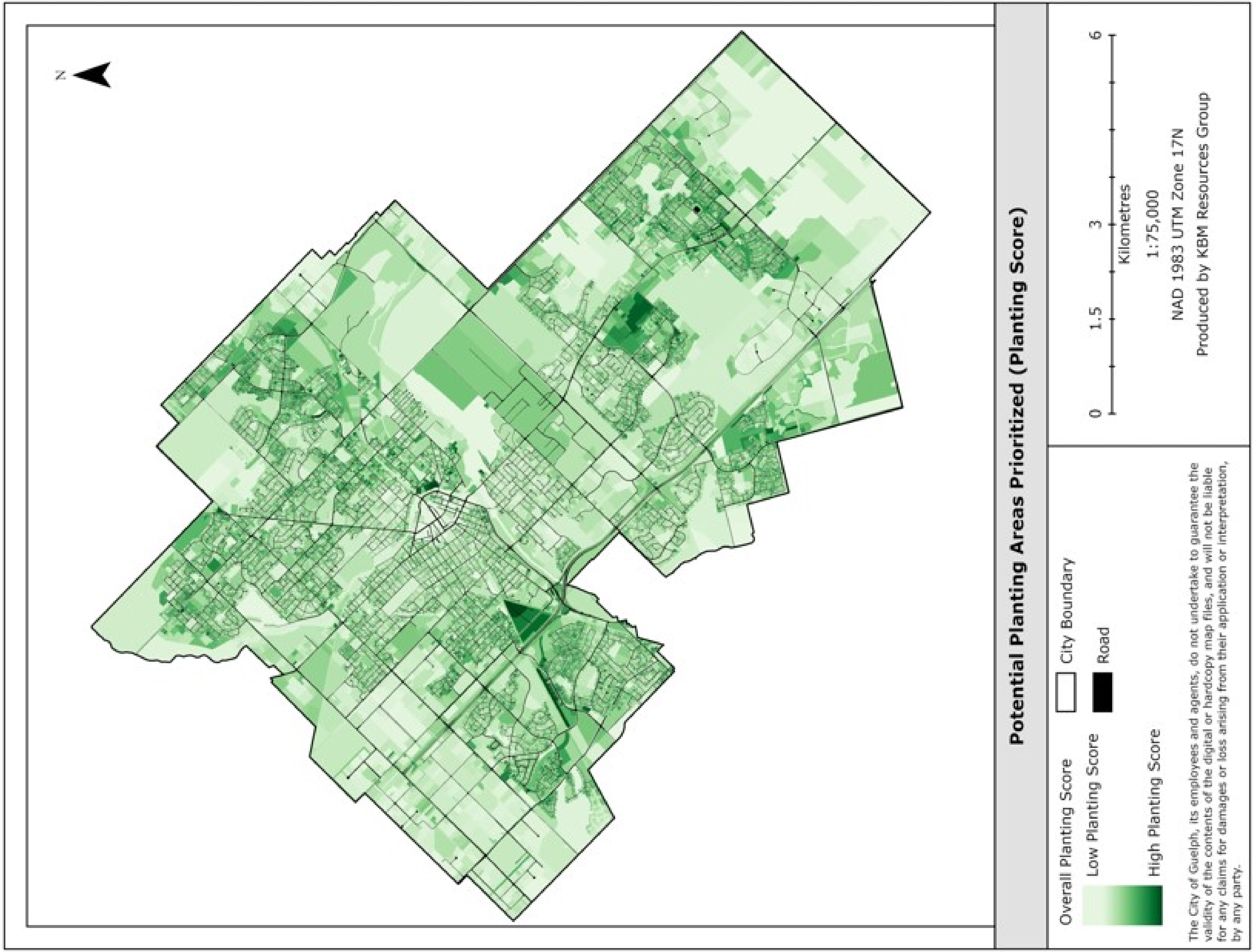


Figure 32: Planting score map – priority planting locations based on available pervious plantable area (Source: 2019 TPPT output)

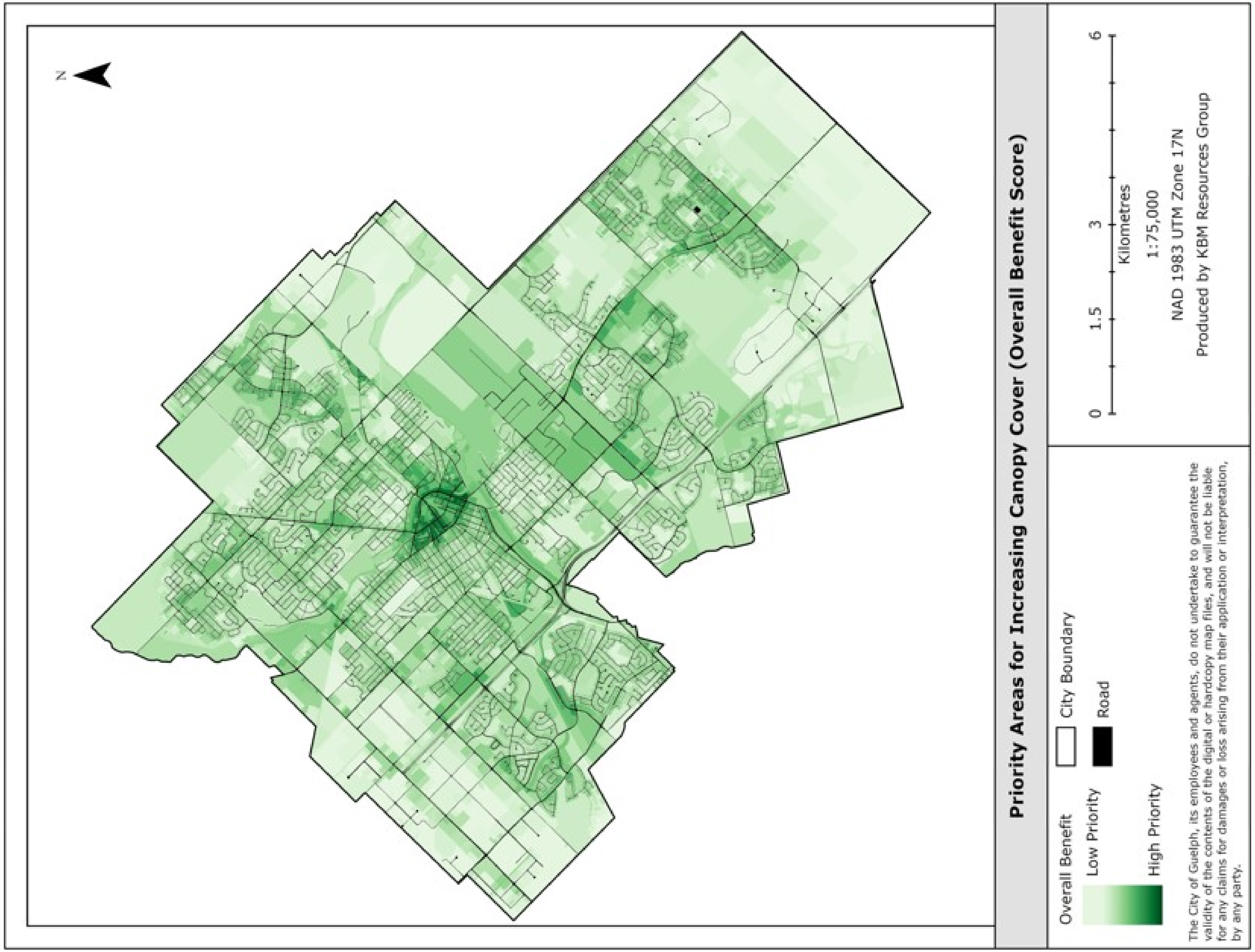


Figure 33: Overall benefit score - priority locations for maximizing the twelve target benefits (Source: TPPT output, 2019)

Threats to the Urban Forest Resource

Table 10 describes current threats to the Guelph's urban forest, as well as emerging threats based on an environmental scan. The current forest management program and other City initiatives include some measures to mitigate some of the threats, which are also identified here. The next forest management plan for the City of Guelph should use the information in this study in conjunction with a review of progress made since the last plan to inform specific actions to address identified threats and issues.

Table 10: Current and emerging threats to Guelph's urban forest.

Threat	Current Mitigation Measures in Effect
Climate Change	The Strategic plan speaks to the role of trees and forests in adapting to climate change and mitigating the effects of climate change to achieve net zero carbon by 2050. Some strategies to mitigate the effects of climate change on the urban forest are integrated into forestry operations like matching species to site, testing new tree species in planting and watering newly planted trees. The City has extreme weather response plans.
Tree Removal/Canopy Loss	Guelph's Private tree by-law prohibits damage or destruction of any tree measuring at least 10 centimetres in diameter at 1.4 metres above the ground on lots larger than 0.2 hectares (0.5 acres) without permission from the City. Trees removed under by-law allows the City to ask for $500 per tree when replacement trees not achievable on subject land. Removal of trees greater than or equal to 20 cm DBH in the City's Brooklyn-College Hill Heritage conservation district require approval from the heritage committee.
Forest Pests and Pathogens	The 2013 UFMP included a recommendation to conduct proactive forest health monitoring. The City has been implementing an Emerald Ash Borer program to address hazards and canopy loss from EAB mortality.
Invasive Plant Species in Natural Areas	The City undertakes some active management in natural areas (e.g. tree removals to manage hazards along trails in recreational areas, treatments in select areas to control common buckthorn, etc.). There has been extensive ash dieback in some natural areas, which often leads to colonization by invasive species, like

Threat	Current Mitigation Measures in Effect
	buckthorn. This has implications for forest health and native biodiversity. The City's Natural Heritage Action Plan outlines a number of actions to address these issues over the longer term, including an invasive species strategy. Implementation is ongoing.
Loss and degradation of the soil resource (planting site quality)	The Tree Technical Manual includes standards for soil volume and quality. The City has installed Silvacells in select locations to provide quality growing conditions for trees in the downtown core.
Lack of funds for scale of tree planting required to meet 2031 canopy target	The City of Guelph has a tree planting program that is focused on replacing trees that are removed. Greening Guelph is a private donation program to supplement city funds for increasing the canopy in Guelph. The City collects cash-in-lieu through the tree by-law from tree removals as 'tree compensation funds' which is used to replace trees that are removed.
Lack of regulatory tools or incentives to require the integration of canopy cover in new and infill development	Guelph's Official Plan includes policies that encourage the protection of trees through development opportunities and require compensation for removals. Guelph's Urban Design Manual speaks generally to the integration of trees and greenspace in development, as well as planting more trees on public land to improve urban design. The Urban Design Action Plan Update recommended updating tree guidelines for rights-of-way to ensure they reflect current best practices for sustaining street trees through the Tree Technical Manual. The Natural Heritage Action Plan includes actions to improve integration of green infrastructure, create green development standards and increase use of LID.

Threat	Current Mitigation Measures in Effect
Shortfall in funding for adequate/proactive asset management	The Municipal Street Tree Maintenance Protocol lays out requirements for tree maintenance. Forestry responds to approximately 1,200 requests for service for tree issues and services an average 2200 trees yearly. Preventative maintenance programs consist of street tree pruning; tree inspections, tree preservation, and tree fertilization to ensure that the trees are safe are healthy. Inspections for reported tree concerns are completed within 10 to 15 business days. Approved work is prioritized. Due to an existing back log low priority work may take 18 months to complete.
Institutional Barriers	The City's internal "tree team", an inter-departmental committee, works collaboratively to solve complex policy barriers and find solutions to reduce conflict between trees and other infrastructure. The Ecosystem Restoration Implementation Committee was established as an action under the Natural Heritage Action Plan to provide oversight and support the mobilization of City-led restoration projects.
Managing Risk	Risk is managed proactively in some woodlands by removing dead ash and other trees near trails. Other proactive risk management is in the form of regular inspections of larger (i.e., over 60 cm DBH) trees, cabling, and follow-up on service calls related to potential tree risks. However, no formal risk management program is in place.
Stock Availability and Species/Genetic Diversity	Resilience in the urban forest is increased by maintaining species and genetic diversity in the urban forest. The Tree Technical Manual includes criteria for tree species and nursery stock quality.

Threat	Current Mitigation Measures in Effect
Land ownership – private land offers the most opportunity for expanding the City's canopy cover	The 2013 UFMP identified the need to provide support and incentives for tree protection, maintenance and planting on private lands. Further investments would be required to capitalize on private land tree planting opportunities.
Changing population demographics	The current UFMP or management program does not specifically include measures to address changing population demographics and their implications for urban forest management.
Failure to institutionalize best practices for urban forests into city planning and development, in both private sector and public works	Guelph has developed policy and strategic priorities for integrating the urban forest as a part of its vision for building healthy, sustainable communities. Examples include the Official Plan, the Strategic Plan and the City's Urban Design Guidelines that speak to the need to consider trees in City planning and design.
Reluctance to implement new/unfamiliar practices or practices that require greater upfront investments	The City of Guelph has supported efforts to use new techniques for planting trees in hard surfaces in the downtown core (e.g. Silvacells).

Conclusions

Community priorities outlined in the 2019 Guelph Strategic Plan set the tone for the next phase of management of the City's urban forest. Environmental quality was identified as the top priority by residents in terms of their vision for the future of the City. The urban forest has a significant role to play in supporting many aspects of community sustainability, including improved neighbourhoods and commercial areas, contributions to residents' physical and mental health, mitigation of climate change impacts including the urban heat island effect as well as supporting Guelph's grey infrastructure functions.

The City is starting at a baseline of 23.3 per cent canopy cover, with a forest that is showing the effects of past management and current threats and pressures. Land cover change from urbanization is contributing to a loss of natural cover in the region, including a loss of forest cover over the last several decades. Field surveys show a high proportion of invasive tree and shrub species found in the urban forest canopy and understory. Some remnant woodlands and private properties have a high proportion of dead standing trees, many of which are ash – an after-effect of the emerald ash borer, which has all but eliminated mature ash trees within the infested zone of the province.

The street tree population has a notable proportion of mature trees and is generally in good condition. However, the high proportion of maple species in the urban forest canopy makes the city's forest vulnerable to the threat of Asian longhorned beetle, which has been controlled in Ontario to date by intensive forest health monitoring, early detection and rapid response. There is room to improve on the retention of mature trees in Guelph, through improved regulations and incentives to protect loss of the existing tree canopy. New planting maps that are a product of this study will help inform a comprehensive tree planting strategy for the City, with an ultimate goal of achieving 40 per cent canopy cover on public and private lands. Mapping of significant trees (defined as those with canopy reaching over 20 m in height) can help inform outreach efforts to property owners in support of improved retention of large trees, which provide the City with the most social benefits and ecosystem services.

The 2013-2032 Forest Management Plan for Guelph laid out nine strategic goals for the City's urban forest. Table 11 identifies how the study findings link to the strategic priorities and can help inform the management activities in the next five-year plan.

Table 11: Links between UFMP strategic priorities and study findings.

2013 UFMP Strategic Priority	Relevant Study Findings
Improve knowledge of the City's urban forest assets through a more comprehensive inventory program.	The study has provided information about forest composition, condition, and structure that can help inform future management priorities. For example, the sample-based i-Tree and street tree analysis show a high proportion of maple in the population that make the forest vulnerable to Asian longhorned beetle. It also showed a high proportion of standing dead trees, suggesting a need for more active management to improve forest condition in some land uses. Finally, the proportion of large trees in Guelph is relatively low compared to the population of small trees, which matters because large trees provide proportionately more urban forest benefits. These and many other findings will help direct management activities in the next UFMP.
Monitor and review the status of the City's urban forest management every five years using established criteria and indicators, and revise planning and practices as required to ensure ongoing progress towards realizing the vision.	The study provides Guelph with baseline information, which can be used to assess progress on specific forest management objectives in future. The i-Tree Eco plots established for this study constitute a network of plots that may be reassessed in future studies, providing data to produce a statistical change analysis.
Foster a "tree friendly" culture among City staff through interdepartmental coordination on tree issues and sharing of ideas and best practices for tree protection, maintenance and planting.	Urban canopy and land cover mapping provide useful communication tools that can be shared between departments. The study findings highlight some policy issues that can be addressed through interdepartmental collaboration and contribute to multiple objectives in the City's Strategic Plan.
Foster a "tree friendly" culture in the community through exemplary programs and activities on municipal lands, sharing best practices and techniques, and providing support and incentives for tree protection, maintenance and planting on private lands.	The study findings show the important role of private lands for meeting the City's 40 per cent canopy goal, since more than half of the City's trees are found on private property and a majority of future planting opportunities are on private land, particularly in the Residential land use. Neighbourhood maps produced for the study provide a useful communication tool with residents.

2013 UFMP Strategic Priority	Relevant Study Findings
Prioritize protection of mature, healthy trees and preservation of older large-canopied species to the greatest extent possible.	The size class structure of the City's forest to be skewed toward trees in the smaller age classes. To some extent, this is a desirable state since it is required to achieve a sustainable population over time. However, large trees (over 61 cm) represent only 1 per cent of the tree population in Guelph, highlighting the need to explore options for improved retention of mature trees in Guelph.
Transition towards proactive tree establishment and replacement whereby all potential plantable spots in the City are explored.	There remains a considerable amount of City land that has been identified as potentially available for planting, including areas in ROWs. The rate of ash replacement has not kept pace with removals to date and presents an opportunity to increase canopy cover by proactive planting on City lands.
Explore the use of new technologies in selected areas for integration of trees in hardscapes such as downtown and parking lots.	The study findings highlight a considerable opportunity for increasing canopy cover in impervious surfaces, which has the benefit of mitigating heat island effect and creating a more pleasant living environment, as well as potentially increasing traffic in business areas. The City has implemented some hard surface planting (Silvacells) in the downtown core but should explore opportunities to expand the use of these techniques in areas with high levels of impervious land cover. Priority areas are identified in the study planting maps.
Move towards proactive tree risk assessment and Plant Health Care practices on municipal lands and reduce the need for emergency responses.	The tree condition ratings from the study support the need for proactive tree risk assessment, particularly in some land uses where the proportion of dead standing trees is unusually high.
Improve the resilience of the urban forest to current and anticipated stressors, including climate change, by implementing policies and management practices that optimize tree species diversity, structure and age classes.	The high proportion of maples in the street tree and overall tree population make the forest more susceptible to pests that target these species and varieties. Observed mortality in the street tree population in recent plantings suggest the need to improve site selection (e.g., managing soil quantity and quality) as well as species selection and young tree care to improve future planting outcomes in new neighbourhoods and business areas.

The observations in the table above link to specific recommendations that result from the detailed study findings.

The City has many areas of opportunity to build on past practices and the urban forest framework that is already in place. Across North America, “Million Tree” and similar initiatives have focused on tree planting goals to achieve specific sustainability objectives. The focus on tree planting sometimes detracts from other pervasive management challenges, such as ensuring a good return on the planting investment through survival and ongoing care of planted trees. A commitment to sustained funding for tree maintenance and care in addition to tree planting must be part of Guelph’s urban forest strategy moving forward. A good forest management program considers all components holistically and comprehensively as per the monitoring criteria identified in the UFMP, including resources, knowledge, community framework and optimal management approaches.

In some cities, planting targets have been lowered in favor of managing and sustaining the existing canopy in the face of future pressures from urban development, climate change, and emerging pests. In other cities with exemplary urban forestry programs, there are comprehensive, long-term management plans in place that employ a range of strategies to maintain and grow the urban forest. How cities prioritize and capitalize on opportunities for protecting and growing the urban forest is ultimately a reflection of the values, training and perceptions of the people and politicians who design and manage cities.

The next phases of the UFMP, most importantly the second 5-year plan, provide an opportunity to integrate the findings from this study in the next urban forest management cycle in Guelph. In light of the strong community support and a shared vision of environmental consciousness, the City has many opportunities to engage with residents to use urban forest management as a tool for supporting the City’s sustainability goals.

SUMMARY OF RECOMMENDATIONS

COLLOBORATING TO GROW THE URBAN FOREST

6 - Identify options for improving the preservation of quality pervious growing space and soil resources in new residential and non-residential development. (p 38)

7 - Ensure all future growing space designed for trees in new residential and non-residential development is high quality, including sufficient soil volume, quality and crown space to support long-term growth. (p 39)

8 - Identify and implement best practices in zoning and urban design that maximize quality growing space on public and private land. (p 39)

9 - Use the results of the canopy cover and plantable space analyses to develop canopy cover targets for implementation at the project or site level. Integrate targets into Guelph's policies, by-laws or built form guidelines or other guiding documents as appropriate. (p 39)

18 - Document the contribution of trees in supporting net zero carbon by 2050 in future updates to the Community Energy Initiative and other climate resilience planning initiatives. (p 52)

19 - Forestry should work with the City of Guelph Water Services to identify priority locations for planting trees in areas prone to high levels of runoff and flooding. (p 53)

20 - Examine opportunities for extending stormwater credit calculations based on per cent hard surface to include per cent relative tree canopy to incentivize tree planting on industrial, commercial and institutional properties. (p 53)

26 - Extend the time horizon for achieving 40 per cent canopy to 50 years, consistent with other city strategies. (p 77)

IMPROVING FOREST STRUCTURE, COMPOSITION AND FUNCTION

15 - Develop suitable species lists for urban trees and natural areas and review lists annually as part of operational planning. Include as an Appendix to the Tree Technical Manual. (p 48)

4 - Prioritize planting opportunities in and adjacent to the Natural Heritage System to enhance NHS function. (p 34)

10 - Work collaboratively with other forest managers to develop an invasive species monitoring and management strategy for the City of Guelph. (p 43)

11 - Fund and implement invasive species management in high priority areas within and adjacent to the Natural Heritage System. (p 43)

22 - Identify populations of senescent street trees where underplanting would help maintain urban forest benefits and increase resilience to storm events. (p 57)

23 – Implement proactive maintenance and inspection programs to optimize the services delivered by street trees, including maintenance and watering of newly planted trees. (p 57)

INCREASING FOREST RESILIENCE

14 - Include consideration of current species abundance and leaf area as well as vulnerability to pests in species selection as part of a comprehensive planting strategy. (p 48)

16 - Include an update on the status of major forest health threats as part of annual operational planning. (p 48)

17 - Develop a forest monitoring program to support early detection and response to threats from pests, disease and invasive plant species. (p 48)

24 - Compare i-Tree Storm estimates to current expenditures and use the information to forecast future resource requirements. (p 62)

25 - Increase structural diversity in the forest through strategic planting and species mixes to improve resilience to extreme weather events. (p 62)

TREE PLANTING

3 - Identify opportunities to increase hard surface planting in highly urbanized land use areas. (p 33)

21 - Increase the rate of street tree planting to ensure a sustainable street tree population in the City. (p 57)

28 - Use planting prioritization maps to inform tactical and operational planning for City tree planting programs. (p 82)

29 - Use criteria in the Tree Technical Manual to evaluate and prioritize high quality planting sites in ROWs and other public lands. (p 82)

COMMUNITY ENGAGEMENT

1 - Use canopy cover maps with height models to support targeted and proactive outreach/ education to landowners with large/mature trees. (p 29)

2 - Fund and implement an outreach campaign with landowners and community organizations in Guelph to build partnerships and expand the urban forest on private lands. (p 31)

13 - Increase outreach to and education for landowners to provide information about invasive species and options for stewardship on private lands. (p 46)

ADAPTIVE MANAGEMENT

5 - Monitor forest and land cover change regularly using open source tools developed by the USDA Forest Service (i-Tree) or other proven methods. (p 37)

12 - Review the effectiveness of current tree by-laws, protection policies and development review processes for protecting trees and promoting mature tree retention in Guelph. Identify options for promoting the retention of mature, heathy trees. (p 44)

27 - Use criteria and indicators to assess progress toward sustainable urban forest management goals as defined in the next Urban Forest Management Plan. (p 77)

Appendix A: Detailed Study Methodologies

PHASE 1: CONTINUOUS LAND COVER CLASSIFICATION

The continuous land cover classification was completed in four stages, starting with eCognition[47], an object-oriented image analysis software package. The software provides a way to integrate remotely sensed data and GIS. Classification inputs for Guelph included:

- Pleiades 2017, leaf-on satellite Imagery for City of Guelph (50cm resolution, 4-band, orthorectified/pansharpened/colour-balanced mosaic, horizontal accuracy to 2 pixels (1m), 0.1 per cent cloud, 3.5 degrees off Nadir, 8-bit Geo-TIFF format, UTM NAD83)
- LiDAR point cloud for City of Guelph (8 points per m2, acquired 2017/2018)
- City of Guelph ancillary data (water, roads, building footprints, overhead utilities, city boundary, etc.)

STAGE 1 – INTEGRATE LIDAR

Integration of the lidar point cloud into the land cover analysis included:

- Data processing and generation of the derived raster LiDAR products:
- Digital surface model (DSM),
- Digital elevation model (DEM),
- Normalized digital surface model (nDSM), and
- Point cloud colourization (for visualization purposes only)
- Additional ruleset development in eCognition to support the integration of the 3-dimensional point- cloud and raster datasets.

STAGE 2 – CLASSIFY AND EXTRACT FEATURES

Spectral bands from satellite imagery were used as a basis for segmentation. The Normalized Difference Vegetation Index (NDVI) is an index used, which measures the ratio between two of these spectral bands – the visible (red) and near-infrared regions of multi-spectral imagery to identify and classify land cover and vegetation types and conditions based on reflectance levels. Custom rule sets were developed to classify and extract features and produce a preliminary land cover map with seven classes, including:

1. Forest canopy (defined as vegetative cover equal to or greater than 2m in height)
2. Non-canopy vegetation (all vegetation under 2m in height)
3. Buildings

[47] E-cognition.

4. Transportation (roads)
5. Other impervious (parking lots, sidewalks, driveways)
6. Bare soil
7. Water

DETAILED STEPS IN CLASSIFICATION

- Extract areas greater than 2 m elevation.
- Separate urban forest from building infrastructure using the texture of a slope layer.
- Use pixel grow and shrink functions to eliminate power lines from the previous two classifications, smooth building edges.
- Use NDVI and brightness values to extract impervious areas, low vegetation, and shadows.
- Classify shadow as either impervious or vegetation depending on the neighbouring regions.
- Separate impervious areas into impervious and Roads using a manually corrected road layer shapefile.
- Separate vegetation into Low Vegetation and Soil classification using a red-green filter.
- Reintroduce water layer from the provided water shapefile and correct polygons to match changes in waterways.

STAGE 3 – USING ESRI ARC PRO (LOCALIZED MODIFICATIONS)

Following the initial classification, the land cover classes from eCognition were transferred to ESRI's Arc Pro for manual modifications and quality control.

- The water and transportation/road were reviewed for overlapping areas. Where overlaps were found reclassification was done. (i.e. water and roads were clipped by Urban Forest Cover).
- Baseball diamonds (bright pervious regions of crushed gravel) were reclassified as soil instead of the detected impervious class.
- Cars, transport trailers, and other identifiable non-permanent objects, were reclassified to surrounding classes.

The final step was a review of parking or empty lots and reclassifying areas to soil if the area were identifiable as packed soil instead of asphalt or concrete.

ACCURACY ASSESSMENT OF LAND COVER DATASET

A referenced point accuracy assessment was completed on the land cover classification. This is important in order to understand the reliability of the land cover mapping for various applications, including in this case the development of a planting priority index for the City of Guelph as well as a canopy feasibility assessment.

Accuracy assessment is "the process by which the accuracy or correctness of an image classification is evaluated and involves the comparison of the image classification to reference data that are assumed to be true."[48]

The accuracy assessment used the available Pleaides imagery for the City of Guelph to perform a separate (manual) point sample of land cover to compare against the classification. Generally, at least 50 points per class is recommended and was achieved in all but the water land cover class, which was manually classified in the land cover dataset. The results were tabulated in an "error matrix", which compares the reference data to the classified map.

The overall accuracy of the land cover dataset was calculated at 87.3 per cent, with varying levels of accuracy in different land cover classes (Table 12). Generally, 80 per cent overall accuracy is considered good.[49]

Table 12: Results of accuracy assessment of land cover classification, City of Guelph. Overall accuracy rate is 87 per cent.

Unbiased Accuracy	Area (ha)	95% Confidence Interval	User's Accuracy	Producer's Accuracy
Building	1,005.46	36.19	97.8%	93.5%
Non-Canopy Vegetation	3,748.56	117.33	84.7%	94.8%
Other Impervious	1,068.02	110.67	74.5%	65.9%
Soil	231.03	75.88	68.5%	39.6%
Transportation	604.18	55.80	81.7%	90.0%
Urban Forest Canopy	2,059.75	62.66	97.4%	92.3%
Water	113.83	17.97	88.2%	100.0%

[48] Cindy Schmidt and Amber McCullum. Assessing the Accuracy of Land Cover Classifications.

[49] NASA's Applied Remote Sensing Training Program, Assessing the Accuracy of Land Cover Classifications.

PHASE 1: DEVELOPMENT OF A SPATIALLY EXPLICIT PLANTING PRIORITIZATION PLAN

It is commonly accepted in the literature that trees provide significant benefits to both governments and residents in urban environments. Urban forestry departments across North America are tasked with implementing many aspects of forest management in cities, including tree planting programs. Questions often arise about how best to direct limited resources to maximize the multiple environmental, social, and economic benefits of trees to the community. In 2015, the development of an Urban Forest Strategy for the Region of Peel identified the need for a rigorous science-based mapping tool that could help environmental stewards, planners and urban foresters prioritize geographic areas for tree planting based on scientific evidence of their multiple benefits.

A multi-disciplinary technical steering committee – with expertise in parks, forestry, environmental education and stewardship, public health, planning, transportation, and human services – worked for two years between 2013 and 2015 to develop what is referred to as the "Peel Tree Planting Prioritization Tool" (TPPT).[50] The purpose of the Tool was to help prioritize possible tree planting in areas of Peel Region to meet multiple environmental, social and economic objectives. The TPPT was made available to the City of Guelph in order to complete planting prioritization mapping for the 2019 study.

PREPARING DATA INPUTS FOR OVERALL BENEFIT AND PRIORITY PLANTING SCORES

The framework developed for the TPPT consists of five nested components, as shown in Figure 34.

[50] 2015 Peel Tree Planting Prioritization Tool.

Figure 34: Diagram of the nested TPPT framework.

Tier 1 (Sustainability Theme) consists of three components, including criteria for Environmental, Economic and Social Sustainability. Each of these themes includes at least two Overall Benefits to help identify tree planting priority areas related to that theme.

Tier 2 (Overall Benefits) refers to the category of urban forest benefits (or function) that relates to one of the three Sustainability Themes an reflects a priority within the City of Guelph that can be addressed, at least in part, by tree planting. Examples are mitigating heat island effect, stormwater runoff, etc.

Tier 3 (Target Benefits) describes the specific benefits being targeted through the TPPT as identified through scientific, technical and practical considerations such as data availability, as well as input from consultations.

Tier 4 (Opportunity Zones) are areas of geographic space related to each Target Benefit based on defined parameters.

Tier 5 (Opportunity Zone Categories) sub-divides Opportunity Zones into two or three sub-categories (primary, secondary, tertiary) where relevant. The categories divide the Target Benefit into 'sub-zones' that define where the most benefits are achieved through planting (e.g. primary zone for air pollution mitigation is 0-133m from provincial highways, secondary zone is 334-500m from provincial highways, etc.) While tree planting anywhere in Guelph will create overall benefits, the TPPT allows for prioritizing areas based on themes of interest to the City and residents of Guelph. Tables 13, 14, and 15 list three themes – environmental sustainability, economic sustainability, and social sustainability – and name process, and criteria for each of the target benefits.

Table 13: Benefit name, process and criteria for each of the target benefits – Environmental sustainability theme.

Overall Benefit	Target Benefit	Criteria
1. Mitigating Air Pollution	1. Air Pollution Mitigation Near High Traffic Roads	Primary Zone 0-333m from provincial highways, 0-67m from major roads, 68-133m from major roads that are truck routes Secondary Zone 334-500m from provincial highways, 68-133m from major roads, 134-200m from major roads that are truck routes Tertiary Zone 134-200m from major roads, 0-200m from other truck routes
2. Mitigating Urban Heat Island Effect	2. Cooling Where Heat Island Effects Are Greatest	Primary Zone Surface temperatures 35-44°C Secondary Zone Surface temperatures 33-34°C Tertiary Zone Surface temperatures 31-32°C

Overall Benefit	Target Benefit	Criteria
3a. Contributing to Management of Surface Water Quantity and Quality	3a. Contributing to Local Water Quantity Management	Primary Zone Area without stormwater controls outside the NHS Secondary Zone Areas without stormwater controls within the NHS
3b. Contributing to Management of Surface Water Quantity and Quality	3b. Contributing to Water Quality Improvements	Opportunity zone not subdivided into categories for this benefit.
4a. Maintaining and Enhancing Natural Heritage	4a. Maintaining and Enhancing the Natural Heritage System (NHS)	Opportunity zone not subdivided into categories for this benefit.
4b. Maintaining and Enhancing Natural Heritage	4b. Maintaining and Enhancing Lands Adjacent to the NHS	Primary Zone 0-30m from the NHS Secondary Zone 31-100m from the NHS

Table 14: Benefit name, process and criteria for each of the target benefits - Economic sustainability theme

Overall Benefit	Target Benefit	Criteria
5. Enhancing Economic Value	6. Enhanced Commercial Activity	Primary Zone Commercial nodes, as well as areas within 5 minutes walking distance (400m) Secondary Zone Areas within 6-10 minutes walking distance (800m) of commercial nodes
6. Providing Direct Cost Savings	7. Contributing to Local Energy Conservation	Opportunity zone not subdivided into categories for this benefit.

Table 15: Benefit name, process and criteria for each of the target benefits – Social sustainability theme

Overall Benefit	Target Benefit	Criteria
7a. Supporting Improved Physical Health	7a. Supporting Walkability and Outdoor Recreation	Primary Zone Public parks, within 30m of trails and active transportation routes,

Overall Benefit	Target Benefit	Criteria
and Emotional Wellbeing		within 5 minutes walking distance from schools (400m) Secondary Zone Within 6-10 minutes walking distance from schools (800m)
7b. Supporting Improved Physical Health and Emotional Wellbeing	7b. Improving Environments for Learning, Working and Healing	Opportunity zone not subdivided into categories for this benefit.
8a. Strengthening Communities and Enhancing Social Equity	8a. Strengthening Communities Through Better Canopy Cover	Primary Zone Residential areas with 0-33% of the average canopy cover Secondary Zone Residential areas with 34-66% of the average canopy cover Tertiary Zone Residential areas with 67-99% of the average canopy cover

Overall Benefit	**Target Benefit**	**Criteria**
8b. Strengthening Communities and Enhancing Social Equity	8b. Enhancing Lower Income Neighbourhoods Through Better Canopy Cover	Opportunity zone not subdivided into categories for this benefit. “Low income” is defined using Stats Can Low Income Measure (LIM) data.

The TPPT is a flexible GIS model that can generate maps that illustrate areas to prioritize tree planting at different geographic scales. Local municipalities and conservation authorities can use the tool to guide their efforts in managing and growing the urban forest, with examples of different objectives as follows:

- To guide outreach and restoration efforts on public and private lands;
- To identify gaps in the tree canopy on municipal lands where planting space is available and planting activities can be focused;
- To use in future review of development applications; and
- For identifying existing woodlots and justifying management plans and proposed extensions to them.

The TPPT requires land cover data that classifies ground conditions based on existing tree cover, permeable areas and impermeable areas, as this defines planting space. For the purposes of this project, "Planting Space" was defined as permeable areas, which includes vegetated areas without trees as well as bare earth. The Tool generates two types of indices:

1. An index of "Benefit Scores" generated by the TPPT defines where planting **should** be undertaken, based on the parameters of the Target Benefits and is based on the relative area of Opportunity Zones for each unit at the selected geographic scale.

An example of the mapping project at the property (parcel) scale when all twelve Target Benefits are combined can be seen below (Figure 35 – Overall Benefit Score).

2. The index of Priority Planting Scores identifies where planting could take place based on the Planting Space within the Opportunity Zone. An example of the mapping product at the property (parcel) scale when all twelve Target Benefits are combined is provided below (Figure 36 – Overall Planting Score).

When generating both indices, the TPPT takes into account the variability in area covered by each Target Benefit, the use of internal weightings within the Opportunity Zones defining the Target Benefits, and the different sizes of Geographic Units by normalizing scores at a scale between 1 and 100.

For the purposes of this study, the tool was run at the parcel level, to provide detailed information about priority planting locations that would be useful for tactical and operational planning.

These maps have been provided to the City of Guelph in a digital format as a study deliverable and will be used to help prioritize future planting programs.

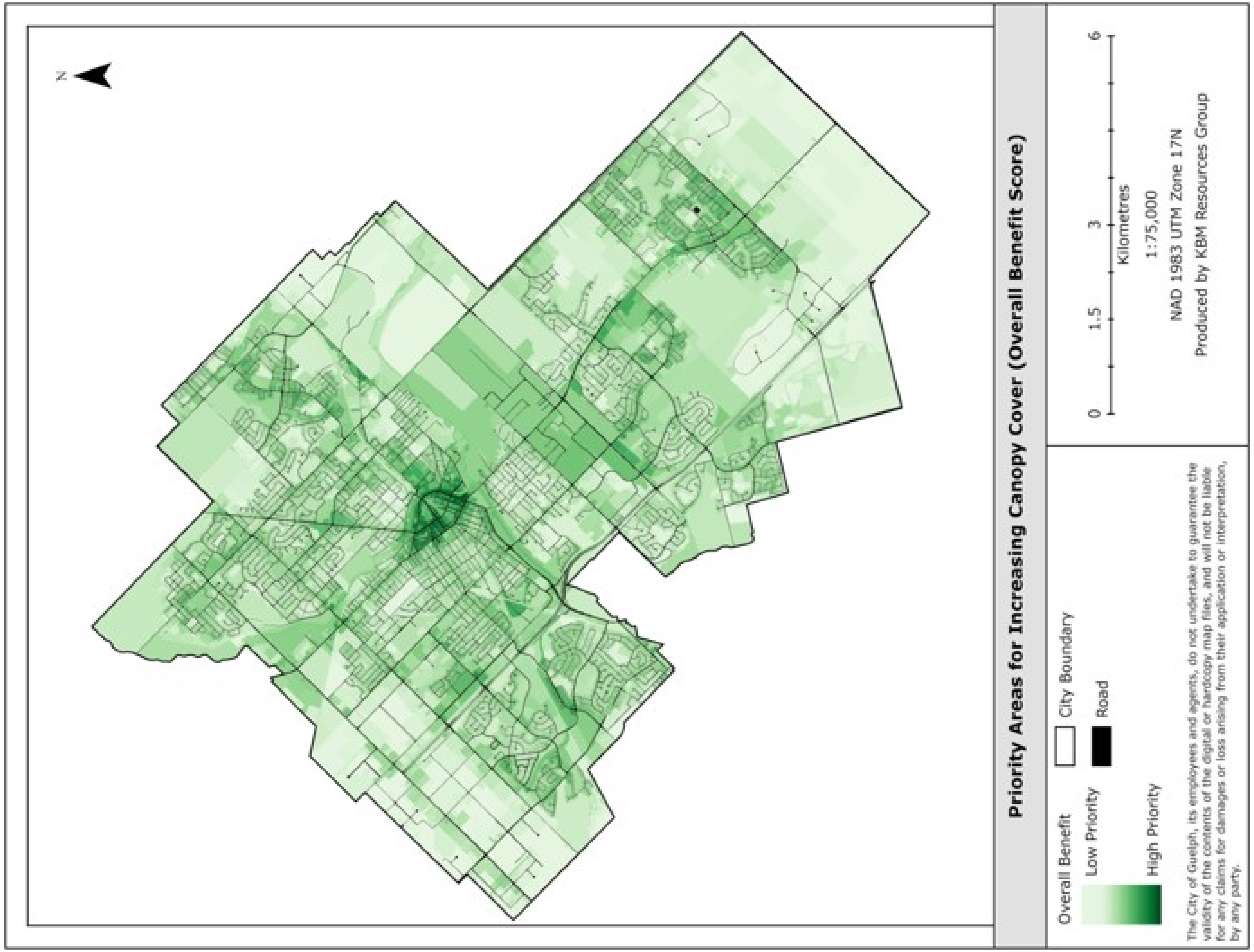


Figure 35: Overall benefit score map for City of Guelph (Source: TPPT 2019 output for City of Guelph).

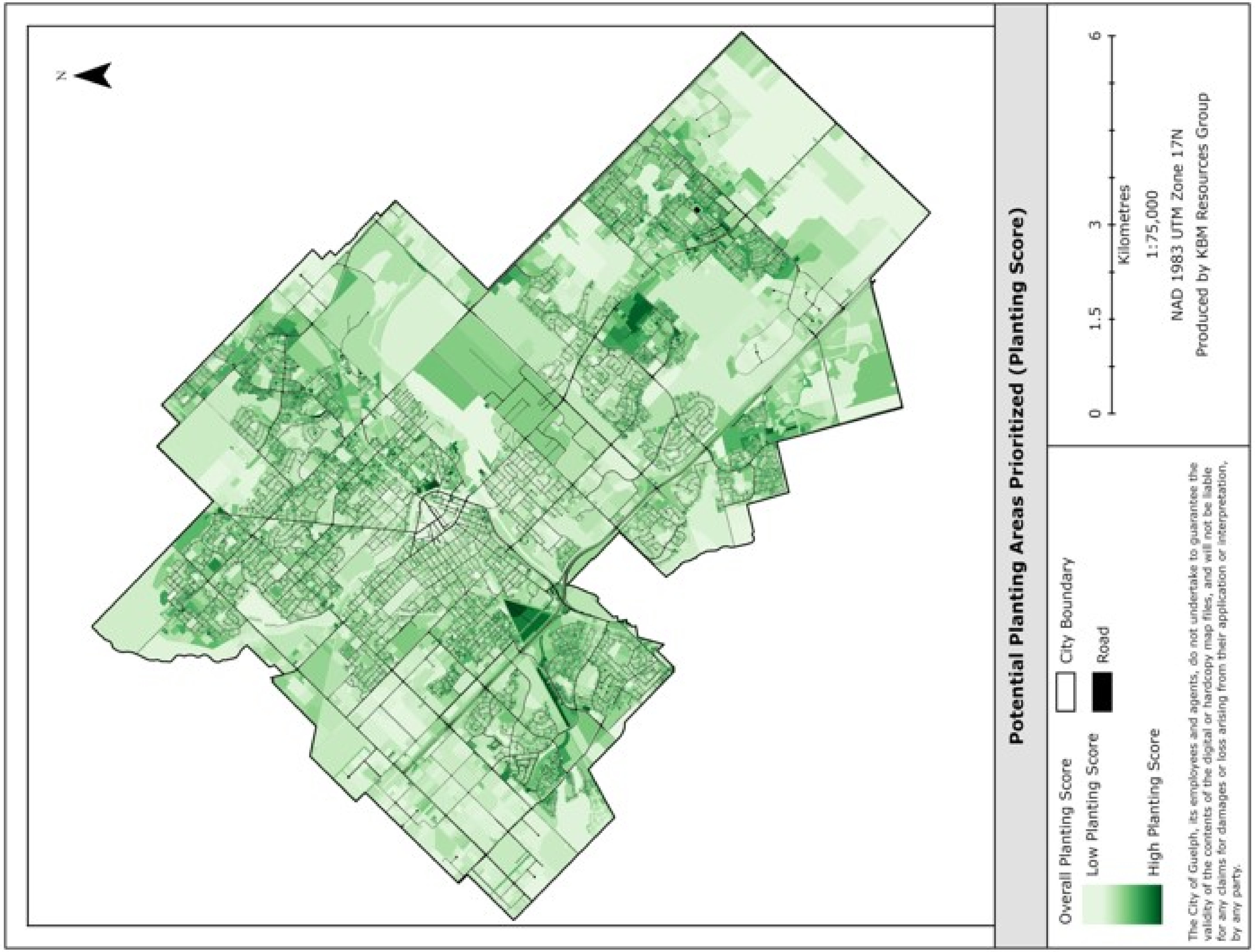


Figure 36: Overall planting (priority) score City of Guelph (Source: TPPT 2010 for City of Guelph).

PHASE 1: ASSESSING FEASIBILITY OF ACHIEVING 40 PER CENT CANOPY COVER

One of the questions often asked by municipalities is whether or not a canopy cover goal is achievable. Methodologies commonly used to answer this question refer to "Urban Tree Canopy (UTC) Assessment"[51], which looks at existing UTC (canopy cover) along with "potential UTC" to determine at a high level to determine what kind of UTC goal is achievable.

The UTC assessment protocols were designed to take advantage of high resolution geospatial datasets that describe municipal environments. During a UTC assessment high resolution land cover is integrated with planitmetric datasets, such as buildings and roads to determine the Existing UTC and Possible UTC.

The UTC metrics can then be summarized using cadastral and boundary datasets consisting of rights-of-way (ROW), property parcels, and target geographies. Target geographies are boundary datasets such as wards, neighborhoods, census blocks, zoning districts, etc.

The steps involved in this approach as applied to Guelph using detailed land cover data as a key input are summarized in Table 16.

Table 16: Steps in UTC Assessment (USDA Forest Service).

Step	Approach/Mapping and Data Products
Assess present condition - How much UTC do I have?	Use remote sensing to measure existing urban tree canopy. Mapping: Average tree cover by parcel, neighbourhood, City
Assess potential UTC - How much UTC can I get?	Assessment of potential UTC by site type - Watershed, districts, neighborhoods, parks, private residential parcels

[51] USDA Forest Service – About UTC Assessment.

Step	Approach/Mapping and Data Products
	Mapping: Relative canopy cover, potential maximum UTC by parcel, neighbourhood, City
Adopt/refine canopy cover goal based on the findings of the assessments	If target is feasible based on UTC assessment, proceed with implementation plan. If target is not feasible at high level, review and adjust target.

The results of the UTC Assessment link to the management of the urban forest through the development of an implementation plan, which in Guelph will be achieved by updating the 2013 Urban Forest Management Plan. Considerations for the development of the next plan include:

- UTC prioritization using community priorities to identify locations for planting (Planting Prioritization Plan)
- Institutionalize UTC goals in legislation, regulation, or the community's comprehensive or sustainability plan
- Implement requirements for new tree planting, protection and maintenance of existing trees, and predicted canopy loss from tree mortality and land conversion.
- Define relationship of canopy goals to local ordinances, regulations, and the community's comprehensive plan.
- Develop strategies for including a range of stakeholders in the implementation process.

PHASE 2: FOREST INVENTORY FIELD DATA COLLECTION AND REPORTING (ITREE ECO V6)

MODEL OVERVIEW

The study used i-Tree Eco version 6 (Eco), a model that uses tree measurements and other data to estimate ecosystem services and structural characteristics of the urban or rural forest. The inputs to the model included data from 208 randomly located study plots across the City of Guelph.

Eco is a flexible software application designed to use data collected in the field from single trees, complete inventories, or randomly located plots throughout a study area along with local hourly air pollution and meteorological data to quantify forest structure, environmental effects, and value to communities.

Eco is a complete package that provides:

- Sampling and data collection protocols - For plot-based sample projects, total population estimates and standard error of estimates are calculated based on sampling protocols. For complete inventories, Eco calculates values for each tree.
- Flexible data collection options – Use the mobile data collection system with web-enabled smartphones, tablets or traditional paper sheets.
- Automated processing – A central computing engine that makes estimates of the forest effects based on peer-reviewed scientific equations to predict environmental and economic benefits.
- Reports – Summary reports that include charts, tables and a written report.

PLOT SELECTION

The i-Tree Eco protocol recommends a minimum of 200 random plots to derive a statistically relevant sample of a study area. In May 2019, BioForest and KBM, in collaboration with the City of Guelph, established 226 random plots on public and private land across Guelph. Plots were assigned to each land use post-stratification in order to derive a representative sample from each land use with an acceptable margin of error. A minimum of 20 plots were generated for each land use class, in accordance with i-Tree Eco protocols, with at least one plot created in reserve, in case access issues arose. Land use classes that comprised a relatively larger share of land in Guelph were assigned more plots than land uses that represented a small amount of land. However, the distribution of plot numbers is not in exact proportion to the amount of land area represented by each land use class, as the number of plots required to accomplish this would entail a very large project beyond the scope of the urban forest study. Table 17 lists the number of plots generated for each land use class and the number of plots that were assessed during the study.

Table 17: Distribution of i-Tree Eco plots by land use created for the 2019 Guelph Urban Forest Study.

Land Use Class	Area (ha)	Number of Plots	Number of Plots Assessed
Commercial	544.26	22	21
Farm	438.24	22	20

Land Use Class	Area (ha)	Number of Plots	Number of Plots Assessed
Industrial	1,096.00	28	27
Institutional	610.66	22	20
Multi-Residential	94.81	21	21
Residential	2,471.73	50	44
Special and Exempt	249.51	21	20
Vacant	1,907.38	40	35
Total	**7,412.59**	**226**	**208**

During field surveys, field crews were denied permission to access properties in 6 residential plots and one commercial plot. Physical impediments to access plot centre prevented data collection in one Farm plot, one Institutional plot, one Special and Exempt plot, and one Vacant plot. A total of 208 plots were assessed during the field surveys. The remaining incomplete plots were held as reserve plots for future reassessments, if necessary.[52]

[52] Appendix J, Supplement 1 contains an overview map showing the locations of all 226 i-Tree Eco plots created for the 2019 Guelph Urban Forest Study.

LANDOWNER CONTACT

In order to secure permission from landowners whose properties were included in i-Tree plots, BioForest drafted a letter, in collaboration with the City of Guelph, addressed to property owners explaining the project purpose and requesting permission for field crews to access their property. BioForest staff mailed the letters, along with pre-paid return envelopes, to landowners in spring, 2019. BioForest received all replies to the letters and tracked landowner permissions. BioForest staff conducted in-person follow-up visits to properties whose owners did not return a reply to the initial letters. Additional permissions were obtained in this manner, and BioForest field crews continued to conduct landowner outreach during the data collection period, as necessary. Where permission was denied, field crews refrained from entering the property and ceased contact with the landowner.

I-TREE ECO FIELD METHODOLOGY

All 208 circular plots measuring 0.04 ha were assessed in leaf-on conditions in 2019. A field crew of two BioForest staff conducted data collection under the supervision of a project manager and a project coordinator. Field crew training and orientation took place on June 12 at various plots across the City of Guelph, with city staff in attendance. Field crews collected data independently from June 13 to October 4, 2019. Field crews recorded data on paper or electronically, using digital tablets. At each plot, field crews navigated to plot centre using GPS coordinates and planted a temporary marker at plot centre.

Field crews collected the following data at each plot:

PLOT INFORMATION

- Plot ID number
- Date of data collection
- Crew
- GPS coordinates of plot centre (NAD 83)
- Plot address/notes
- Reference object descriptions, and distance and compass directions to plot centre
- Tree measuring point, if used, where plot centre was inaccessible
- Per cent tree cover (visual estimate)
- Per cent shrub cover (visual estimate)
- Per cent plantable space (visual estimate)
- Land use, as observed in the field
- Per cent of plot within each land use (visual estimate, based on field map)
- Per cent ground cover (visual estimate of each cover type)

SHRUB DATA

- Species ID
- Shrub mass height
- Shrub mass per cent of total shrub area (visual estimate)
- Shrub mass per cent missing (visual estimate of the percentage of shrub's volume not occupied by leaves)

TREE DATA

- Tree ID number
- Trees receive a numerical ID, starting at 1, moving clockwise around the plot from North.
- Tree status (planted, ingrowth, or unknown)
- Compass direction and distance from plot centre (or tree measuring plot, if using)
- Land use in which tree is rooted
- Species ID
- Diameter at breast height (1.37 m) for up to six stems, if tree is multi-stemmed
- Tree height
- Live crown height
- Height to crown base
- Crown width (two measurements, in East-West and North-South directions)
- Per cent canopy missing (visual estimate)
- Per cent dieback (visual estimate)
- Per cent impervious surface area under the canopy of the tree (visual estimate)
- Per cent shrub area under the canopy of the tree (visual estimate)
- Crown light exposure (number of sides of the tree's crown that are exposed to direct sunlight)
- Distance and direction to residential buildings, for trees at least 6 m in height, and within 18 m of a residential building
- Tree site (street tree or not)
- Ownership (public or private)

QUALITY CONTROL AUDITS

The i-Tree Eco protocol outlines methods for ensuring quality and accuracy of the data collected by field crews during the survey. Hot checks are procedures in which an auditor works along with the field crew as they collect data at an i-Tree plot to ensure that the crews have a good understanding of the protocol. Errors are corrected in person, and these checks are typically included in the initial field crew training sessions. Cold checks are procedures in which an auditor makes follow-up visits to plots where the field crew has already collected data. The auditor verifies the crew's data to ensure that it is accurate and complete. Plots selected for cold checks are chosen at random, and ideally include a variety of settings.

BioForest staff completed hot checks at 3 plots during the training and orientation sessions and cold checks at 6 plots in the week following training. Thus, a total of 9 plots were audited, which represents 4.3 per cent of plots.

Cold check procedures varied slightly based on the number of trees present in a plot. For plots with 5 trees or less, each tree was audited. The species ID, DBH, height, crown width, and building interaction (if applicable) were confirmed by the auditor. The land use, as reported by field crews, plot tree cover, and number of trees in the plot were verified. For plots with more than 5 trees, the auditor randomly selected 5 trees and confirmed species ID, DBH, height, crown width, and building interaction (if applicable). The auditor also confirmed the land use, plot tree cover, and total tree count, and verified species ID for all trees in the plot. During the audits, auditors encountered only one minor error where a tree species had been misidentified. The auditor followed up with the field crew and insured that the correct identification was included in the plot data.

DATA SUBMISSION AND ANALYSIS

Throughout the data collection period, the field crew used its Samsung tablet to submit data to the i-Tree server, allowing the project coordinator to download and view the data using i-Tree Eco v. 6 on a desktop computer. Data was either inputted directly through the i-Tree web form in the field, or was entered at a later date, when field crews used paper data sheets to record field data. Following the completion of data collection, the project coordinator reviewed the collected data for errors.

Once the final edited version of the 2019 database was prepared, it was submitted for analysis using i-Tree Eco v. 6. The results of the analysis were returned by the i-Tree server on the same day. Results were downloaded from i-Tree Eco and organized into Microsoft Excel databases for further analysis and reporting purposes.

Results are presented as an extrapolation of the field data gathered from the 208 i-Tree plots used in the study. These plots constitute a statistically representative sample of Guelph's urban forest. A study using 200 urban plots in a stratified random sample is expected to yield a standard error of about 10 per cent (USDA 2014). Therefore, the 208 plots used in Guelph's i-Tree survey produce results that fall within the bounds of acceptable standard error. Only a complete inventory would eliminate the possibility of error, but the time requirements, ability to access private properties, and financial cost would make such an undertaking unfeasible.

PHASE 2: ANALYSIS OF STREET TREE BENEFITS

BioForest acquired street tree inventory data from the City of Guelph's Department of Parks and Recreation in November, 2019. The data provided by the City included a total of 52,510 trees, which encompassed street and park trees. At the direction of City of Guelph staff, all park trees (a total of 8,100 trees) were removed from the database so that the analysis would focus solely on street trees. No attempts were made to ground truth the content of the databases, as the data was collected and provided by the City of Guelph, and no field audits of street tree data were scheduled as part of the Guelph Urban Forest Study project.

i-Tree Eco version 6 software was used to process the tree inventory data and produce the benefits analysis. The street tree inventory was edited in accordance with the parameters of the i-Tree Eco software. All data fields that fed directly into the i-Tree Eco analysis were retained: address, DBH, species, and condition. The tree ownership field was retained to add context to the analysis. All other data fields were removed from each ward's inventory.

The species and condition fields were further edited to make the entries compatible with i-Tree Eco. The entries in the species field were converted to i-Tree species codes. Subspecies, varieties, and cultivars were designated by the appropriate species codes and listed as unique entries. Any subspecies, varieties, or cultivars that were not included in the list of species codes were assigned the closest applicable species code. For example, *Acer rubrum* 'Autumn Spire', a cultivar of red maple, was assigned the species code for red maple because a specific i-Tree species code for this cultivar did not exist. Finally, the tree condition field was converted to condition percentage ranges that reflected the designation assigned to each tree in the city's inventory. For example, a condition rating of Poor was assigned a percentage of 52, which is expressed in the i-Tree Eco software as a canopy condition rating of 50-55 per cent.

The street tree database was further edited to remove records with erroneous DBH entries. Through this process one entry, which had a DBH of 9996, was removed.

Once edited the database was uploaded from Excel to Eco. After the process of editing the inventory, a total of 43,659 street trees were submitted for analysis. The project was submitted to the i-Tree server and results were retrieved and compiled using Microsoft Excel.

PHASE 2: ASSESSMENT OF STORM COSTS USING I-TREE STORM

PRE-STORM SURVEY

The i-Tree Storm protocol advises sampling 2 per cent of all public roads for which the municipality is responsible in the event of an emergency, with a minimum of 10 street segments and a maximum of 30, to achieve an estimate of storm damage that is within 5 per cent of the true value.

In consultation with the City of Guelph, BioForest used ward boundaries to divide the city into six separate study areas with an individual Storm survey for each ward. This was done so as to account for variation across the city of Guelph in development age and density, which affect the size and distribution of trees in and adjacent to the right-of-way. In the event of a severe storm, having six separate study areas also helps to identify which areas of the city have been most affected by storm damage and enables the city to allocate resources accordingly. Prioritizing and targeting areas of greater concern will increase resource efficiency at a time when demands on staff are likely to be high.

Only public roads that fall under the municipality's jurisdiction were included in the i-Tree Storm survey. Any provincial, federal, and private roads were removed from the survey so that results reflect only the roads that the municipality is responsible for managing in the event of an emergency.

From the total eligible linear street kilometers, random street segments were generated using GIS software for each study area, following the protocol outlined in the i-Tree Storm User's Manual v4.0. All shapefiles created through this process (edited roads and randomly selected sample street segments) for each study area will be provided to the City of Guelph for storm preparedness. Figure 37 illustrates the division of the city by ward and the distribution of street segments surveyed during the pre-storm survey.

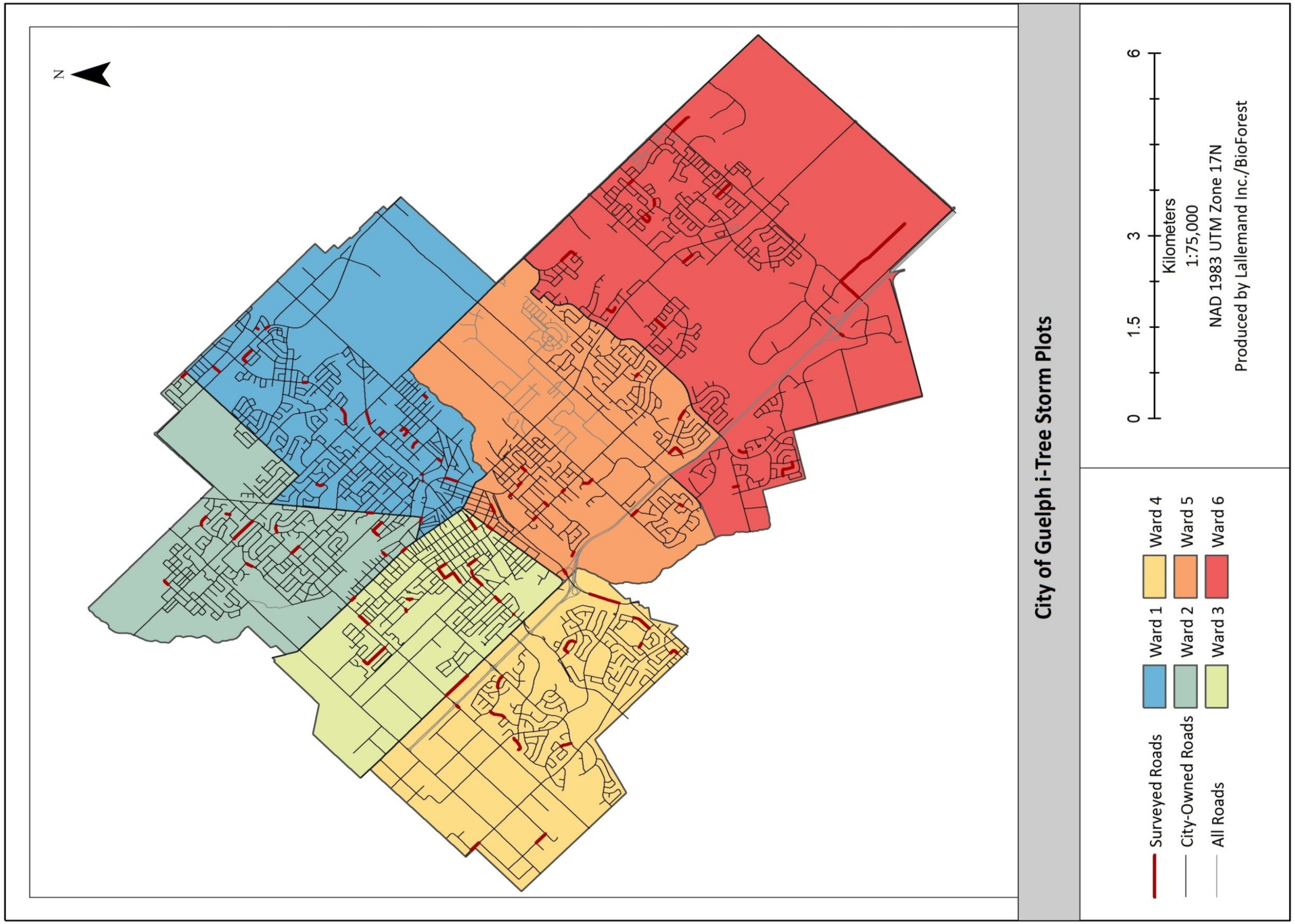


Figure 37: City of Guelph ward boundaries and distribution of street segments surveyed during i-Tree Storm pre-storm survey.

Only street segments representative of a typical “blockside”, as described in the Initial Storm Damage Assessment Protocol produced by the USDA Forest Service and Davey Resource Group (2001) were selected to be surveyed. By this definition, a “blockside” is bound by intersecting streets on either end. The intersecting streets can include dead ends and T-intersections, as well as four-way intersections. Any segments that did not meet these criteria (for example, segments within major intersections), or segments that were exceptionally short, were substituted for more suitable street segments. BioForest staff created field maps of each street segment and tables of sample plot information for each study area. All maps and tables will be provided to City of Guelph staff for storm preparedness.

DATA COLLECTION

The i-Tree Storm pre-storm assessment followed the protocol as outlined in the i-Tree Storm User’s Manual v4.0. All trees within the ROW and within 15.24 metres (50 feet) of the ROW were counted and tallied in each of the following diameter classes: 15 – 30 cm (6 – 12 in), 30 – 45 cm (13 – 18 in), 45 – 61 cm (19 – 24 in), 61 – 76 cm (25 – 30 in), 76 – 91 cm (31 – 36 in), 91 – 106 cm (37 – 42 in), and greater than 106 cm (43 in). Only live trees with a DBH greater than 15 cm (6 in) were counted. Trees on both sides of a street within the estimated ROW and on the median (if applicable) were counted. Field crews used parcel layer data provided by the City of Guelph, along with the location of sidewalks and public utilities to estimate ROW boundaries. DBH was measured using a DBH tape.

All plots were visited by BioForest staff in October and November 2019, and data was collected manually using the paper data form template provided by i-Tree. BioForest staff gathered the municipal values for removal or pruning by size class shown in Table 18 from City of Guelph Forestry staff to use as inputs in the i-Tree Storm template. The estimated cost per cubic yard for total debris management provided by the City was $19.84, and the estimated hourly rate for tree removal and for pruning provided by the City was $77.13.

Table 18: Municipal cost and work hour estimates related to storm clean up (Souce: City of Guelph)

Storm Input Information Required	Municipal Values	
Estimated time required for removal/pruning by size class	Removal (hours)	Pruning (hours)
15 – 30 cm	2	1

Storm Input Information Required	Municipal Values	
30 – 45 cm	2	1
45 – 61 cm	4	2
61 – 76 cm	4	2
76 – 91 cm	6.5	3
91 – 106 cm	6.5	3
106 cm +	6.5	3

DATA ANALYSIS

BioForest staff manually entered field data and the required municipal information directly into the i-Tree Storm interface. The Pre-Storm analysis was completed following the instructions from the Storm User's Manual v4.0. All costs were converted to US dollars for compatibility with the i-Tree Storm software. Outputs consisted of six separate workbooks (one for each ward in Guelph) outlining estimated costs associated with tree removal, pruning, and brush clearing.

Appendix B: Literature Review

Part of the urban forest study included a literature review to investigate recent science and best practices in urban forest management. The following review looks at subject areas that link to the goals of the urban forest study and includes key findings under each subject heading.

- Urban forest structure
- Urban forest function
- Modelling and forecasting
- Methodologies for assessing urban forest values (goods and services)
- Monitoring land cover change
- Costs of maintaining and not maintaining urban forest
- Increasing the resilience of urban forest to threats
    - Climate change
    - Storms and extreme weather events
    - Susceptibility to pests and disease and invasive species
    - Urbanization and development pressure
    - Invasive species
- Sustainable urban forest management – monitoring and adaptive management to achieve multiple/optimal benefits

URBAN FOREST STRUCTURE

As per an early report on this subject by the USDA Forest Service (1994), urban forest structure is defined as the spatial arrangement of vegetation in relation to other objects, such as buildings, within urban areas (Rowntree 1984). Three broad factors determine urban forest structure:

1) Urban morphology, which creates the spaces available for vegetation;
2) Natural factors, which influence the amount and type of vegetation likely to be found within cities; and
3) Human management systems, which modify vegetation configurations across land-use types (Whitney and Adams 1980, Sanders 1984).

Urban forest structure can also be described a measure of various attributes of urban tree vegetation including tree species composition, tree density and species diversity etc. As an indicator of forest condition or value, structure is relevant because it greatly influences the services and benefits offered by urban trees (Akbar, Ashraf and Shakoor, 2014).

DIVERSITY

Different habitats in a city vary in growth conditions for trees and accordingly influence aspects of urban forest structure, including species diversity. Pauleit et al., (2002) and Sabo et al., (2003) recorded higher diversity of tree species in parks and green spaces than in streets and paved areas in European cities. They attributed this difference in tree diversity due to higher levels of stressful conditions in more urbanized habitats such as elevated temperatures, low air humidity, increased pollution and limited soil volume.

The extent to which a particular land use can provide ecosystem services depends on the current urban forest structure (e.g. tree species, number, tree canopy cover, height, health, composition, tree size, location, health), which can provide useful information for estimating trees' structural characteristics such as leaf biomass and total leaf area, and quantifying multiple ecosystem services and forest functions (Nowak et al., 2008). For example, land covers containing remnant and regenerated forest patches, such as vacant lots and greenspaces, had the highest net rate of carbon sequestration (848.7 mt/ha/yr) in the urban forest (Zipperer, 2000).

Local elements of biodiversity are affected by urban forest structure, which in turn is influenced by the level of urbanization in a municipality. For example, as per Burton et al. (2005) the proportion of non-native species in the forest stand and regeneration layer decreased and Shannon diversity of the regeneration layer increased with increasing distance from the urban center. Shifts in diversity indicate that anthropogenic disturbance may subdue the ability of diverse communities to resist non-native plant invasions (Burton et al., 2005). This may be helpful for understanding where best to target invasive species early detection and management efforts, by prioritizing site with higher vulnerability.

Urban forest structure at the local and landscape scape has also been shown to influence bird species richness in urban ecosystems (Savard et al., 2000). Efforts to turn cities into a more friendly habitat for a variety of bird [and other] species should focus not only on habitat and vegetation [forest] structure, but also on niche opening for subordinate species, by excluding locally aggressive, synanthropic and invasive species.

VALUE

Forest structure can also affect economic values in cities, including real estate value. Escobedo et al., (2015) found that more trees with greater Leaf Area Indices (LAIs) add to property value, while biomass and tree–shrub cover have a neutral effect and replacing trees with grass cover had a lower value for properties.

BEST PRACTICE

In terms of best practices or optimizing forest structure, this is to some degree specific to local conditions but there are some guidelines around, for example, size/age/height class distribution and species composition and suitability that can be applied. Principles of landscape ecology, including the concept of core areas and connectivity for supporting biodiversity, are also relevant for managers. For species composition, managers have often used the "10-20-30 Rule" for guidance. This suggest that cities plant no more than 10 per cent of any one species, no more than 20 per cent of any one genus and no more than 30 per cent of any one family (Santamour, 1990). However, a 2016 review suggests this is very difficult for cities to meet and that measures of diversity by basal area that focus at the genus level may be more useful for evaluating risk related to species diversity (Ambrose, 2016). The same review also points out that species selection will be constrained by other factors, such as availability of stock, success rates with some species over others and water use considerations (Ambrose, 2016).

Size class distribution is often used as another measure of urban forest sustainability. Using size as a proxy for age, Richards (1983) identified an "ideal" distribution for municipal forests as having about 40 per cent of the urban tree population in the smallest diameter class (less than 6 inches in diameter). Too many in the smallest class means the urban area is not yet receiving the full benefits of a tree canopy. When too many trees are in the larger diameter classes, concerns arise about mortality and replacement (Adapted from McPherson et al., 2005 by Melanie Lenart, University of Arizona). The 2016 "*Sustainable Urban Forest Guide: A Step-by-Step Approach*" suggests that the total tree population across a municipality should approach an ideal age distribution of "40 per cent juvenile, 30 per cent semi-mature, 20 per cent mature, and 10 per cent senescent." (Leff, 2016). Rather than focusing on specific percentages, this information may be more useful to illustrate the general principle of having a range of size classes to ensure a sustainable, long-term tree population. To inform the number of smaller trees, local mortality rates for newly planted trees can be factored in where that data is available.

Urban forest assessments, including measures of forest structure, are essential in supporting urban forest management and planning to improve environmental quality and human health in cities (Nowak et al., 2008). Information about forest structure is generally provided by sample-based inventories of municipal urban forests, or in some cases in more detail at a stand level in woodland or park inventories. The increasing availability of LiDAR data for urban forest planning can add to the understanding of height stratifications within the urban forest and remnant woodlands and provide managers with more information about urban forest values at different scales.

KEY FINDINGS – URBAN FOREST STRUCTURE

- Information about urban forest structure is essential for supporting planning and management
- Urban forest structure attributes include tree species composition, height, tree density, size class and distribution, tree condition, etc.
- Urban forest structure is influenced by the urban landscape and built form, natural factors like soils, climate and existing vegetative communities as well as human management systems.
- Urban forest structure in turn influences many benefits and values provided by the urban forest, including biodiversity, ecological services, susceptibility to invasive plant establishment and even real estate values.
- Structural information about the urban forest is generally derived through forest inventories, which can be complete inventories (e.g. street trees), sample-based inventories (across an entire municipality) or in some cases at the stand level in remnant woodlands or parks where more detail is required.
- There are some suggested guidelines for optimizing aspects of forest structure, including composition and target size class distribution – however, how these are applied will need to take local context and management or environmental constraints into consideration.

LITERATURE CITED - URBAN FOREST STRUCTURE

K. F. Akbar, I. Ashraf and S. Shakoor. (2014). Analysis of Urban Forest Structure, Distribution and Amenity Value: A Case Study. The Journal of Animal & Plant Sciences, 24(6): 2014, Page: 1636-1642 ISSN: 1018-7081.

Mark J. Ambrose. 2016. The 10-20-30 Rule Revisited: Is It a Useful Standard for Urban Forest Diversity? NC State University, Partners in Community Forestry, Indianapolis, IN, November 16-17, 2016. Available at: The10, 20, 30 rule revisted: Is it still a useful measure of diversity?

Michele L. Burton, Lisa J. Samuelson and Shufen Pan. (2005). Riparian woody plant diversity and forest structure along an urban-rural gradient. Urban Ecosystems March 2005, Volume 8, Issue 1, pp 93–106.

M. Bodson and T.B. Randrup. (2002). Tree establishment practice in towns and cities – result from a European survey. Urban Forestry & Urban Greening. 1(2): 83–96.

Francisco J.Escobedo, Damian C.Adams, Nilesh Timilsina. (2015). Urban forest structure effects on property value. Ecosystem Services Volume 12, April 2015, Pages 209-217

Michael Leff. (2016). The Sustainable Urban Forest Guide: A Step-by-Step Approach. Davey Institute / USDA Forest Service, USFS Philadelphia Field Station.

McPherson, G., J.R. Simpson, P.J. Peper, S.E. Maco, and Q. Xiao, 2005. Municipal forest benefits and costs in five U.S. cities. Journal of Forestry. 103: 411-416. *Adapted by*: Melanie Lenart, University of Arizona.

Nowak, D.J.; Crane, D.E.; Stevens, J.C.; Hoehn, R.E.; Walton, J.T.; Bond, J. A Ground-Based Method of Assessing Urban Forest Structure and Ecosystem Services. Arboric. Urban For. 2008, 34, 347–358

Pauleit, S., N. Jones., G. Garcis-Martin., J.L. Garcia- Valdecantos., L.M. Riviere., L. Vidal- Beaudet., M. Bodson and T.B. Randrup. (2002). Tree establishment practice in towns and cities – result from a European survey. Urban Forestry & Urban Greening. 1(2): 83–96.

Richards, N.A., 1983. Diversity and stability in a street tree population. Urban Ecology. 7: 159-171.

Dr. Frank Santamour, (1990). Research Geneticist at the US National Arboretum.

Jean-Pierre L. Savard, Philippe Clergeau, Gwenaelle Mennechez. (2000). Landscape and Urban Planning Volume 48, Issues 3–4, 1 May 2000, Pages 131-142.

Wayne C. Zipperer. (2002). Species composition and structure of regenerated and remnant forest patches within an urban landscape. Urban Ecosystem, December 2002, Volume 6, Issue 4, pp 271–290.

URBAN FOREST FUNCTION

The functions and value of the urban forest have received increased attention in recent decades as urban ecology and ecosystem services have become prominent areas of research (e.g. McPherson et al., 1997; Sander, Polasky, & Haight, 2010).

Healthy urban forests can produce ecosystem functions, goods and services that benefit humans and the environment. Ecosystem services, or ecoservices, include energy conservation, air quality improvement, carbon storage, stormwater runoff reduction and wildlife habitat (Nowak and Crane, 2002; Nowak et al., 2006; Simpson and McPherson, 1998; Tzilkowski et al., 1986; Xiao et al., 1998). Trees can raise property values (Donovan and Butry, 2010), produce goods such as food and wood products, and provide social, economic, aesthetic and health benefits (Hartig et al., 2014; Lee and Maheswaran, 2011; Lohr et al., 2004; Wolf, 2003).

Ecoservices provided by trees to human beneficiaries are classified according to their spatial scale as global and local (Costanza, 2008). For example, removal of carbon dioxide (CO_2) from the atmosphere by urban forests is global because the atmosphere is not contained to a local area. On the other hand, the effect of urban forests on building energy use is an example of a local scale service because it depends on the proximity of trees to buildings. Other local-scale urban forest services include rainfall interception, shade, air quality effects and property values.

Many municipalities are interested in quantifying the value of these ecosystem functions/services to improve understanding of the costs and benefits of urban forest management. There are a variety of tools and approaches used to do this, but commonly many cities in North American use tools and models developed by the USDA Forest Service to do this. Specific urban forest functions as described in the literature are explored in more detail in the following sections.

STORM WATER ATTENUATION

Trees are an appealing stormwater control measure because they provide a suite of ancillary social, economic, and environmental benefits (Escobedo, Kroeger, & Wagner, 2011; Mullaney, Lucke, & Trueman, 2015; Nowak & Dwyer, 2007). In urban areas, trees are part of the managed municipal infrastructure. Green infrastructure has emerged as a set of wastewater and stormwater management strategies that act as a complement to gray infrastructure (Fletcher et al., 2015). Green infrastructure leverages the properties of soil and vegetation to enhance watershed or sewershed detention capacity, and in this way, helps manage stormwater volumes (Berland et al., 2017). Trees are often integrated to support GI functions.

Specifically, trees can help manage stormwater by:

- Reducing runoff by capturing and storing rainfall in their canopy and releasing water into the atmosphere;
- Promoting infiltration of rainwater through soil conditions created by tree roots and leaf litter;
- Slowing down and temporarily storing runoff and reducing pollutants by taking up nutrients and other pollutants from soils and water through their roots; and
- Transforming pollutants into less harmful substances (EPA, 2013).

However, many of these interactions are inadequately understood, particularly at spatial and temporal scales relevant to stormwater management. As such, the reliable use of trees for stormwater control depends on improved understanding of how and to what extent trees interact with stormwater, and the context-specific consideration of optimal arboricultural practices and institutional frameworks to maximize the stormwater benefits trees can provide (Berland et al., 2017).

Research on the interaction between the urban forest and stormwater has been relatively understudied compared to other topics such as air quality and carbon sequestration benefits (Roy, Byrne, & Pickering, 2012; Xiao & McPherson, 2016).

However, some information is available to help quantify the effects of trees on stormwater management by interception, evapotranspiration and infiltration. These are discussed below.

INTERCEPTION

Canopy interception loss is the sum of water stored in tree canopies and evaporated from tree surfaces. Canopy interception loss protects water quality by reducing the volume of stormwater runoff and by reducing soil erosion and pollutant washout (Asadian & Weiler, 2009). Forest type is a key determinant of canopy interception rates.

In terms of quantifying interception, the following figures are presented from the literature:

- Interception on residential properties with relatively high canopy cover in North Carolina, USA, was measured at 19.9–21.4 per cent of total precipitation (Inkiläinen, McHale, Blank, James, & Nikinmaa, 2013).
- Xiao, McPherson, Simpson, and Ustin (1998) estimated that the urban forest in Sacramento, California, USA, intercepts 1.8 per cent of gross annual precipitation citywide at only 14 per cent canopy cover. This would be higher for cities with higher levels of tree canopy.
- Expected 10 per cent reduction in peak flows (peak storm event) to City's stormwater system based on modeling results of installation of 173 street trees using a modular system of structural cells that supported the sidewalk (Minneapolis, MN and Charlottetown, NC) (EPA, 2013)
- In a comparison of different species, *Fagus grandifolia* (American beech) intercepted an average of approximately 500 L per storm event (21.5 per cent interception) compared to approximately 650 L per event (27.8 per cent interception) for similarly-sized *Liriodendron tulipifera* (tulip tree) (Van Stan et al. (2015))

Table 19: Major factors* influencing the performance of trees as a stormwater control measure (Berland et al., 2017).

Tree[1]	Atmosphere[2]	Soil[3]	Landscape[4]
Evergreen/deciduous Species Phenology (leaf-on period) Size/age	Climate zone Annual precipitation Precipitation intensity	Rooting volume Water holding capacity Fertility Compaction	Surrounding land cover Impervious surfaces Watershed

Tree[1]	Atmosphere[2]	Soil[3]	Landscape[4]
Health Leaf area index Leaf morphology Branch angle Bark texture Evapotranspiration rate Root structure/depth	Precipitation duration Precipitation frequency Time between storm events Temperature Evaporative demand Wind	Drainage Green infrastructure installations (e.g. structural soils) Least limiting water range	position Pollution (air, water, soil) Tree density Open grown vs. overlapping crowns Ground cover (e.g. shrubs, turfgrass, bare ground) Slope/aspect

* This is not an exhaustive list. The research community should determine which factors must be quantified to reliably model the stormwater benefits expected from a tree.

EVAPOTRANSPIRATION

Given its importance in water cycling, evapotranspiration (ET) can play a critical role in urban management decisions regarding reduction of stormwater runoff, water resource use, and mitigation of urban heat islands via evaporative cooling (Peters, Hiller, & McFadden, 2011). However, while ET often represents the largest loss in water balance equations, relatively little attention has been paid to the role of ET by urban hydrologists.

Collectively, studies of urban water balance from cities representing different climates, geographic regions, and land development types demonstrate that urban areas vary in magnitude and seasonality of ET due to differences in climate, soil moisture status, irrigation, and vegetation cover (Balogun et al., 2009; Grimmond & Oke, 1999; Moriwaki & Kanda, 2004; Offerle, Grimmond, Fortuniak, & Pawlak, 2006; Peters et al., 2011).

Pataki et al. (2011) surveyed urban forest transpiration rates during August in the Los Angeles, California, USA, metropolitan region and observed substantial differences among species, with estimates ranging from 3.2 ± 2.3 kg·tree−1·d−1 in *Pinus canariensis* (Canary Island pine), a slower-growing coniferous tree, to 176.9

± 75.2 kg·tree−1·d−1 in *Platanus hybrida* (London plane tree), a faster-growing deciduous tree. McCarthy, Pataki, and Jenerette (2011), who also investigated transpiration rates of the urban forest in Los Angeles, reported transpiration rates varying from <5.0 × 10^3 kg·yr−1 for *Brachychiton populneus* (Kurrajong) to ~2.5 × 10^4 kg·yr−1 for *Gleditsia triacanthos* (honeylocust).

Evergreen needleleaf trees tend to have lower leaf transpiration rates than deciduous broadleaf trees (Givnish, 2002), yet both functional types tend to be more deeply rooted, and thus able to access deeper water sources, than cool season turfgrasses (Ludwig, Dawson, Prins, Berendse, & de Kroon, 2004).

In terms of ET rates, transpiration rates are 30 per cent higher for trees grown over asphalt compared to trees grown over turfgrass (Kjelgren & Montague, 1998). Densely planted trees also transpire at rates two to three times lower than sparsely planted trees (Hagishima, Narita, & Tanimoto, 2007). Optimal tree planting strategies can minimize measured differences in ET, and in addition capitalize on large canopy interception losses from trees. As such, cities in mesic regions experiencing frequent rainfall events may place higher value on maintaining large-canopied trees rather than turfgrasses because trees provide co-benefits of canopy interception and water cycling via ET (Wang, Endreny, & Nowak, 2008).

INFILTRATION

Incorporating trees into urban landscapes can substantially reduce stormwater runoff by improving infiltration. In experimental plots in Manchester, UK, tree pits containing small trees reduced runoff from asphalt control plots by 62 per cent, and this reduction was largely attributed to infiltration into the tree pit (Armson, Stringer, & Ennos, 2013). However, many urban trees grow on convex or mounded landscape settings that encourage runoff rather than detention and infiltration. As practiced with rain gardens and most other types of green infrastructure designed to detain and infiltrate stormwater, planting water-tolerant tree species in shallow, concave settings may be a good option for collecting runoff and allowing natural drawdown. Where soils slope away from the tree, the influence of tree morphology may be important to slow stemflow and throughfall to maximize infiltration, or to reduce ponding and subsequent erosion around the base of the tree.

KEY FINDINGS – STORMWATER ATTENUATION

- Canopy interception losses can contribute to the protection of water quality by appreciably reducing the volume of stormwater runoff and by reducing soil erosion and pollutant washout (Berland et al., 2017)
- Infiltration of water into tree pits reduced stormwater runoff from asphalt control plots by 62 per cent (Armson, Stringer, & Ennos, 2013)

- Increased planting of broadleaf evergreens and conifers has been proposed to maintain higher levels of canopy interception during leaf-off periods for deciduous trees (Clapp, Ryan, Harper, & Bloniarz, 2014; Xiao et al., 2000).
- However, evergreen needleleaf trees tend to have lower leaf transpiration rates than deciduous broadleaf trees (Givnish, 2002).
- A green infrastructure design that incorporates a mixture of plant functional types may be preferred for providing year-round cycling of stormwater volume inputs in urban landscapes (Berland et al., 2017).
- As practiced with many green infrastructure designs intended to detain and infiltrate stormwater, planting water-tolerant tree species in shallow, concave settings may be a good option for collecting runoff and allowing natural drawdown.

LITERATURE CITED - STORMWATER ATTENUATION

Asadian Y, & Weiler M (2009) A new approach in measuring rainfall interception by urban trees in coastal British Columbia. Water Quality Research Journal of Canada, 44, 16–25.

Berland A, Shiflett SA, Shuster WD, Garmestani AS, Goddard HC, Herrmann DL, Hopton ME. (2017). The role of trees in urban stormwater management. Landsc Urban Plan. 2017 Jun;162:167-177.

Escobedo FJ, Kroeger T, & Wagner JE (2011). Urban forests and pollution mitigation: Analyzing ecosystem services and disservices, Environmental Pollution, 159, 2078–2087.

Inkiläinen ENM, McHale MR, Blank GB, James AL, & Nikinmaa E (2013). The role of the residential urban forest in regulating throughfall: A case study in Raleigh, North Carolina, USA. Landscape and Urban Planning, 119, 91–103.

McCarthy HR, Pataki DE, & Jenerette GD (2011). Plant water-use efficiency as a metric of urban ecosystem services. Ecological Applications, 21, 3115–3127.

Mullaney J, Lucke T, & Trueman SJ (2015). A review of benefits and challenges in growing street trees in paved urban environments. Landscape and Urban Planning, 134, 157:166.

Nowak DJ, & Dwyer JF (2007). Understanding the benefits and costs of urban forest ecosystems, Urban and Community Forestry in the Northeast (Kuser JE, ed.), Springer, pp. 25–46.

Pataki DE, McCarthy HR, Litvak E, & Pincetl S (2011). Transpiration of urban forests in the Los Angeles metropolitan area. Ecological Applications, 21, 661–677.

Roy S, Byrne J, & Pickering C (2012). A systematic quantitative review of urban tree benefits, costs, and assessment methods across cities in different climatic zones. Urban Forestry & Urban Greening, 11, 351–363.

U.S. Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds, Nonpoint Source Control Branch (2013). Stormwater to Street Trees: Engineering Urban Forests for Stormwater Management. EPA 841-B-13-001, https://www.epa.gov/sites/production/files/2015-11/documents/stormwater2streettrees.pdf

Van Stan JT II, Levia DF Jr., & Jenkins RB (2015). Forest canopy interception loss across temporal scales: Implications for urban greening initiatives. The Professional Geographer, 67, 41–51.

Xiao Q, McPherson EG, Simpson JR, & Ustin SL (1998). Rainfall interception by Sacramento's urban forest. Journal of Arboriculture, 24, 235–244.

Xiao Q, McPherson EG (2016). Surface water storage capacity of twenty tree species in Davis, California. Journal of Environmental Quality, 45, 188–198.

AIR QUALITY

It has long been accepted that urban trees improve air quality through the interception of particulate matter and gases by leaves and branches. For example, a 2017 study showed that the public trees of Strasbourg reduce about 7 per cent of the emitted coarse particulate matter (PM_{10}) in the city's atmosphere. Exposure to particulate matter can contribute to respiratory issues and hospital admissions (Chatignoux and Host, 2013). Therefore, the role of trees in reducing or intercepting air pollution is of interest to municipalities from a public health perspective.

Improvements to public health linked to better air quality are often cited as a benefit of urban trees. A recent and very comprehensive review of the literature by Eisenman et al. (2019) examined the interactions between trees, air quality in urban areas and their relationship to asthma rates. The review concluded that causal pathways between urban trees, air quality, and asthma are very complex, and there are substantial differences in how natural science and epidemiology approach this issue.

On the one hand, urban trees can potentially reduce air pollution by having particulates and gases deposit on their leaves and branches. On the other hand, trees can potentially reduce air quality through a range of mechanisms, one being emission of organic compounds that can lead to ozone formation. A third effect of trees is their contribution to the restriction of air circulation in 'street canyons', which is a common condition in cities around the world. In this case, trees can actually concentrate pollutants in the places where people walk, bike and work by restricting air circulation in urban street canyons. And they can produce pollen, which can cause exacerbate seasonal allergies (Eisenman, 2019).

Different species have different capacities for mitigating air pollution. For example, the European beech (Fagus sylvatica) is considered as one of the top-rated species for removing the ozone and the carbon monoxide. Other species are also estimated as important for reducing (i) particulate matter: black walnut (*Juglans nigra*); and (ii) carbon monoxide: ginkgo (*Ginkgo biloba*), Crimean linden (*Tilia euchlora*), tulip tree (*Liriodendron tulipifera*), silver linden (*Tilia tomentosa*) (Nowak, 2000). More research is needed to understand differing species abilities to remove air pollution (e.g. Beckett et al., 2000; Yang et al., 2015). This research will help in providing better recommendations to managers regarding selecting trees species to improve air quality.

Urban trees help to mitigate air pollution, but they are one of many potential solutions to this problem. Reducing emissions from the source prevents pollutant emissions and trees should not be used as alternate solution to emission reduction, but rather as complementary one. Though not investigated in this study, trees can reduce pollutant emissions by lower air temperatures and/or reducing building energy use. However, tree can also produce particles (e.g. pollen), limit pollutant dispersion and thus increase local pollutant concentrations (e.g. near roadways) (e.g. Gromke and Ruck, 2009; Wania et al., 2012; Salmond et al., 2013).

Planting and managing trees should be associated with other integrative planning strategies usually based on either technological (e.g. more energy efficient technology) or non-technological measures (e.g. built and organize cities to reduce energy consumption and associated emissions).

KEY FINDINGS – AIR QUALITY

- Different tree species have different capacities for intercepting air pollution.
- The interaction of urban trees and air quality is complex – while trees have been proven to intercept particulate matter and produce oxygen, they also produce VOCs and may contribute to ground level pollution by trapping air pollution in ‘street canyons’ (Eisenman, 2019)
- Even though overall pollutant concentration in cities can be reduced by trees, it may be increased at the local scale depending on several factors including urban forest and street design and local roadside emissions (Wania et al., 2012; Vos et al., 2013).
- Planners need to consider the impact of urban trees and green spaces on local air quality to create better and more informed plans that ensure air purification and sustain human health in cities (Selmi et al., 2017).

- There is a need for more interdisciplinary research, and in particular, more empirical research by epidemiologists to understand the link between urban trees, their effects on air quality and implications for human health (Eisenman, 2019).
- Trees provide numerous benefits to wildlife and human health and well-being that are unrelated to air quality (Eisenman 2019).
- The lack of certainty around interactions between urban trees and air pollution does not preclude the many other values of planting trees in urban areas (Eisenman, 2019).

AIR POLLUTION - LITERATURE CITED

Chatignoux, E., Host, S., 2013. Expositions à la pollution atmosphérique et recours aux urgences pour pathologies respiratoires chez les enfants en Ile-de-France, Expositions à la pollution atmosphérique et recours aux urgences pour pathologies respiratoires chez les enfants en Ile-de-France

Eisenman, T. S., Churkina, G., Jariwala, S. P., Kumar, P., Lovasi, G. S., Pataki, D. E., ... Whitlow, T. H. (2019). Urban trees, air quality, and asthma: An interdisciplinary review. Landscape and Urban Planning, 187, 47-59. Available at: Urban trees, air quality, and asthma: An interdisciplinary review

Gromke, C., Ruck, B., 2009. On the impact of trees on dispersion processes of traffic emissions in street canyons. Boundary Layer Meteorol. 131, 19–34.

Nowak, D.J., 2000. Tree species selection, design, and management to improve air quality. Construction Technology: Annual Meeting Proceedings of the American Society of Landscape Architects.

Salmond, J.A., Williams, D.E., Laing, G., Kingham, S., Dirks, K., Longley, I., Henshaw, G.S., 2013. The influence of vegetation on the horizontal and vertical distribution of pollutants in a street canyon. Sci. Total Environ. 443, 287–298.

Wania, A., Bruse, M., Blond, N., Weber, C., 2012. Analysing the influence of different street vegetation on traffic-induced particle dispersion using microscale simulations. J. Environ. Manage. 94, 91–101.

Wissal Selmi, Christiane Weber, Emmanuel Rivière, Nadège Blond, Lotfi Mehdi, David Nowak. Air pollution removal by trees in public green spaces in Strasbourg city, France. Urban Forestry & Urban Greening 17 (2016) 192–201.

ENERGY SAVINGS (HEATING AND COOLING)

The use of urban vegetation in cities is a common landscape planning strategy to alleviate the heat island effect as well as to enhance building energy efficiency. The presence of trees in street canyons can effectively reduce environmental temperature via radiative shading (Wang et al., 2016). In summer, trees block unwanted solar radiation entering the building and hence reduce the cooling load if placed properly around the building. Trees reduce surface temperature, glare, and block the diffuse radiation reflected from the sky and the surrounding surfaces, thereby alerting the heat exchange between the buildings and its surroundings (Abdel-Aziz, 2015).

A study in Beijing, China showed the following advantages of trees in energy savings through cooling (Zhang et al., 2014):

- Green spaces absorbed 3.33 × 1012 kJ of heat via evapotranspiration during summer.
- The cooling effect annually reduced demand for air conditioning by 3.09 × 108 kWh.
- Annual reduction in CO_2 emissions from power plants could exceed 243 thousand tons.

A 2015 study assessed tree survivorship, growth, and energy performance over 22 years in Sacramento, CA. It found that annual cooling saving per property and per tree were 107 kW h per property and 80 kW h per tree, representing a seasonal cooling energy savings of 30 per cent (Ko et al., 2015; Akbari et al., 1992). A 25 per cent increase in tree cover (three trees per house) was estimated to reduce cooling energy use by 57 per cent in Sacramento, 25 per cent in Lake Charles, LA and 17 per cent in Phoenix, AZ (Nowak et al., 2017)

Trees and their alterations to local climate generally reduce building energy consumption during summer seasons when building cooling is the dominant space conditioning energy use (Heisler 1986b). However, during the winter season when heating energy use dominates, trees can increase energy use if trees cast shade on buildings. This shade is particularly important for trees to the south side of buildings in the United States as solar input on south facing walls at 40 degrees north latitude are 1.5–2 times greater in the winter than in summer (Heisler 1986b). Even deciduous trees cast winter shade and typically block 35 per cent of incoming solar radiation when leaf-off (McPherson 1984).

In Canada (urban houses of Edmonton, Montreal, and Vancouver), savings in heating energy use by combining tree planting with increasing the albedo of houses showed that heating was reduced about 10 per cent. Cooling energy using the same techniques can be totally offset in Edmonton and Vancouver, and average savings of 35 per cent can be achieved in Montreal (Akbari and Taha, 1992).

KEY FINDINGS – ENERGY SAVINGS

- Energy conservation and associated values could be enhanced through strategic planting of trees around buildings.
- Tree size, species (evergreen vs. deciduous), and tree distance and direction from the building all affect building energy use (McPherson and Simpson 1999)
- Residential energy reduction from trees in the US is about 7.2 per cent (Nowak et al., 2017)
- Trees contribute to energy savings from cooling and heating in both summer and winter – however, shade trees used for cooling make a greater contribution to energy savings than the effects of trees for saving heating energy in winter (Akbari and Taha, 1992).
- Specific designs to reduce energy use using urban trees could increase these values and further reduce energy use (Nowak et al., 2017)
- While results vary by climate zone, in general:
    - Large trees to the west side of the building provide the greatest average reduction in cooling energy savings (Nowak et al 2017)
    - Large trees to the south side tend to lead to the greatest increase in winter energy use (Heisler 1986a) by blocking incoming solar radiation in winter.
- Planting medium stature trees and rapidly growing large trees achieves the greatest long-term energy savings (Ko et al., 2015)

LITERATURE CITED – ENERGY SAVINGS

Akbari, H., Davis, S., Dorsano, S., Huang, J., Winnett, S., 1992. Cooling our communities; A guidebook on tree planting and light-colored surfaces. Lawrence Berkeley Laboratory Report LBL-31587. U.S. Environmental Protection Agency, Washington, DC (217 p).

Dania M. Abdel-Aziz, Abdulsalam Al Shboul, Nabeel Y. Al-Kurdi. (2015). Effects of Tree Shading on Building's Energy Consumption - The Case of Residential Buildings in a Mediterranean Climate. American Journal of Environmental Engineering 2015, 5(5): 131-140. DOI: 10.5923/j.ajee.20150505.01

Yekang Ko, Jun-Hak, Lee, E. Gregory McPherson, Lara A. Romand. (2015). Long-term monitoring of Sacramento Shade program trees: Tree survival, growth and energy-saving performance. Landscape and Urban Planning Volume 143, November 2015, Pages 183-191.

David J. Nowak, Nathanial Appleton, Alexis Ellis, Eric Greenfield. (2017). Residential building energy conservation and avoided power plant emissions by urban and community trees in the United States. Urban Forestry & Urban Greening, 21: 158-165.

Zhi-Hua Wang, Xiaoxi Zhao, Jiachuan Yang, Jiyun Song. 2016. Cooling and energy saving potentials of shade trees and urban lawns in a desert city. Applied Energy Volume 161, 1 January 2016, Pages 437-444, Cooling and energy saving potentials of shade trees and urban lawns in a desert city

Biao Zhang, Gao, Xie, Ji-xi Gao, Yang Yang. The cooling effect of urban green spaces as a contribution to energy-saving and emission-reduction: A case study in Beijing, China. Building and Environment Volume 76, June 2014, Pages 37-43.

URBAN FOREST MODELLING AND FORECASTING

This increasing recognition of ecosystem service value is changing the perception of nature in cities and is a result of the recent surge in the systematic assessment and the quantification of urban forests benefits. Additionally, software that assesses and models ecosystem benefits, such as i-Tree and inVest, has made the quantification and comparison of ecosystem services both commonplace and cost-effective. Any discussion of urban forest benefits — aesthetic and socio-cultural values, energy and climate management, air and water quality, storm water and soil retention, habitat and biodiversity enhancement, carbon sequestration, or economic benefit — will now assuredly include an estimated dollar amount.

Urban forest modeling is becoming increasingly complex, global, and transdisciplinary. Historically, modeling is more advanced in the fields of traditional forestry and pomology than in urban forestry because of the highly variable growing conditions in cities (McPherson and Peper, 2012). Increased modeling of urban forest structure and function presents an urgent need for comparative studies to assess the similarities and differences between modeling techniques and applications.

A recent (2019) literature review provides a systematic review of 242 journal papers over the past two decades and identifies 476 case studies in urban forest modeling. It assesses model case studies among different locations, units and scales, compares the ability and functional capacity of the models and different tools, compares papers published in different disciplines, and identifies new emerging topics in the field of urban forest modeling.

Conclusions from this analysis include:

- The spatial distribution of case studies is primarily clustered around the US, Europe, and China, with the most popular units to model being streets and parks;
- The most commonly used model types are the i-Tree toolset, ENVI-met, computational fluid dynamic models, and the Hedonic price model;

- Uncertainty assessment of urban forest models is limited;
- Spatially explicit models are critically important for estimating of ecosystem services as well as for environment management;
- Most case studies focus on biophysical benefits with few studies estimating economic and social benefits; and
- Linkages between urban forests and their social-psychological and health effects are less common due to subjectivity and uncertainty in expressing and quantifying human cultures, attitudes and behaviors.

Many of the current urban forest modelling tools in use across North America have been developed by the USDA Forest Service and its research partners. These tools are increasingly focusing on an integrated ecological system, rather than individual trees, and new tools are being developed to help foster environmental stewardship. For example, the Stewardship Mapping and Assessment Project (STEW-MAP) is a geospatial tool utilized by several cities, including New York City, to understand the intersections of green space and social space. These maps quantify stewardship networks and linkages to encourage more cooperation among organizations (Bartuska, 2013).

The i-Tree suite of models developed by the United States Department of Agriculture (USDA) Forest Service and partners provides a number of tools and methodologies for quantifying and assessing the structure and function of urban forest ecosystems. The i-Tree Eco model in particular has been used by a large number of municipalities to assess their urban forest resource and inform policy development (Ordóñez and Duinker 2013; USDA Forest Service 2013). The i-Tree Forecast model has been developed to simulate temporal changes in urban forest structure and function and can therefore be used to investigate future urban forest vulnerability.

Vulnerability assessment and analysis is another approach that can provide strategic planning initiatives with valuable insight into the processes of structural and functional change resulting from management intervention (Steenberg et al., 2017). Vulnerability science can provide an approach for integrating the biophysical, social, and built dimensions of urban forest stress and disturbance, shifting the focus beyond an impacts-only perspective to a more holistic view of the entire ecosystem and its structure and function (Wickham et al. 2000; Turner et al. 2003a; Adger 2006; Steenberg et al. 2016).

The temporal nature of vulnerability frequently necessitates some form of ecological modeling to forecast potential scenarios of change (Eakin and Luers 2006). Moreover, ecological modeling in highly complex and uncertain social-ecological systems like the urban forest enables the simulation of alternative experimental scenarios at spatial and temporal scales that would not otherwise be feasible (Jørgensen and Bendoricchio 2001; Landsberg 2003).

KEY FINDINGS - MODELLING AND FORECASTING

- The most commonly used model types are the i-Tree toolset, ENVI-met, computational fluid dynamic models, and the Hedonic price model.
- Uncertainty assessment of urban forest models is limited.
- Spatially explicit models are critically important for estimating ecosystem services as well as for environmental management.
- Most case studies focus on biophysical benefits with few studies estimating economic and social benefits.
- Linkages between urban forests and their social-psychological and health effects are less common due to subjectivity and uncertainty in expressing and quantifying human cultures, attitudes and behaviors.
- Vulnerability assessment and analysis is another approach that can provide strategic planning initiatives with valuable insight into the processes of structural and functional change resulting from management intervention

LITERATURE CITED - MODELLING AND FORECASTING

Bartuska, A. Chapter 2 Urban Forestry: Services, Tools, And Management. Setting Goals and Developing Strategies in Urban Forestry. U.S. Department of Agriculture. Toward an Ecosystem Services Research Agenda - A Workshop Summary. Board on Atmospheric Sciences and Climate Division on Earth and Life Studies. National Research Council of the National Academies.

J. Lin, C.N. Kroll, D.J. Nowak and E.J. Greenfield. 2019. A review of urban forest modeling: Implications for management and future research. Urban Forestry & Urban Greening Volume 43, July 2019.

Steenberg, J.W.N., Millward, A.A., Nowak, D.J. et al. Forecasting Urban Forest Ecosystem Structure, Function, and Vulnerability. Environmental Management (2017) 59: 373. https://doi.org/10.1007/s00267-016-0782-3

K. Thomas and L. Geller, Rapporteurs. 2013. Urban Forestry: Toward an Ecosystem Services Research Agenda, A Workshop Summary. National Research Council of The National Academies. Washington, D.C.

METHODOLOGIES FOR ASSESSING URBAN FOREST VALUES (GOODS AND SERVICES)

The most accurate approach to quantifying an urban forest structure is to conduct a field inventory that measures and records every tree on a site (Gunwoo, 2016). Although such an inventory can work well for small tree populations (e.g. street trees and those in small parks), it is expensive for larger tree populations so random sampling is generally applied as a cost-effective way to assess urban forest structure, function, and value for large-scale assessments (Nowak et al., 2008). There are various sampling techniques to assess urban forests, but most use a form of random sampling (e.g. McBride et al., 1976, McBride and Jacobs, 1986, Miller and Winer, 1984, Nowak, 1991, McPherson, 1998, Nowak and O'Connor, 1991).

The U.S. Forest Service has developed a specialized tool to perform such evaluations, the i-Tree Eco model (formerly known as the Urban Forest Effects (UFORE) model). This model incorporates protocols to measure and monitor urban forest structure and estimate ecosystem functions and economic values (Nowak and Crane, 2000); the associated software utilizes standardized field data from randomly located plots (or tree inventories) and local hourly air pollution and meteorological data to quantify urban forest structure and its numerous effects (Nowak et al., 2008). The i-Tree Eco model has been used in hundreds of cities across the globe to assess urban forest structure and its numerous ecosystem services using a standardized field sampling method (e.g. Nowak and O'Connor, 2002, Nowak et al., 2002, Ham, 2003)

The context in which trees and forests grow in cities is highly variable and influences the provision of ecological, social, and economic benefits. Understanding the spatial extent, structure, and composition of forests is necessary to guide urban forest policy and management, yet current forest assessment methodologies vary widely in scale, sampling intensity, and focus (Pregitzer et al., 2019). Current definitions of the urban forest include all trees growing in the urban environment, and have been translated to the design of urban forest assessments. However, such broad assessments may aggregate types of urban forest that differ significantly in usage and management needs. For example, street trees occur in highly developed environments, and are planted and cared for on an individual basis, whereas forested natural areas often occur in parkland, are managed at the stand level, and are primarily sustained by natural processes such as regeneration (Pregitzer et al., 2019).

Non-stratified assessments of urban forest canopy must be modified to accurately represent the true composition of different urban forest types to inform effective policy and management. Developing new conceptions of urban forests and how they are measured will help to maximize the benefits from trees in cities by promoting tailored forest management and conservation strategies that are appropriate to the forest type, the stand condition, environment, future needs, and the resources available in cities (Pregitzer et al., 2019).

KEY FINDINGS - ASSESSING URBAN FOREST VALUES

- Random sampling is generally applied as a cost-effective way to assess urban forest structure, function, and value for large-scale assessments.
- The U.S. Forest Service has developed a specialized tool to perform such evaluations, the i-Tree Eco model.
- The i-Tree Eco model has been used in hundreds of cities across the globe to assess urban forest structure and its numerous ecosystem services using a standardized field sampling method.
- Broad assessments may aggregate types of urban forest that differ significantly in usage and management needs.
- Using non-stratified assessments of urban forest canopy to accurately represent the true composition of different urban forest types can better inform effective policy and management.

LITERATURE CITED - ASSESSING URBAN FOREST VALUES

Gunwoo. K. Assessing Urban Forest Structure, Ecosystem Services, and Economic Benefits on Vacant Land. Sustainability 2016, 8, 679; doi:10.3390/

McBride, J.; Jacobs, D. Urban forest development: A case study, Menlo Park, California. Urban Ecol. 1976, 2, 1–14.

McBride, J.R.; Jacobs, D.F. Presettlement forest structure as a factor in urban forest development. Urban Ecol. 1986, 9, 245–266.

Miller, P.R.; Winer, A.M. Composition and dominance in Los Angeles Basin urban vegetation. Urban Ecol. 1984, 8, 29–54.

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

McPherson, E.G. Structure and sustainability of Sacramento's urban forest. J. Arboric. 1998, 24, 174–190.

Nowak, D.J.; O’Connor, P.R. Syracuse urban forest master plan: Guiding the city’s forest resource into the 21st century. 2001.

Nowak, D.J.; Crane, D.E.; Stevens, J.C.; Hoehn, R.E.; Walton, J.T.; Bond, J. A Ground-Based Method of Assessing Urban Forest Structure and Ecosystem Services. Arboric. Urban For. 2008, 34, 347–358.

Nowak, D.J.; Crane, D.E.; Dwyer, J.F. Compensatory value of urban trees in the United States. J. Arboric. 2002, 28, 194–199.

Ham, D.L. Analysis of the urbanizing of the South Carolina Interstate 85 corridor. In Proceedings of the 2003 National Urban Forest Conference, San Antonio, TX, USA, 17–20 September 2003; p. 67.

C. Pregitzer, M.S. Ashton, S. Charlop-Powers, A.W. D'Amato, B.R. Frey, B. Gunther, R.A. Hallett, K.S. Pregitzer, C.W. Woodall and M.A. Bradford. Defining and assessing urban forests to inform management and policy. Environ. Res. Lett. 14 (2019) 085002.

MONITORING LAND COVER CHANGE

In an urban environment natural and human-induced environmental changes are of concern today because of deterioration of the environment and human health (Jat et al., 2008). The study of land use/land cover (LU/LC) changes is very important to have proper planning and utilization of natural resources and their management (Asselman and Middelkoop, 1995). Traditional methods for gathering demographic data, censuses, and analysis of environmental samples are not adequate for multicomplex environmental studies (Maktav et al. 2005), since many problems often presented in environmental issues and great complexity of handling the multidisciplinary data set; we require new technologies like satellite remote sensing and Geographical Information Systems (GIS). These technologies provide data to study and monitor the dynamics of natural resources for environmental management (Berlanga-Robles and Ruiz-Luna, 2002).

Remote sensing has become an important tool applicable to developing and understanding the global, physical processes affecting the earth (Hudak and Wessman, 2005). A recent development in the use of satellite data is to take advantage of increasing amounts of geographical data available in conjunction with GIS to assist in interpretation (Tziztiki, et. al., 2012).

Recognizing both the many benefits of urban forests and the continued decline in urban canopy cover, cities and municipalities across the country have developed urban forestry programs, management plans, and urban forest goals driven by public policy and municipal mandates. Within the United States, the majority of municipal afforestation goals and urban forestry plans are tied to a single metric — urban tree canopy, or canopy cover (Piana & Troxel, 2014). A recent study determined that 38.9 per cent of 329 U.S. cities with populations of 50,000 or greater have adopted a canopy cover goal (Krause, 2011), most of which reference targets established by American Forests, who recommends a canopy cover of 40 per cent, with more specific recommendations based on land use and geographic location (American Forests, 2019).

In the United States and Canada, many urban forestry plans include urban tree canopy (UTC), or canopy cover as a key metric (Piana & Troxel, 2014). As far back as 2011, it was determined that 38.9 per cent of 329 U.S. cities with populations of 50,000 or greater have adopted an urban tree canopy cover goal (Krause, 2011).

If cities are using tree canopy cover as a key metric in urban forest management plans, accurate estimation of UTC is a basic management requirement. More broadly, land cover change overall informs the planning and prioritization of future urban forest distribution by using specific types of land cover (pervious and impervious) as a proxy for plantable area. A 2019 USDA synthesis report provides an overview of the approaches, methods, and data sources used in UTC and land cover assessments.

APPROACHES

Approaches include random point sampling methods, such as i-Tree canopy, which provide a cheap and quick estimation of UTC for a large area. They also include remote sensing methods in common use, which use airborne Light Detection and Ranging (LiDAR) and multi-spectral images to produce spatially explicit urban land cover maps with varying degrees of accuracy.

Figure 38: Elements of UTC assessment using remote sensing techniques (Source: USDA 2019).

There are some inherent challenges for comparing sequential estimates of land and tree cover to detect change. In remote sensing, some of these include differences in quality between consecutive years of imagery (e.g. more shadow, which can be misclassified as tree canopy) as well as changes in image resolution and classification methodologies. In the point sampling approach, which requires manual interpretation of imagery, there are opportunities for variability in classification based on interpreter bias, and also on the quality of imagery available (resolution, time of year, leaf on vs. leaf off, etc.) In terms of what this means for accuracy, one study estimated the difference between UTC estimated by remote sensing and manually categorized random point sampling varied in range of 4.5 per cent using a confidence level of 95 per cent (Parmehr et al. 2016).

While every approach has its limitations, these can be managed by understanding how to verify the quality and accuracy of remote imagery assessments (Hartel 2015). In remote sensing, this is usually done by developing an 'error matrix'. An error matrix presents a comparison of the value assigned during the classification process to the actual value interpreted from an aerial photo or other type of base imagery. In addition to the error matrix, UTC assessment should describe how the following issues are addressed in the classification:

- Minimum mapping units (MMU)
    - An entity such as a forest stand mapped as a point at one scale may be represented as a polygon on a map at a finer scale. The representation of features on a particular map is a feature of map scale, data resolution, and mapping conventions. These issues should be identified in UTC assessment to ensure reliability of the mapping.
- Filling "holes and gaps"
    - The contractor should provide detailed descriptions of how gaps were filled and other methods used to improve the overall classification quality
- Integrating ancillary data
    - UTC assessment should detail the datasets used and methods for integrating ancillary datasets into the accuracy assessment.
- Post-classification editing
    - Changes made to the mapping products for error correction should be detailed in terms of the number and extent of corrections, as well as the methodology used.

Finally, using local knowledge to perform a "does-it-make-sense" quality check will help detect any anomalies. Understanding the different capabilities and limitations of various types of remote sensing data and land use/ land cover classification methods, as well as differences in resolution, costs, and accuracy, is essential to choosing the right set of tools to meet information objectives.

KEY FINDINGS – MONITORING LAND COVER CHANGE

- The study of land use/land cover (LU/LC) changes is very important for proper planning and management of natural resources.
- Remote sensing has become an important tool for understanding the global, physical processes affecting the earth, including land cover change in cities.

- Urban tree canopy assessment (UTC) provides a valuable tool for monitoring land and tree canopy change to assess program performance toward municipal tree canopy goals.
- There are two main approaches to conducting UTC assessments, including manual point sampling techniques, which can use open source software like i-Tree Canopy (non-spatial) and remote sensing using multispectral imagery and/or LiDAR (spatial).
- Every approach to monitoring land use has some limitations in terms of reliability, accuracy and comparability over consecutive years of imagery.
- These limitations can be managed by having a sound understanding of how to verify the quality and accuracy of remote imagery assessments.

LITERATURE CITED – MONITORING LAND COVER CHANGE

M. K. Jat, P. K. Garg, and D. Khare, "Monitoring and modelling of urban sprawl using remote sensing and GIS techniques," International Journal of Applied Earth Observation and Geoinformation, vol. 10, no. 1, pp. 26–43, 2008.

N. E. M. Asselman and H. Middelkoop, "Floodplain sedimentation: quantities, patterns and processes," Earth Surface Processes & Landforms, vol. 20, no. 6, pp. 481–499, 1995.

D. Maktav, F. S. Erbek, and C. Jürgens, "Remote sensing of urban areas," International Journal of Remote Sensing, vol. 26, no. 4, pp. 655–659, 2005.

C. A. Berlanga-Robles and A. Ruiz-Luna, "Land use mapping and change detection in the coastal zone of northwest Mexico using remote sensing techniques," Journal of Coastal Research, vol. 18, no. 3, pp. 514–522, 2002.

Hartel, D. 2015a. Urban tree canopy: discussion of 3rd party roles & opportunities. Available at: Urban tree canopy: discussion of 3rd party roles & opportunities (15 August 2017).

Marie Rachel Krause, "An assessment of the greenhouse gas reducing activities being implemented in US cities." Local Environment 16, no. 2 (2011): 193-211.

E.G. Parmehr, M. Amati, E.J. Taylor, and S.J. Livesley. 2016. Estimation of urban tree canopy cover using random point sampling and remote sensing methods. Urban Forestry & Urban Greening Volume 20, 1 December 2016, Pages 160-171.

M. Piana and B. Troxel. (2014) Beyond Planting: An Urban Forestry Primer. Scenario Journal. Scenario 04: Building the Urban Forest. Available at: Beyond Planting: An Urban Forestry Primer. Scenario Journal. Scenario 04: Building the Urban Fores

Setting urban tree canopy goals. American Forests website, American Forests, Washington, DC. Accessed on 8/1/09. Available at: Setting urban tree canopy goals

COSTS OF MAINTAINING/NOT MAINTAINING THE URBAN FOREST

Increasingly, city trees are viewed as a best management practice to control stormwater, an urban-heat–island mitigation measure for cleaner air, a CO_2-reduction option to offset emissions, and an alternative to costly new electric power plants. Measuring benefits that accrue from the community forest is the first step to altering forest structure in ways that will enhance future benefits (McPherson, Simpson, Peper, Maco and Xiao 2005).

While the dollar value of the services provided by trees have now been recognized and quantified in many urban forestry studies and plans, there are also dollar and opportunity costs associated with planting, maintaining and removing trees across their lifetime (Table 20).

Table 20: Types of cost associated with maintaining urban trees (Vogt et al. 2015).

Type of cost	Examples
Direct costs (of provisioning and maintaining trees)	Planting, pruning, watering, other types of maintenance
Infrastructure interference costs	Pavement and sewer repair, blockage of signs, tree-initiated power outages
Externality-related costs	Emissions of biogenic volatile organic compounds (VOCs), release of carbon dioxide during decomposition, allergies due to pollen release, leaf/debris clean up
Opportunity costs	Space for trees cannot be used for parking, bike lanes, etc.

However, studies that specifically examine the costs of not maintaining the urban forest are scarce. Many of the existing studies were summarized in a 2015 literature review, looking specifically at the costs of maintaining and not maintaining the urban forest. The authors found that overall, the costs of maintaining trees are clearer than are the costs of not maintaining trees in the urban forest. They found that deferring costs at present often leads to future cost much later in a tree’s life span that was not anticipated. It was also noted that certain non-maintenance actions stood out above the rest, including: not doing early tree care, not managing for pests and disease, not planting trees and liability issues related to lack of tree care. Some examples of studies that attempt to quantify costs of non-maintenance are summarized below.

The costs of not pruning trees have rarely been examined outside of the context of utility arboriculture or pruning cycles. One of the few studies available that explicitly looks at this question is by Ryder and Moore (2013). In this study, the authors looked at the difference in cost between formative (early) and mature tree pruning. They estimated that using inflation rates of 3 per cent –5 per cent, trees not formatively pruned today would cost $78 to $112 to structurally prune in 20 years. Thus, the cost of not performing formative pruning on recently planted trees can be calculated as the difference between the costs of formative pruning plus normal structural pruning (~$48) and structural pruning for non-formatively pruned trees ($78–$112), or between $30 and $64.

Many trees in built environments are the direct result of planting trees, though some forest regeneration also happens naturally in cities. Once again, there is a scarcity of literature looking at foregone benefits of not planting trees though a few examples provide some information. In one study, a "benefits forgone" metric looking at lost benefits from trees not planted in parking lots was equal to USD $1.9–3.4 million annually as calculated in this study ($1.4–2.5 million in 2000$; McPherson 2001). However, the author notes that this figure is strictly benefits forgone, rather than net benefits forgone, as it does not include the full costs associated with planting and maintaining the greater number of trees to provide benefits (e.g. repair to pavements due to tree damage). A 1984 study that simulated the changes in a street tree population and related costs over time using street tree data from Wisconsin found that a fully-stocked urban forest was initially the most costly management scenario, but that it resulted in the greatest net benefits over a 40-year run (Miller and Morano 1984).

The impacts of pests are on areas that have been fairly well documented from a cost perspective, particularly as they relate to Emerald Ash Borer. A 2012 projection of the impacts of EAB in Canadian municipalities put the present value of EAB mortality at approximately CAD $524 million (2010 currency rate); this value increased to roughly $890 million when costs associated with backyard trees were included. These estimates were also considered conservative at the time, because they focused only on damage to street (and backyard) trees (did not include woodlands). Estimates for the City of Winnipeg over a 10-year period to manage the effects of EAB are expected to cost $105 million. This includes:

- $22.5 million to remove 72,000 dead trees
- $48 million to plant 65,000 new ones
- $19.5 million to treat/inject 29,000 trees
- $15 million to manage the wood waste from the dead trees.

KEY FINDINGS: THE COST OF MAINTAINING AND NOT MAINTAINING THE URBAN FOREST

- There are many studies quantifying the value of services provided by trees as well as the direct costs of maintaining the urban forest.

- Direct costs of maintaining the urban forest that are tracked by most cities include planting, pruning, removal, pest management and sometimes infrastructure repair - these numbers are fairly well understood.
- Other costs (like the opportunity costs associated with trees) are not tracked and less well understood.
- Literature looking at the cost of not maintaining the urban forest resource is scarce.
- One 2013 study suggests that the difference in cost to municipalities between not performing young pruning maintenance but rather pruning 20 years later, is about $30-$64 per tree, at a 3-5 per cent inflation rate (McPherson 2001).
- Some particular maintenance non-actions stand above the rest (Vogt et al. 2015):
    - not caring for trees in early establishment (i.e., not watering)
    - not managing for diseases or pests, such as DED or EAB, and the subsequent loss of net benefits;
    - not maintaining the urban forest as a whole by not planting trees (and, again, the loss of net benefits resulting therefrom); and
    - instances where lack of tree care may result in decline in tree condition and/ or future liability issues.
- Of these, points two and three are most clearly addressed in the literature.
- Future research partnerships should aim to examine the influence of maintenance regimes on costs and tree outcomes, including examining how the frequency, intensity, duration, and extent of different types of tree maintenance activities are connected to the structure, function, and benefits of trees (Vogt et al. 2015).

LITERATURE CITED – COST OF MAINTAINING/NOT MAINTAINING THE URBAN FOREST

City of Winnipeg, City of Winnipeg EAB webpage

J. M. Vogt, R.J. Hauer and B.C. Fischer. 2015. The Costs of Maintaining and Not Maintaining the Urban Forest: A Review of the Urban Forestry and Arboriculture Literature. Arboriculture & Urban Forestry 2015. 41(6): 293–323.

D.W. McKenney, J.H. Pedlar, D. Yemshanov, D.B. Lyons, K.L. Campbell and K. Lawrence. 2012. Estimates of the Potential Cost of Emerald Ash Borer (*Agrilus planipennis Fairmaire*) in Canadian Municipalities. Arboriculture & Urban Forestry 2012. 38(3): 81–91.

G. McPherson, J.R. Simpson, P.J. Peper, S. E. Maco, Q. Xiao. (2005). Journal of Forestry, Volume 103, Issue 8, December 2005, Pages 411–416

R.W. Miller and M.S. Morano. 1984. URFOR/SIMULATION: An urban forest management computer simulation/game. Journal of Arboriculture 10(2):55–63.

INCREASING THE RESILIENCE OF THE URBAN FOREST TO THREATS

Urban forests face a range of threats that can decrease forest health in the short and long term and thereby reduce the benefits urban forests deliver to the human population. Some of these threats are posed by natural factors, but generally the main threats to urban forests result from human activity.

Human-driven climate change threatens to alter urban forests in ways that cannot be precisely predicted, but are expected to include average temperature changes, increasing instances of severe storms and changes in weather patterns in general. The international trade of goods over the past two centuries has resulted in the introduction of invasive species that have shaped our urban forests, sometimes in very dramatic and negative ways. Furthermore, as the proportion of the human population living in urban areas rises, there is a corresponding increase in urban development, which exerts pressure on urban forests and forests at the fringes of urban areas. It is therefore crucial that municipalities devise management strategies that account for these factors and that seek to increase resilience in the face of a range of threats.

“Resilience” is a concept that can be used to stimulate interdisciplinary research, to support understanding, management and governance of complex linked systems of people and nature, and to guide development pathways in changeable and uncertain environments. Using the concept of resilience to frame a discussion about risks to urban tree performance helps to highlight the difference between the intervention (i.e., the planting of a tree), its intended benefits, and the conditions upon which these benefits depend. Distinguishing the intervention from its intended benefits makes explicit that it is the benefits that the tree delivers that need to be resilient, even if the tree itself, and the urban system within which it is embedded, undergo changes in the future (Hale et al., 2015).

Resilience might be increased by broadening planting locations to include private green spaces immediately adjacent to streets and improving the co-management of street trees by individuals, NGOs and municipal departments. This could be supported by the introduction of market-based systems to incentivise the participation of a broad range of stakeholders in the long-term protection and management of urban street trees. In addition, planting techniques that reduce the need for supplementary watering, reduce maintenance requirements, isolate roots from potentially polluted urban soils, and that facilitate transplantation, have the potential to improve the resilience of urban street tree benefits (Hale et al., 2015).

LITERATURE CITED – INCREASING RESILIENCE

J.D. Hale, T.A.M. Pugh, J.P. Sadler, C.T. Boyko, J. Brown, S. Caputo, M. Caserio, R. Coles, R.Farmani, C. Hales, R. Horsey, D, V. L. Hunt, J.M. Leach, C.D.F. Rogers and

A.R. MacKenzie. Delivering a Multi-Functional and Resilient Urban Forest. Sustainability 2015, 7(4), 4600-4624; https://doi.org/10.3390/su7044600.

CLIMATE CHANGE

Urban forests can help cities adapt to climate change, but they are simultaneously threatened by the effects of climate change. Therefore, managing for climate resilience must balance these realities and account for assets and areas of vulnerability (Pramova et al., 2012).

Exposures related to drought, heat stress, and wind, susceptibility of urban trees to insects and diseases, and the sensitivity of young trees and tree species with specific temperature and moisture requirements, are the main concerns regarding the vulnerability of urban forests to climate change in three Canadian cities (Ordóñez and Duinker, 2015).

Proper species selection may take into account a variety of climate-related influences, such as changes in moisture and temperature regimes and abundance of pests. In a study of four common urban tree species, Fahey et al. (2013) found considerable variation in tree growth response to drought across species, growing conditions, and land uses, suggesting that some portions of the urban forest could be more adversely affected by climate change than others.

While the future impacts of climate change on urban forests are uncertain, some researchers have sought to develop predictive models to map out possible future climate scenarios. At the same time, researchers have developed tools and resources for identifying the vulnerability of trees and urban forests to future climate scenarios. Ordóñez and Duinker (2014) emphasize the need for urban forest managers to develop quantitative and collaborative assessments of urban forest vulnerability and implement strategies such as increasing species diversity to mitigate the influences of climate change.

The Town of Ajax provides an example of how the findings of a vulnerability assessment could be applied. The Town carried out a comprehensive Vulnerability Assessment for Natural Capita in 2018, including effects on the urban forest. The assessment rated trees to identified which species had bioclimatic envelopes outside of future predicted mean annual temperature levels and assigned a climate vulnerability score to species that could help inform future management requirements and planting strategies. The assessment found that the majority municipal trees have a low to low-moderate climate vulnerability score while some would be more susceptible to the effects of changing temperatures. A similar assessment was carried out for treed natural areas, providing useful information that could be integrated into the Town’s GIS system for use as an urban forest asset management tool and allow for interactive use by Town monitoring of urban trees and treed natural areas. The information could also be used to examine operational programming and scheduling of hazard risk monitoring activities across the urban forest.

Climate change vulnerability assessments help us understand how and why urban forests are vulnerable to climate change, identify future areas for research, and determine what adaptation measures could be included in urban forest management. These assessments help bring climate change to the forefront of the decision-making process and contribute to successful urban adaptation to climate change (Ordóñez and Duinker, 2014).

KEY FINDINGS – CLIMATE CHANGE

- Future impacts of climate change on urban forests are uncertain
- Exposures related to drought, heat stress, and wind, susceptibility of urban trees to insects and diseases, and the sensitivity of young trees and tree species with specific temperature and moisture requirements, are the main concerns regarding the vulnerability of urban forests to climate change in three Canadian cities
- Some portions of the urban forest could be more adversely affected by climate change than others (e.g. upland forests, street trees in highly urbanized environments).
- Urban forest managers should complete quantitative and collaborative assessments of urban forest vulnerability.
- Vulnerability assessments can be used to inform future operational programming e.g. scheduling of hazard risk monitoring activities across the urban forest.

LITERATURE CITED - CLIMATE CHANGE

Fahey, R.T., Bialecki, M.B., and D.R. Carter. 2015. Tree growth and resilience to extreme drought across an urban land-use gradient. Arboriculture & Urban Forestry 39(6): 279-285.

Ordóñez, C., Duinker, P. (2014) Assessing the vulnerability of urban forests to climate change. Environmental Reviews 22 (3), 311-321. Assessing the vulnerability of urban forests to climate change

Ordóñez, C. and Duinker, P.N. Climatic Change (2015) 131: 531. Climatic Change.

Pramova, E., Locatelli, B., Houria, D., Somorin, O. Forests and trees for social adaptation to climate variability and change. Climate Change 3(6):581–596 · November 2012.

Sjöman, H., Hirons, A.D., and N.L. Bassuk. 2015. Urban forest resilience through tree selection – Variation in drought tolerance in Acer. Urban Forestry & Urban Greening 14: 858-865.

H. Sjömana, J. Morgenroth, J. Deak, Sjöman A. Sæbød, I. Kowarik. Diversification of the urban forest—Can we afford to exclude exotic tree species? Urban Forestry & Urban Greening Volume 18, 1 August 2016, Pages 237-241.

Town of Ajax Climate Change Study. A Vulnerability Assessment for Natural Capita. 2018. Town of Ajax, carried out with assistance from the Government of Canada and the Federation of Canadian Municipalities.

STORMS AND EXTREME WEATHER EVENTS

Changes in climate are expected to have an impact on weather patterns, which may result in storms and extreme weather that are outside the bounds of the patterns that have been considered normal in recent decades. Studies of ice storms in the 1990s have shown that some species and trees of certain sizes are more adversely affected by storm damage than others and have different radial growth responses, which affect their rates of recovery (Lafon 2006, Smolnik et al. 2006, Sholes 2013). For intact natural forests, the long-term effects may include shifting species composition toward storm-tolerant species, but short-term effects may include an increase in hazards to trail users in municipal woodlands.

The effects of extreme weather on trees in developed areas could include physical damage that threatens personal safety and property, which may be viewed by urban residents as what Conway and Yip (2016) term “urban forest disservices.” Their study of Toronto residents following a damaging December 2013 ice storm revealed that some residents whose properties were adversely affected by the storm opted to remove trees in order to reduce future risk. However, the study also revealed that residents were also more likely to prune their existing trees and that they still wanted the municipality to plant trees, but to focus on structurally resilient tree species.

Structural diversity can make urban forests more resilient to extreme weather events (Steenberg et al., 2013). A variety of species and functional diversity results in better structural diversity (Ordóñez & Duinker, 2014). A structurally diverse forest has uneven-aged trees and a variety of species. A study of one hundred and nineteen windstorm events worldwide found damage within even-aged stands worse than within uneven-aged stands (Marshman, 2018).

Once current structure and associated possible future forces of change are understood, management plans can be designed to diminish the likelihood of an event having negative effects on the urban forest. For example, pro-active pruning and reduction of easily wind-damaged species can reduce the impact of future storms (Nowak 1993).

KEY FINDINGS - STORMS AND EXTREME WEATHER EVENTS

- Some species and trees of certain sizes are more adversely affected by storm damage than others and have different radial growth responses, which affect their rates of recovery.
- Structural diversity can make urban forests more resilient to extreme weather events.

- Pruning and reduction of easily wind-damaged species can reduce the impact of future storms.

LITERATURE CITED - STORMS AND EXTREME WEATHER EVENTS

Conway, Tenley and M. Yip. Assessing residents' reactions to urban forest disservices: A case study of a major storm event. Landscape and Urban Planning Volume 153, September 2016, Pages 1-10.

K.A. Marshman. The Eye of the Storm: Extreme Weather Events and Sustainable Urban Forest Management. Dalhousie Journal of Integrated Management. Volume 14, Spring 2018.

Lafon, C.W. 2006. Forest disturbance by ice storms in Quercus forests of the southern Appalachian Mountains, USA. Écoscience 13(1): 30-43.

Nowak, D. Historical Vegetation Change in Oakland And Its Implications for Urban Forest Management. Journal of Arboriculture 19(5): September 1993.

O.D.V. Sholes. Effects of ice storm damage on radial growth of Quercus spp. The Journal of the Torrey Botanical Society Vol. 140, No. 3 (JULY–SEPTEMBER 2013), pp. 364-368.

SUSCEPTIBILITY TO PESTS AND DISEASE

Urban forests are susceptible to native and non-native pests and disease, some of which have been components of ecosystems for centuries and others that have recently arrived. The effects can range from minor damage to widespread mortality and forest health decline that changes forest composition and results in large increases in municipal urban forest spending. An increase in susceptibility to pests and disease is also an expected outcome of climate change, as trees experience more stress that affect their natural defenses (Tubby and Webber, 2010).

The legacy of invasive pests in North America has severely impacted forests and urban tree populations, from the introduction of chestnut blight to Dutch elm disease in the early twentieth century to more recent introductions like emerald ash borer and Asian longhorned beetle (Schlarbaum et al., 1998, Poland and McCullough, 2006, Dodds and Orwig, 2011). Many of these pests require specific hosts and a city's susceptibility to certain pests may increase or decrease depending on the prevalence of certain species on the landscape. The possibility of pest introductions into urban forests highlights the need for monitoring programs aimed at early detection (Buckelew Cumming et al., 2008).

In the aftermath of these species introductions, it has become evident that forest diversity is a crucial component to increasing resilience and decreasing the risk of widespread forest decline as a result of pest infestations (Raupp et al., 2006).

Introduced tree species represent a substantial component of urban forests in cities all over the world. Yet there is controversy about the further use of introduced tree species. Many practice orientated publications, research papers and governmental websites in the fields of urban planning, urban forestry, and urban ecology argue for planting native species and avoiding introduced species. Examples from Northern and Central Europe show that in some regions, the catalogue of native tree species may be too limited to fulfil ecosystem services and resilience in harsh urban environments. It is suggested for that reason, that cities cannot afford to generally exclude non-native tree species from urban greening and that doing so compromises urban ecosystem resilience. Because both invasion risks and native species pools vary considerably at regional to continental scales urban policies on using non-native trees should be adapted to regional contexts (Sjömana et al., 2016).

KEY FINDINGS - PESTS AND DISEASE

- An increase in susceptibility to pests and disease is an expected outcome of climate change, as trees experience more stress that affect their natural defenses.
- A city's susceptibility to certain pests may increase or decrease depending on the prevalence of certain species on the landscape.
- The legacy of invasive pests in North America has severely impacted forests and urban tree populations.
- The possibility of pest introductions into urban forests highlights the need for monitoring programs aimed at early detection.
- In the aftermath of species introductions, it has become evident that forest diversity is a crucial component to increasing resilience.

LITERATURE CITED - PESTS AND DISEASE

Buckelew Cumming, A., Twardus D.B., and D.J. Nowak. 2008. Urban forest health monitoring: Large-scale assessments in the United States. Arboriculture & Urban Forestry 34(6): 341-346.

Dodds, K.J. and D.A. Orwig. 2011. An invasive urban forest pest invades natural environments – Asian longhorned beetle in northeastern US hardwood forests. Canadian Journal of Forest Research 41: 1729-1742.

Poland, T.M. and D.G. McCullough. 2006. Emerald ash borer: Invasion of the urban forest and the threat to North America's ash resource. Journal of Forestry 104(3): 118-124.

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

Schlarbaum, S.E., Hebard, F., Spaine, P.C., and J.C. Kamalay. 1998. Three American tragedies: Chestnut blight, butternut canker, and Dutch elm disease. Exotic Pests of Eastern Forests Conference Proceedings; 1997 April 8-10.

Sholes, O.D.V. 2013. Effects of ice storm damage on radial growth of Quercus spp. The Journal of the Torrey Botanical Society 140(3): 364-368.

H. Sjömana, J. Morgenroth, J. Deak, Sjöman A. Sæbød, I. Kowarik. Diversification of the urban forest—Can we afford to exclude exotic tree species? Urban Forestry & Urban Greening Volume 18, 1 August 2016, Pages 237-241.

Tubby, K.V. and J.F. Webber. 2010. Pests and diseases threatening urban trees under a changing climate. Forestry 83(4): 451-459.

URBANIZATION AND DEVELOPMENT PRESSURE

As landscapes urbanize, increased population density, built environments, human activity, and associated emissions tend to increase air temperatures, degrade air and water quality, and reduce human health and well-being. Thus, as areas urbanize, sustaining tree cover becomes increasingly paramount to sustaining human health, environmental quality, and quality of life (Nowak and Walton, 2005).

As cities grow and populations become more urbanized, both urban forests and forests adjacent to cities will be impacted by human activity and development. An increase in development at the edges of cities will have an impact on forests, not only in terms of a loss of forest cover through clearing but also as a result of an increase in human recreational use in woodlands. Specific effects of urbanization on forests include: deforestation, fragmentation, inappropriate forest management, habitat alteration, environmental deterioration, urban heat island effect and translocation (introduction) of alien species (Referowska-Chodak, 2019).

Converting forested or rural areas into residential developments also often has the effect of increasing impervious surfaces and fragmenting the landscape into smaller parcels with more individual owners, and hence more inconsistent approaches to tree and urban forest management. Daniel et al. (2016) found that residential developments since the 1990s have 30 per cent less canopy cover than older developments, and that a trend in relatively small lots in new developments threatens to curtail the establishment of sufficient canopy in the future.

Once development has taken place, residents themselves can become agents of disturbance in urban forests. McWilliam et al. (2010) found substantial degradation effects in urban forests as a result of residential encroachment in six southern Ontario municipalities. The long-term effects of this degradation may include an increase in invasive species, altered vegetation and mammalian communities, and degraded forest health. It is therefore important that municipalities use outreach programs to connect with residents about the importance of urban forest health and the impact their activities can have on it.

Solutions to counteract the effects of urbanization on forests include (Referowska-Chodak, 2019):

- Stopping deforestation (through stricter laws or better enforcement or afforestation.
- Mitigating forest fragmentation by improving the quality of cooperation between forest managers and the city land-use planners.
- In the case of forests disturbed by inadequate forest management (e.g. monotypization), restructuring is needed with respect to species composition and spatial structure
- To limit habitat alteration and environmental degradation, education of society, appropriate legislation, and land-use planning are also required
- Planting trees that are more resistant to pollution
- In order to reduce the Urban Hear Island effect, it is advisable to introduce more trees and forests into cities
- Define and monitor forest degradation, the area of forest change due to an invasive species may be mapped every 3–5 years using aerial photographs or satellite imagery or by using ground or aerial surveys.
- It may also be necessary to undertake radical measures to eradicate or limit the expansion of problematic species
- Having the appropriate infrastructure to direct recreational traffic.
- In practice, the search for solutions to the presented problems should take into account their specificity as well as scale and should refer to local conditions. Public participation in urban forest management can also impact accepted solutions. Undoubtedly, there will be resource issues and therefore trade-offs between what forest managers are able to achieve.

KEY FINDINGS – URBANIZATION AND DEVELOPMENT PRESSURE

- As cities grow and populations become more urbanized, both urban forests and forests adjacent to cities will be impacted by human activity and development.
- Specific effects of urbanization on forests include: deforestation, fragmentation, inappropriate forest management, habitat alteration, environmental deterioration, urban heat island effect and translocation (introduction) of alien species.
- Solutions to counteract the effects of urbanization on forests include:
    - Stopping deforestation (through stricter laws or better enforcement or afforestation.
    - Mitigating forest fragmentation by improving the quality of cooperation between forest managers and the city land-use planners.
    - In the case of forests disturbed by inadequate forest management (e.g. monotypization), restructuring is needed with respect to species composition and spatial structure.

- To limit habitat alteration and environmental degradation, education of society, appropriate legislation, and land-use planning are also required
- Planting trees that are more resistant to pollution.
- In order to reduce the Urban Heat Island effect, it is advisable to introduce more trees and forests into cities.
- Define and monitor forest degradation, the area of forest change due to an invasive species may be mapped every 3–5 years using aerial photographs or satellite imagery or by using ground or aerial surveys.
- It may also be necessary to undertake radical measures to eradicate or limit the expansion of problematic species.
- Having the appropriate infrastructure to direct recreational traffic.

LITERATURE CITED - URBANIZATION AND DEVELOPMENT PRESSURE

Daniel, C., Morrison, T.H., and S. Phinn. 2016. The governance of private residential land in cities and spatial effects on tree cover. Environmental Science & Policy 62: 79-89.

McWilliam, W., Eagles, P., Seasons, M., and R. Brown. 2010. Assessing the degradation effects of local residents on urban forests in Ontario, Canada. Arboriculture & Urban Forestry 36(6): 253-260.

Referowska-Chodak, E. Pressures and Threats to Nature Related to Human Activities in European Urban and Suburban Forests. Forests 2019, 10(9), 765; Pressures and Threats to Nature Related to Human Activities in European Urban and Suburban Forests.

INVASIVE SPECIES

Efforts at mitigating global biodiversity loss have often focused on preserving large, intact natural habitats. However, preserving biodiversity should also be an important goal in the urban environment, especially in highly urbanized areas where little natural habitat remains (Alvey, 2006).

Invasive non-native species are often more prevalent in cities than in rural areas because of numerous environmental disturbances and higher propagule pressure. Attempts to manage invasive species in cities are often controversial because of the diversity of stakeholder views. Until now, however, environmental managers in cities have managed invasive species using approaches and paradigms developed for a rural context, despite the radically different socio-environmental conditions that prevail in cities. (Gaertner et al., 2016).

Control of biological invasions depends on the collective decisions of resource managers across invasion zones. Regions with high land-use diversity, which we refer to as “management mosaics”, may be subject to severe invasions, for two main reasons. First, as land becomes increasingly subdivided, each manager assumes responsibility for a smaller portion of the total damages imposed by invasive species; the incentive to control invasives is therefore diminished. Secondly, managers opting not to control the invasion increase control costs for neighboring land managers by allowing their lands to act as an invader propagule source. Coordination among managers can help mitigate these effects, but greater numbers – and a wider variety – of land managers occupying a region hinder collective action (Epanchin-Niell et al., 2010).

It has been suggested that existing frameworks for guiding management of invasive species in rural areas and protected areas are inadequate for dealing with invasions in urban settings. Decision-support frameworks can assist managers in placing invasive species into management categories (Gaertner et al., 2017).

To effectively address biological invasion risks, a public decision-maker must evaluate complex trade-offs to determine what actions will achieve the best outcomes for society. These outcomes can be achieved through top-down implementation (e.g. regulation or public implementation) or design of policies or incentives to alter private behavior. Examples of top-down strategies include state-implemented surveillance programs and mandated control of noxious weeds on private lands. Alternatively, a cost-share program may be implemented to enhance private control of an invader (Epanchin-Niel, 2017).

Underlying public decision-making is the challenge of how to efficiently allocate scarce monetary, natural, human, or other resources. Management of invasive species often requires making decisions about how much to control or what level of a measure to implement, rather than a simple binary decision of whether to fund or not fund.

In addition, it often is worth asking how much should be spent—what should the budget be or what would be the gains from increasing available resources? In general, decisions take the form of choosing how much to invest in a particular action or how stringent a policy should be to provide the greatest net gains (Epanchin-Niel, 2017).

Interventions to mitigate the impacts of invasive species include reducing the rate of invasive species introduction (prevention), eradicating new invader populations, and reducing damages by slowing the spread of invasions across the landscape or adapting to an invader’s presence through control or altered management practices. In addition, monitoring is key to most invasion mitigation strategies—for knowing what and where to control and for evaluating the effectiveness of management actions (Epanchin-Niel, 2017).

KEY FINDINGS - INVASIVE SPECIES

- Existing invasive species management frameworks are inadequate in urban areas.
- Decision-support frameworks can assist managers in placing invasive species into management categories.

- Approached to control of invasive species can include top-down implementation (e.g. regulation or public implementation) or design of policies or incentives to alter private behavior.
- Management of invasive species often requires making decisions about how much to control or what level of a measure to implement, rather than a simple binary decision of whether to fund or not fund.
- Interventions to mitigate the impacts of invasive species include reducing the rate of invasive species introduction (prevention), eradicating new invader populations, and reducing damages by slowing the spread of invasions across the landscape or adapting to an invader's presence through control or altered management practices.
- Monitoring and early detection are key to most invasion mitigation strategies.

LITERATURE CITED - INVASIVE SPECIES

A. Alvey. Promoting and preserving biodiversity in the urban forest. Urban Forestry &Urban Greening Volume 5, Issue 4, 1 December 2006, Pages 195-201.

M. Gaertner, B.M.H.Larsona, U.M. Irlich, P.M.Holmes, L. Stafford, B. W.van Wilgen, D. M. Richardson. Managing invasive species in cities: A framework from Cape Town, South Africa. Landscape and Urban Planning Volume 151, July 2016, Pages 1-9.

M. Gaertner, A. Novoa and J. Fried. Managing invasive species in cities: a decision support framework applied to Cape Town Biological Invasions, 19(12), 3707-3723, December 2017.

R.S. Epanchin-Niell, M.B. Hufford, C.E. Aslan, J.P Sexton, J.D. Port, T.M. Waring. Controlling invasive species in complex social landscapes. Frontiers in Ecology and the Environment. Volume 8, Issue 4, May 2010, Pages 210-216.

R.S. Epanchin-Niell. Economics of invasive species policy and management. Biological Invasions November 2017, Volume 19, Issue 11, pp 3333–3354.

SUSTAINABLE URBAN FOREST MANAGEMENT – MONITORING AND ADAPTIVE MANAGEMENT

Adaptive management promotes flexible decision making that can be adjusted in the face of uncertainties, as outcomes from management actions and other events become better understood. It's a systematic process for continually improving management policies and practices by learning from the outcomes of programs. Some of the characteristics of adaptive management include: monitoring, analysis of the treatment outcomes in consideration of the original objectives, incorporation of the results into revised treatment decisions (UFMP Toolkit, 2019).

Adaptive management is important for handling the complex decision problems involving uncertainty and risk, like the impacts of climate change on the urban forest. In forest management, there is a whole range of decisions that a decision maker must consider concerning the forest: choice of species, provenances, regeneration approach, thinning and tending practices, harvest age or size, drainage, protection measures, afforestation, deforestation, etc. (Yousefpour et al., 2012).

Management of course directly influences the state of the forest, but it may also affect the dose–response relationship, e.g. susceptibility to windthrow or consequences of drought, and the economic impact of a given ecological response may be modified through management (cutting losses, enhancing benefits). Management decisions are described by actions in time and context (Hahn and Knoke, 2010).

Individual management decisions may be part of a long-term strategy including a set of pre-planned actions, triggered by basic state variables, such as age or stand density. sing an adaptive management approach, individual decisions are made on the basis of observed trends and fluctuations and resulting beliefs about the future, and since future developments are uncertain, the decisions are not assumed to always lead to perfect results but to outcomes that are, on average, the best possible (Yousefpour et al., 2012). Evidence suggests that forest managers base their decisions on different sets of information and in ways quite different from those assumed (Ananda and Herath 2005; Couture and Reynaud 2008; Hoogstra 2008). For this reason, the use of robust criteria and indicators for monitoring and adaptive management is an important part of the adaptive management cycle.

INDICATORS

Indicators are a common tool used to measure progress towards an objective. For example, the use of criteria and indicator sets is well established in sustainable forest management plans [Harshaw et al., 2007, Gough et al., 2008, Sheppard and Meitner, 2005) and literature exists on what constitutes a good indicator. According to Harshaw et al., 2007, the characteristics of a good indicator are defined as:

- Relevant;
- Credible;
- Measurable;
- Cost-effective; and
- Connected to [urban] forestry

In some cases, a dichotomy exists between what cities strive for, and what they monitor as key indicators. For example, there is increasing awareness of the role of urban forests in enriching human health and well-being (Donovan et al., 2013, Kaplan, 2001 and Hartig et al., 2014), but to date few proposed indicator sets include a measure of how trees can be planted to enhance their effects on human health or other social indicators to measure community engagement or support for the urban forest (Barron et al., 2016).

FRAMEWORK

Many North American municipalities have adopted a framework developed by the USDA Forest Service in partnership with the Davey Institute (Leff, 2016) that is included in their publication "*A Sustainable Urban Forest Management Guide: A Step-by-Step Approach*". This framework includes 28 indicators grouped under three themes:

1. Trees and Forest – Targets related to the status of the vegetation resource itself and/or knowledge of that resource.
2. Community Framework – The necessary engagement of stakeholders at all levels, and collaboration among them.
3. Resource Management Approach – Plans, practices, and policies to improve and sustain the forest resource.

Some of the indicators used rely on quantitative data from inventories and replicable studies (e.g. relative canopy cover) whereas others rely on a more subjective assessment of performance (e.g. Others rely on data that may require further work to obtain, like a list of what species are 'suitable' for planting in a given environment. This can change rapidly under different environmental scenarios. Some of these limitations can be addressed by adding specific parameters the proposed indicators, e.g. defining suitable species as non-invasive, drought tolerant, etc.

Data to support certain indicators about forest composition, structure and function are also inherent to forest inventories, as a result of the type of information they collect. For example, inventories may provide data to support indicators or measures of species diversity, forest structure (size class), forest health (tree condition), ownership (tree location) and other measures of interest. Cities can also mine other sources of information to provide data to support indicators for measures of e.g. public health, social engagement and other areas of interest.

A 2016 study aimed to develop a decision support framework for urban forestry, centered on a set of key indicators, used to build and test various scenarios of future urban forests. The study found that academics and practitioners had differing opinions on the value of specific indicators for assessing sustainable urban forest management. Practitioners had a higher regional focus (for example. mentioning evergreen conifers as important storm water management trees in a region where most storm water falls during times when deciduous trees have lost their leaves.) This is an important point for managers to consider, in that the ultimate user or purpose of the indicator for informing forest management should be closely considered in developing a monitoring framework for municipal urban forest programs (Barron et al., 2016).

In urban forestry, the purpose of monitoring is usually to measure progress toward a Plan's goals. The type of monitoring plan that is developed will depend on factors such as scope, size of area, and costs. If available resources limit the scope of monitoring, it may be necessary to set priorities and focus monitoring on the highest priority areas (UFMP Toolkit, 2019).

KEY FINDINGS – MONITORING AND ADAPTIVE MANAGEMENT

- Adaptive management is a systematic process for continually improving management policies and practices by learning from the outcomes of programs.
- Adaptive management is important for handling the complex decision problems involving uncertainty and risk (e.g. effects of climate change on the urban forest).
- Characteristics of adaptive management include: monitoring, analysis of the treatment outcomes in consideration of the original objectives, incorporation of the results into revised treatment decisions.
- Monitoring is a critical part of the adaptive management cycle – it helps managers assess the effectiveness of urban forest management approaches.
- Indicators for urban forest monitoring should be relevant, credible, measurable, cost-effective and have clear links to urban forestry.
- Sets of criteria and indicators as proposed in the literature can be a starting point for municipalities in determining a monitoring approach – these can be tailored to the local context and reflect available data and resources.

- Many North American municipalities have adopted a framework developed by the USDA Forest Service and Davey Tree Ltd. - "A Sustainable Urban Forest Management Guide: A Step-by-Step Approach".
- If available resources limit the scope of monitoring, it may be necessary to set priorities and focus monitoring on the highest priority areas.

LITERATURE CITED – MONITORING AND ADAPTIVE MANAGEMENT

Barron, S.; Sheppard, S.R.J. and P.M. Condon. Urban Forest Indicators for Planning and Designing Future Forests. Forests 2016, 7, 208.

Donovan, G.H.; Butry, D.T.; Michael, Y.L.; Prestemon, J.P.; Liebhold, A.M.; Gatziolis, D.; Mao, M.Y. The Relationship between Trees and Human Health: Evidence from the Spread of the Emerald Ash Borer. Am. J. Prev. Med. 2013, 44, 139–145.

Gough, A.D.; Innes, J.L.; Allen, S.D. Development of common indicators of sustainable forest management. Ecol. Indic. 2008, 8, 425–430.

Hahn WA, Knoke TH (2010) Sustainable development and sustainable forestry: analogies, differences, and the role of flexibility. Eur J For Res 129:787–801

Harshaw, H.W.; Sheppard, S.; Lewis, J.L. A Review and Synthesis of Social Indicators for Sustainable Forest Management. J. Ecosyst. Manag. 2007, 8, 17–37.

Hartig, T.; Richard, M.; Sjerp, V.; Howard, F. Nature and Health. Annu. Rev. Public Health 2014, 35, 207–228.

Kaplan, R. The Nature of the View from Home Psychological Benefits. Environ. Behav. 2001, 33, 507–542.

Harshaw, H.W.; Sheppard, S.; Lewis, J.L. A Review and Synthesis of Social Indicators for Sustainable Forest Management. J. Ecosyst. Manag. 2007, 8, 17–37.

Sheppard, S.R.; Meitner, M. Using multi-criteria analysis and visualisation for sustainable forest management planning with stakeholder groups. For. Ecol. Manag. 2005, 207, 171–187.

Urban Forest Management Plan Toolkit. Developed by the Inland Urban Forest Council with funding from CAL FIRE and U.S. Forest Service, and with administrative assistance from California Urban Forests Council. Available at: Urban Forest Management Plan Toolkit

Appendix C: Stakeholder Tree Planting Survey Results

The City of Guelph was looking for input from stakeholders who are directly involved in tree planting and/or land development projects in the city. Input from stakeholders was intended to improve understanding of current challenges for achieving optimal planting outcomes and to help prioritize tree planting based on an understanding of land use context in the City of Guelph.

The survey was sent to a list of 127 stakeholders provided by the City of Guelph project team and received a total of 44 responses. The survey had 8 questions, with an opportunity for respondents to add additional comments and thoughts on some of the city’s current challenges and opportunities. A summary of findings follows below.

SURVEY RESPONDENTS

There was a diverse mix of survey respondents, representing both the public and private sector who are interested or involved in tree planting in Guelph (Figure 39).

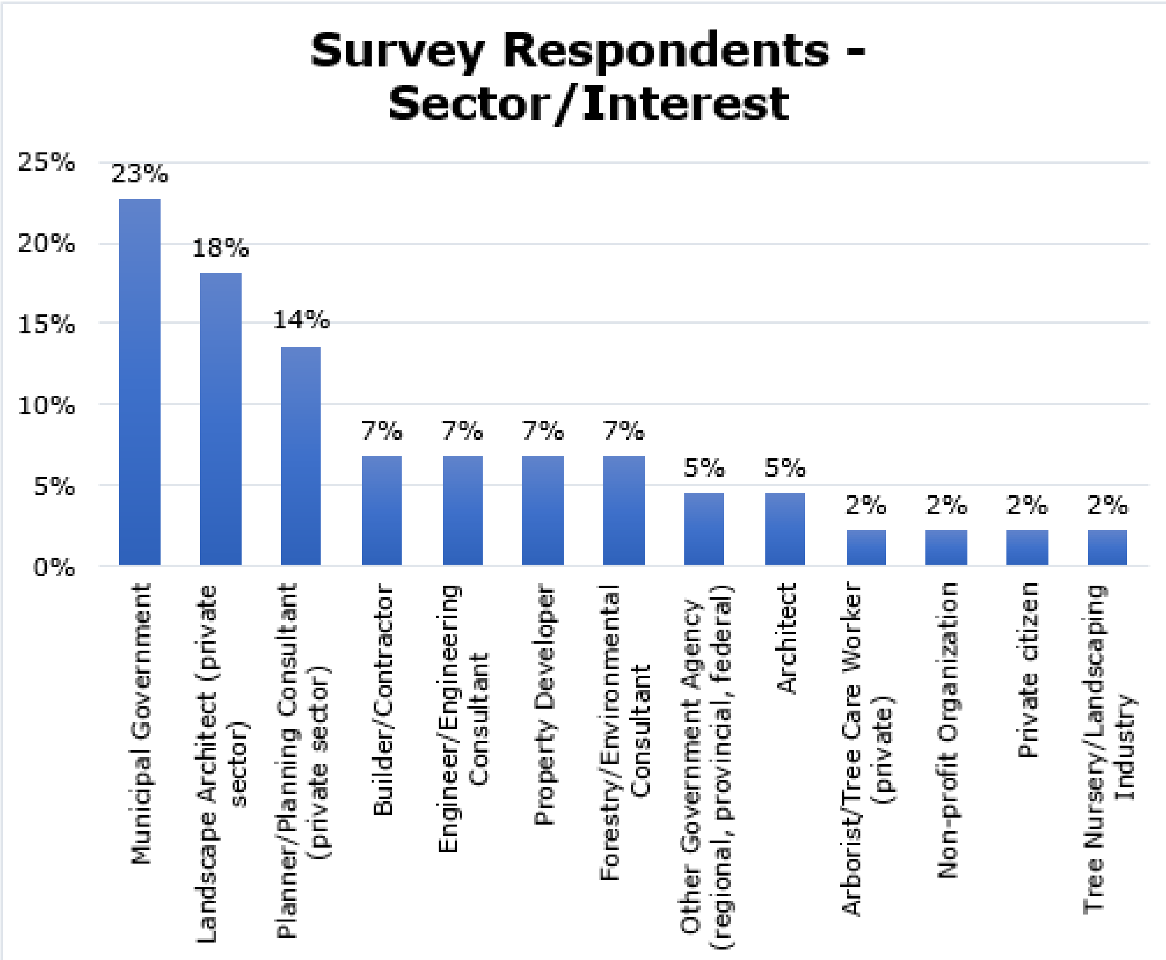


Figure 39: Survey respondents - sector/interest (Source: 2019 Tree Planting Prioritization Survey).

MOST IMPORTANT SERVICES PROVIDED BY TREES.

Survey responses ranked support of natural heritage functions a top value that trees provide. This was following by improved physical and mental health, with community beautification and livability in third place (Figure 40).

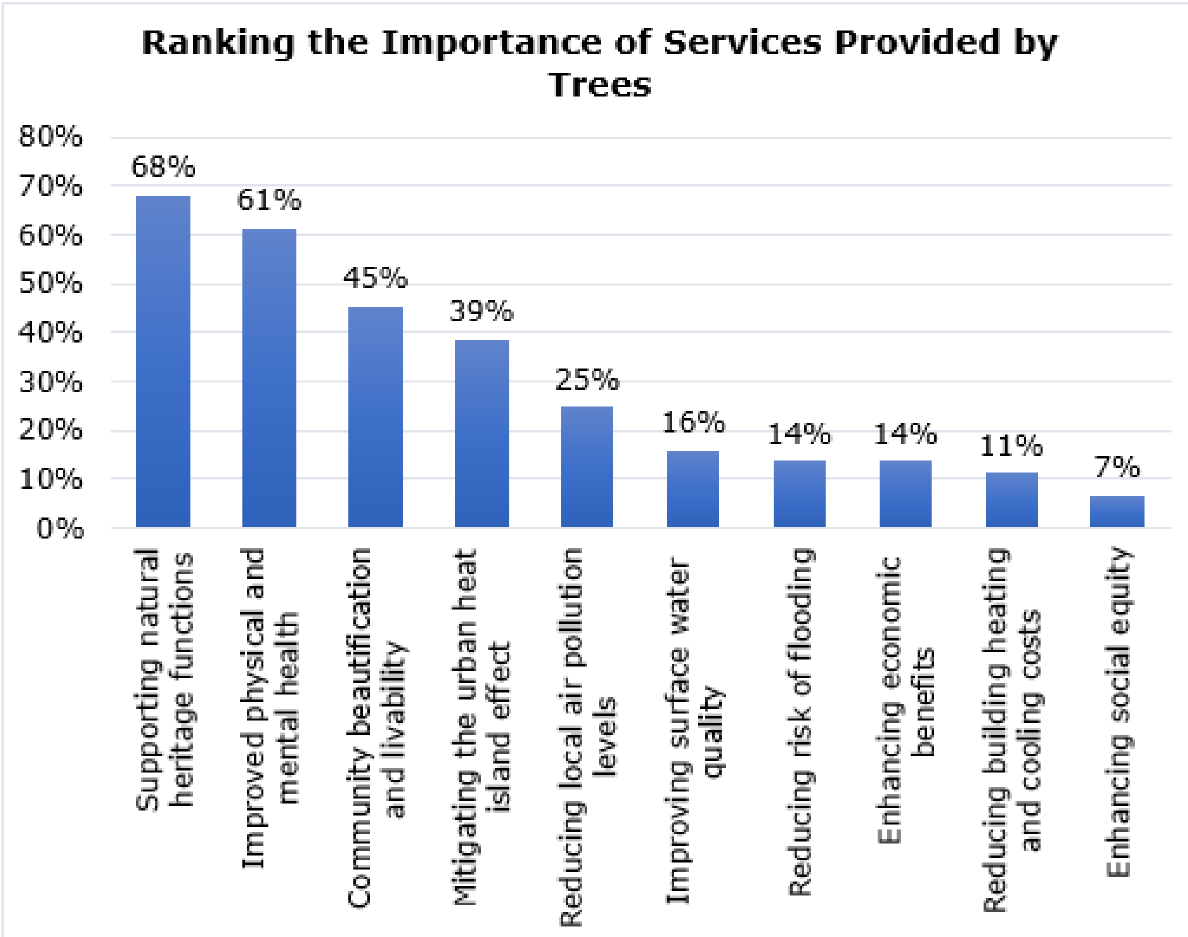


Figure 40: Most important services provided by trees in the City of Guelph (Source: 2019 Tree Planting Prioritization Survey).

PRIORITY LOCATIONS FOR PLANTING TREES

Top priorities of respondents for planting more trees included corridors between designated green spaces as well as any areas in the city with low tree canopy (68 per cent and 61 per cent respectively). Most other locations were ranked similarly, with the exception of hospital and care facilities as well as low income neighbourhoods that were ranked lowest on the list (Figure 41). In any case, these areas may be captured as a priority if they have currently low levels of tree canopy. This is identified as an output of the tree planting prioritization analysis.

Natural heritage values and functions came out number one as both a value and a priority location for planting, suggesting respondents recognize the importance of landscape connectivity and function for supporting local biodiversity. Early planning for integration of tree canopy in new development applications is one of the best ways to support the City's natural heritage objectives.

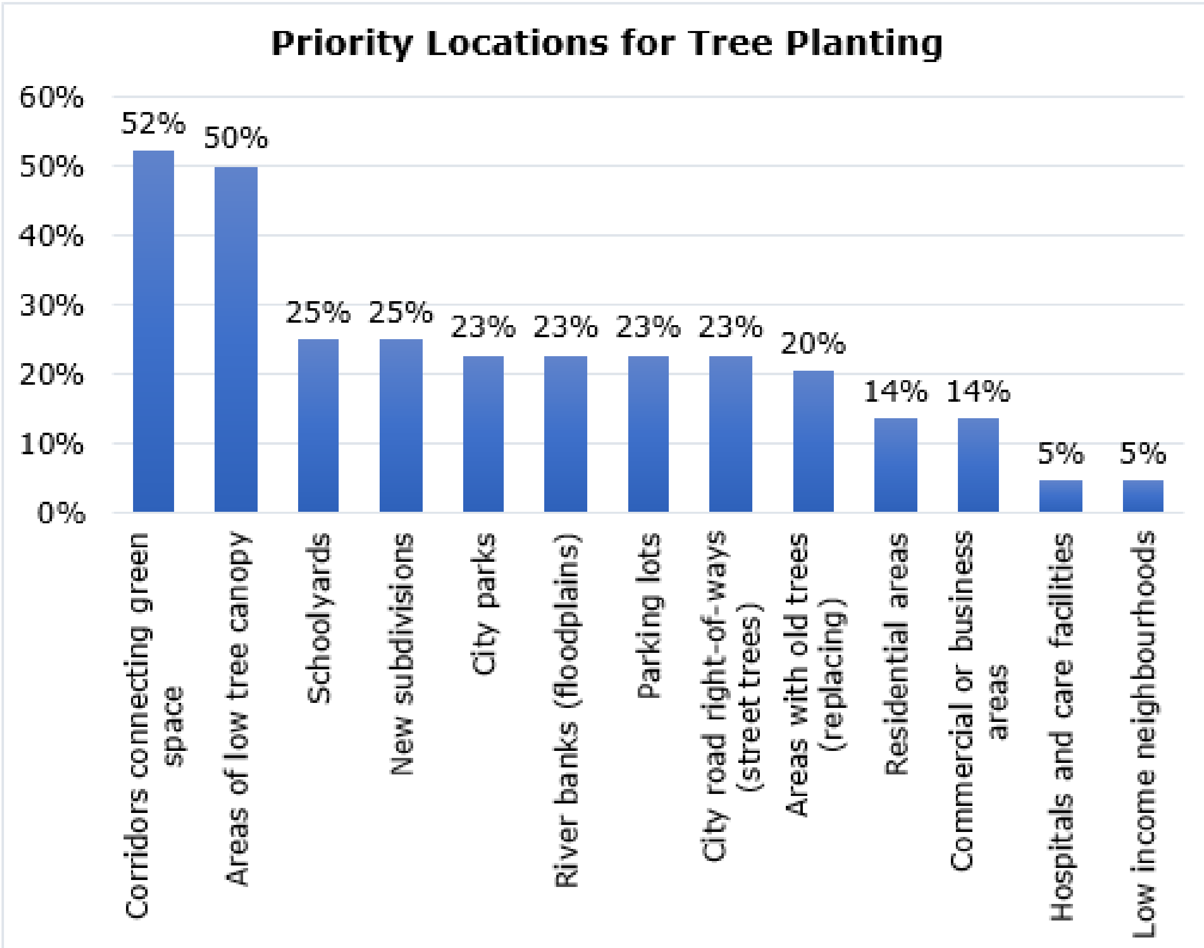


Figure 41: Priority locations for planting more trees in the City of Guelph (Source: 2019 Tree Planting Prioritization Survey).

CONCERNS ABOUT TREE PLANTING

Respondents were largely supportive of the need/benefit of planting more trees in the city (64 per cent had no concerns) (Figure 42). However, they did identify some key conditions that should be met when planting new trees, including:

- Careful pre-planting site and species selection to ensure that sites can support tree growth;
- The importance of regular follow up care and maintenance, for best return on the planting investment; and
- Earlier and mandatory consideration of trees in the planning process to avoid future conflicts with other infrastructure.

In short, respondents suggested there is little value in planting more trees if the above conditions are not met. "Failed urban plantings have become a major concern not only for the landscape industry, but also municipalities, who invest significant resources in urban landscaping."[53]

The critical value of site selection is supported by the literature – "it has been estimated that 80 per cent of the problems urban trees face can be attributed to poor soil, and that these poor soils act synergistically to increase the damage from other stresses. The changes in soil structure found in urban soils compared to natural soils is said to be one of the greatest limiting factors to tree growth and survival." [54]

For this reason, site quality should be the number one consideration in future tree planting programs in Guelph. A cost/benefit analysis of site amelioration versus tree replacement costs over the life cycle of a tree may help inform this program aspect.

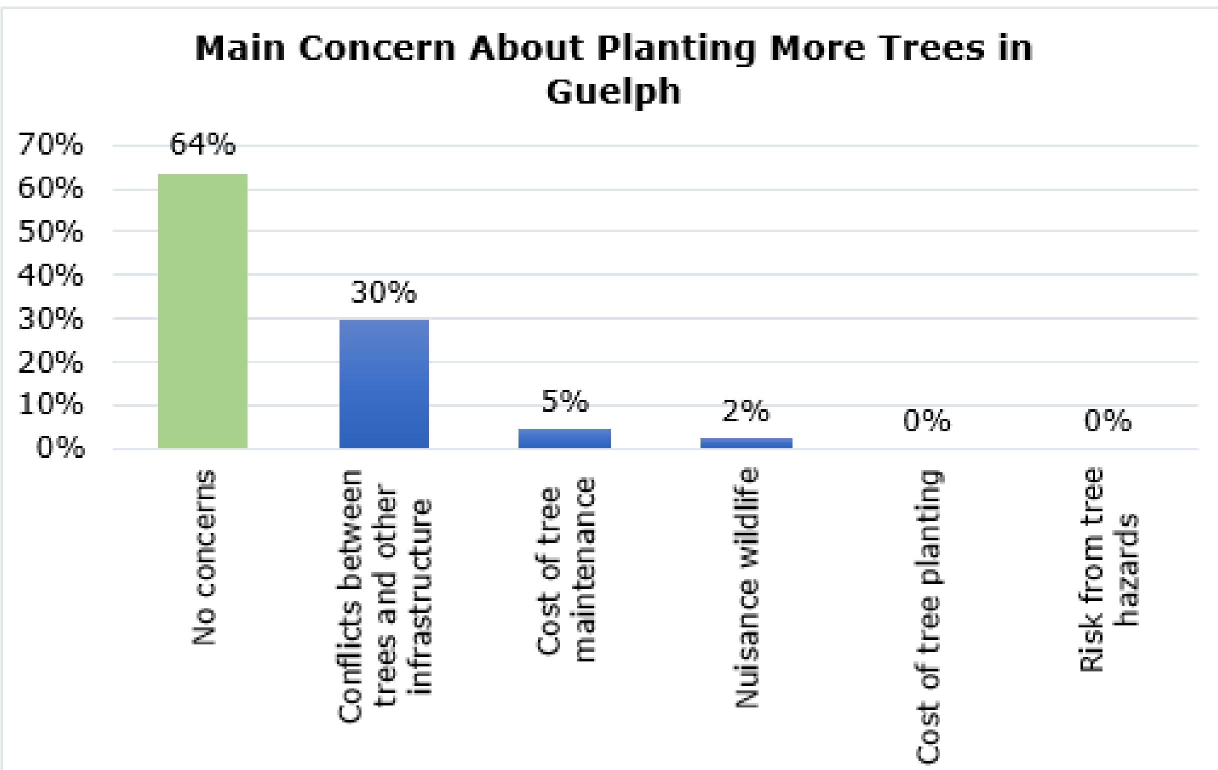


Figure 42: Concerns about planting more trees in the City of Guelph (Source: 2019 Tree Planting Prioritization Survey).

[53] Lemay, J.P and M.A. Lemay. 2015. The impact of environmental stresses on the survivability of the urban landscape: A review of the literature and recommendations. Vista Science and Technology.

[54] Ibid.

WHERE TREES ARE BEING PLANTED

Seventy-three per cent of survey respondents were directly involved with planting trees. Among those who plant trees, the largest proportion were operating on public lands in natural areas, streets and urban parks. This is followed by planting in new development, with the least amount of participation in infill development (Figure 43).

WHERE TREES ARE BEING PLANTED

Seventy-three per cent of survey respondents were directly involved with planting trees. Among those who plant trees, the largest proportion were operating on public lands in natural areas, streets and urban parks. This is followed by planting in new development, with the least amount of participation in infill development (Figure 43).

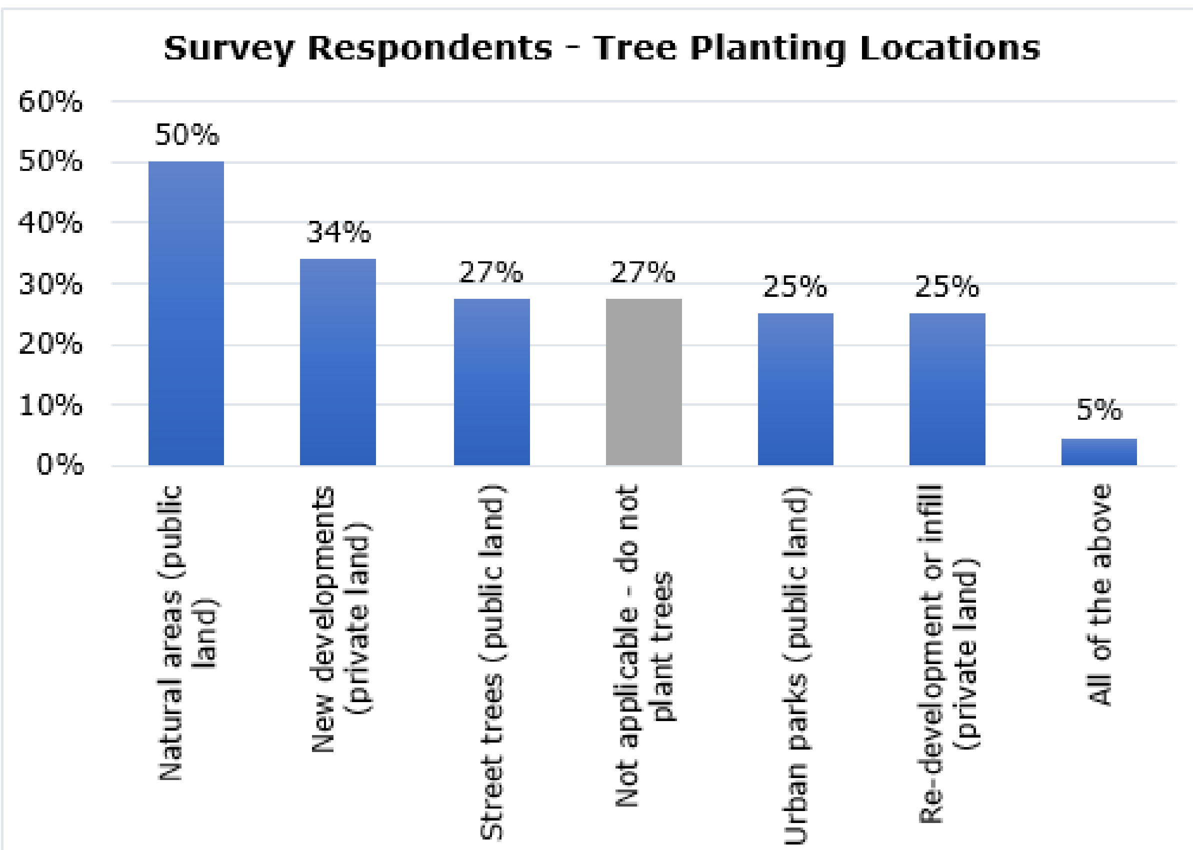


Figure 43: Where trees are being planted in Guelph (Source: Source: 2019 Tree Planting Prioritization Survey).

TOP CHALLENGES FOR SUCCESSFUL PLANTING OUTCOMES

The two main challenges for successful planting outcomes were identified as maintaining and watering newly planted trees. Poor planting site conditions were ranked third (both quality and volume of soils). The availability, cost and quality of stock was not identified as a significant issue (Figure 44).

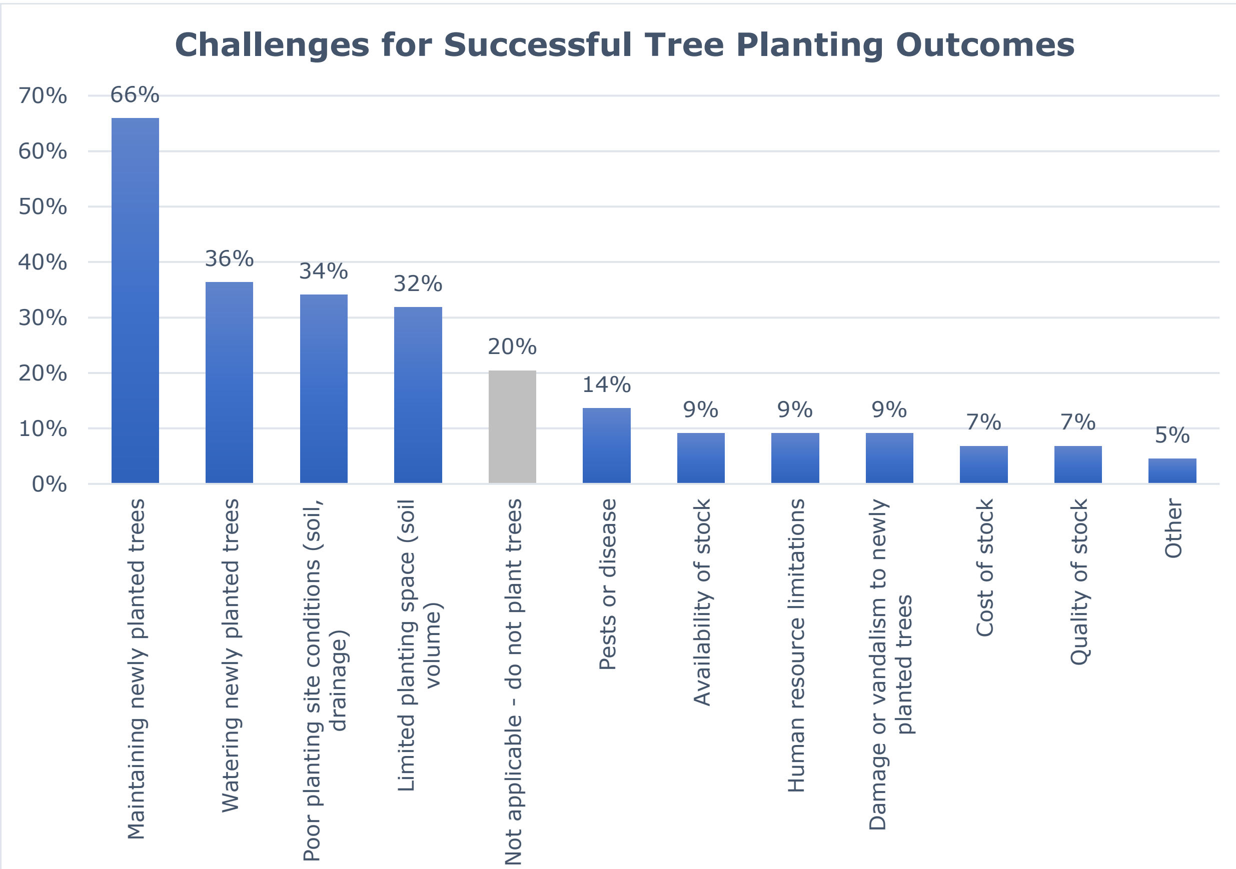


Figure 44: Top factors affecting successful tree planting outcomes (Source: 2019 Tree Planting Prioritization Survey)

OTHER THOUGHTS AND COMMENTS

There were 15 additional comments received from survey respondents. Five of these noted the importance of planting “the right tree on the right site” to get the best payback for planting efforts. Other comments addressed the following:

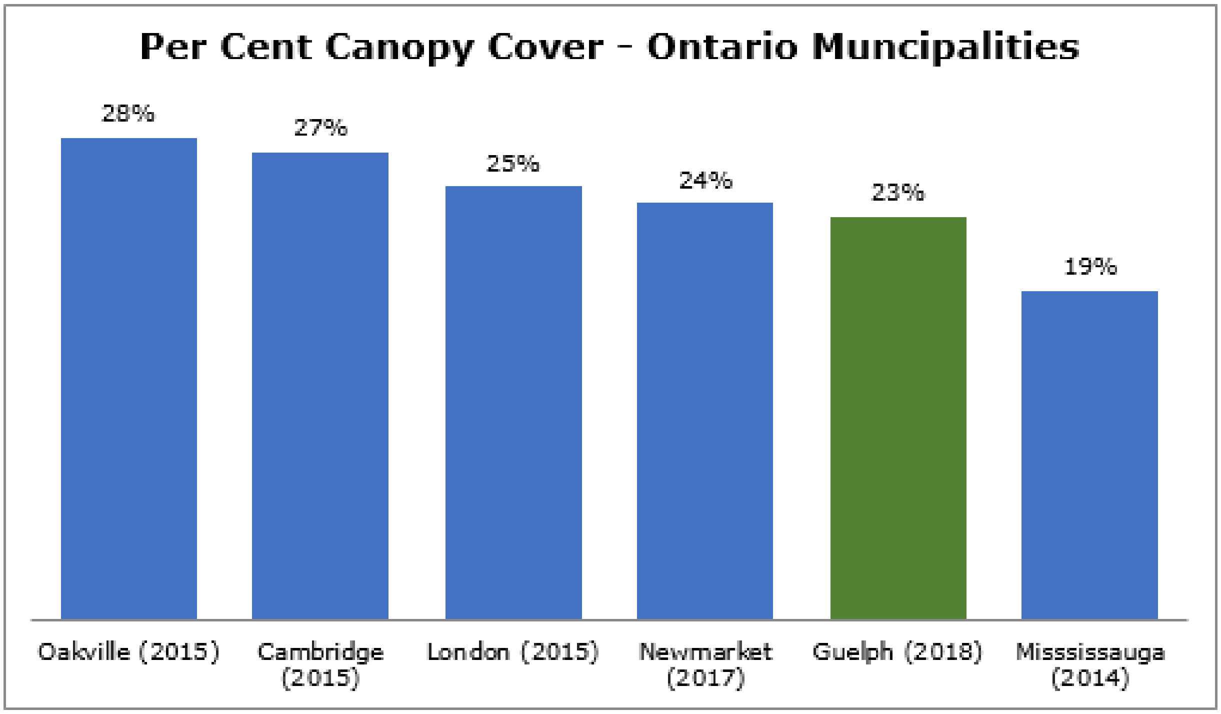
- The importance of preserving existing canopy as well as planting new trees;
- The value of the urban canopy for supporting natural heritage objectives;

- Concerns about the potential for tree by-laws to discourage planting because trees are seen as an impediment to development, with a suggestion to use more incentives instead to encourage tree planting; and
- There is no process to force the integration of trees early in the planning process.

Lastly, there were a few comments for the City's approach to planting:

- Use non-native, non-invasive trees as well as native species in planting;
- The use of evergreens for screening/aesthetics and fencing in new developments has been well received; and
- Use smaller stock to get more trees in the ground at less cost than caliper trees.

Appendix D: Average Canopy Cover in Ontario Municipalities

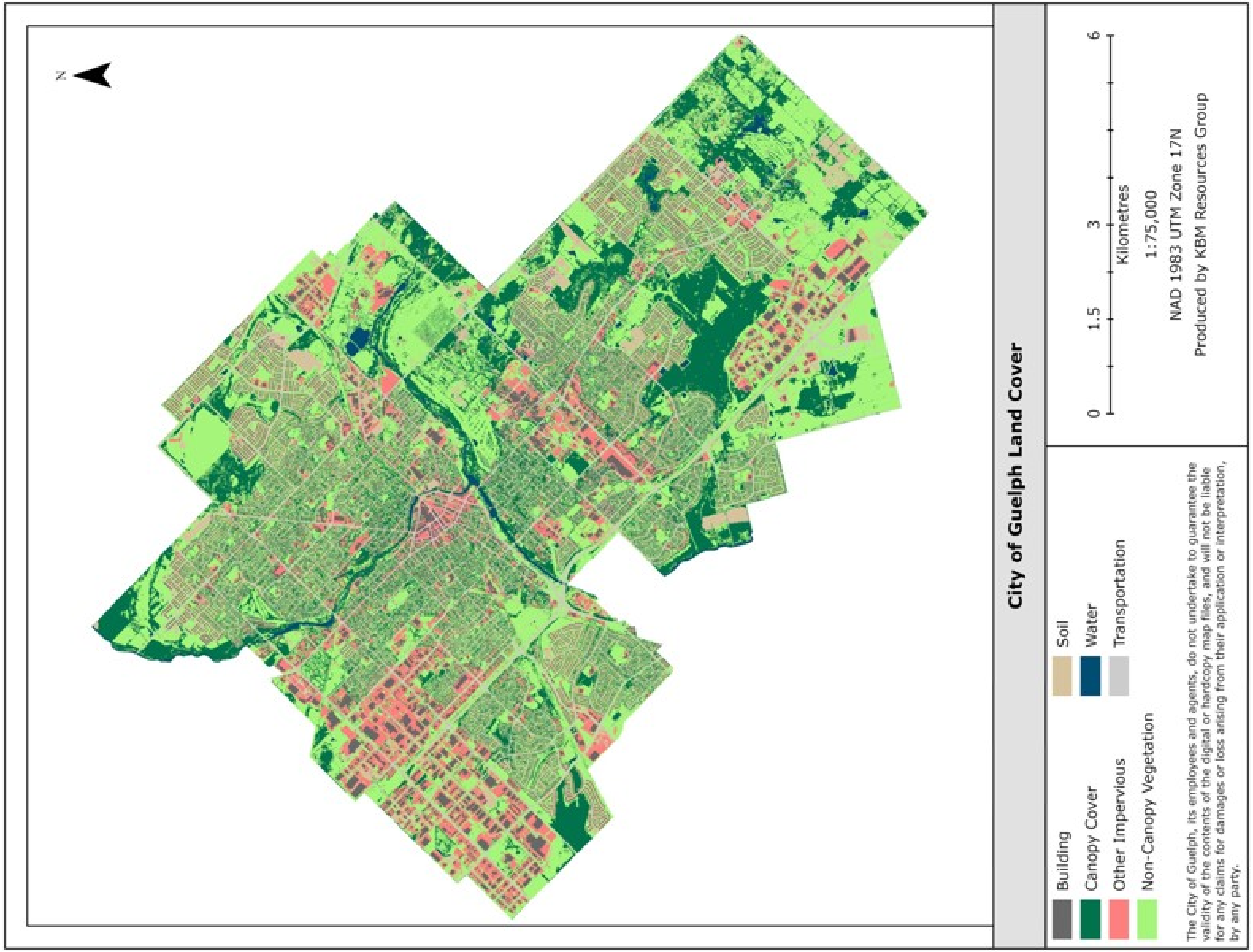


Source: Available studies (online sources) completed in the last 6 years.

Appendix E: City of Guelph Canopy Cover Map Series

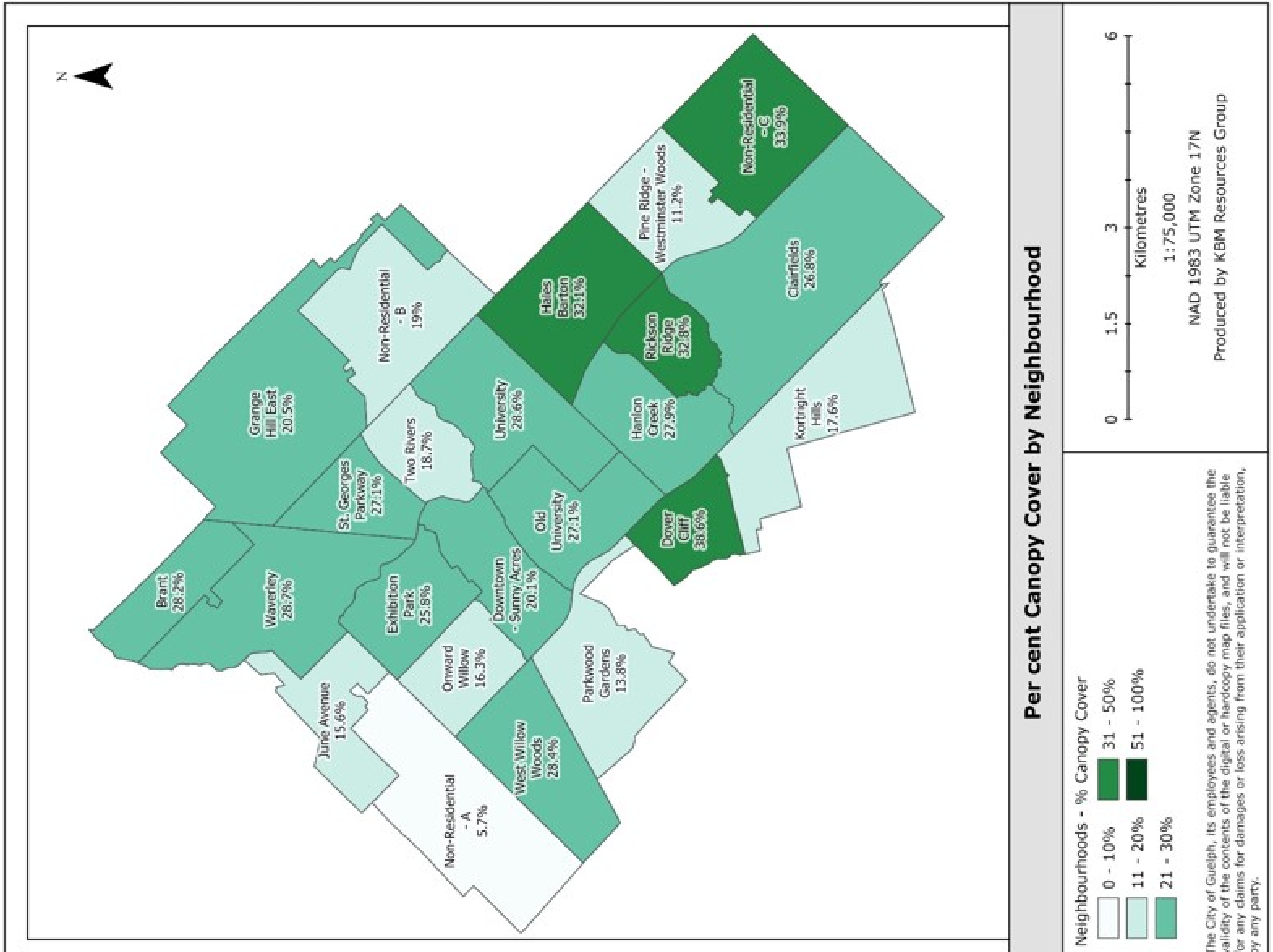
Distribution of Canopy Cover in Guelph

Source: 2019 Urban Forest Study, land cover data



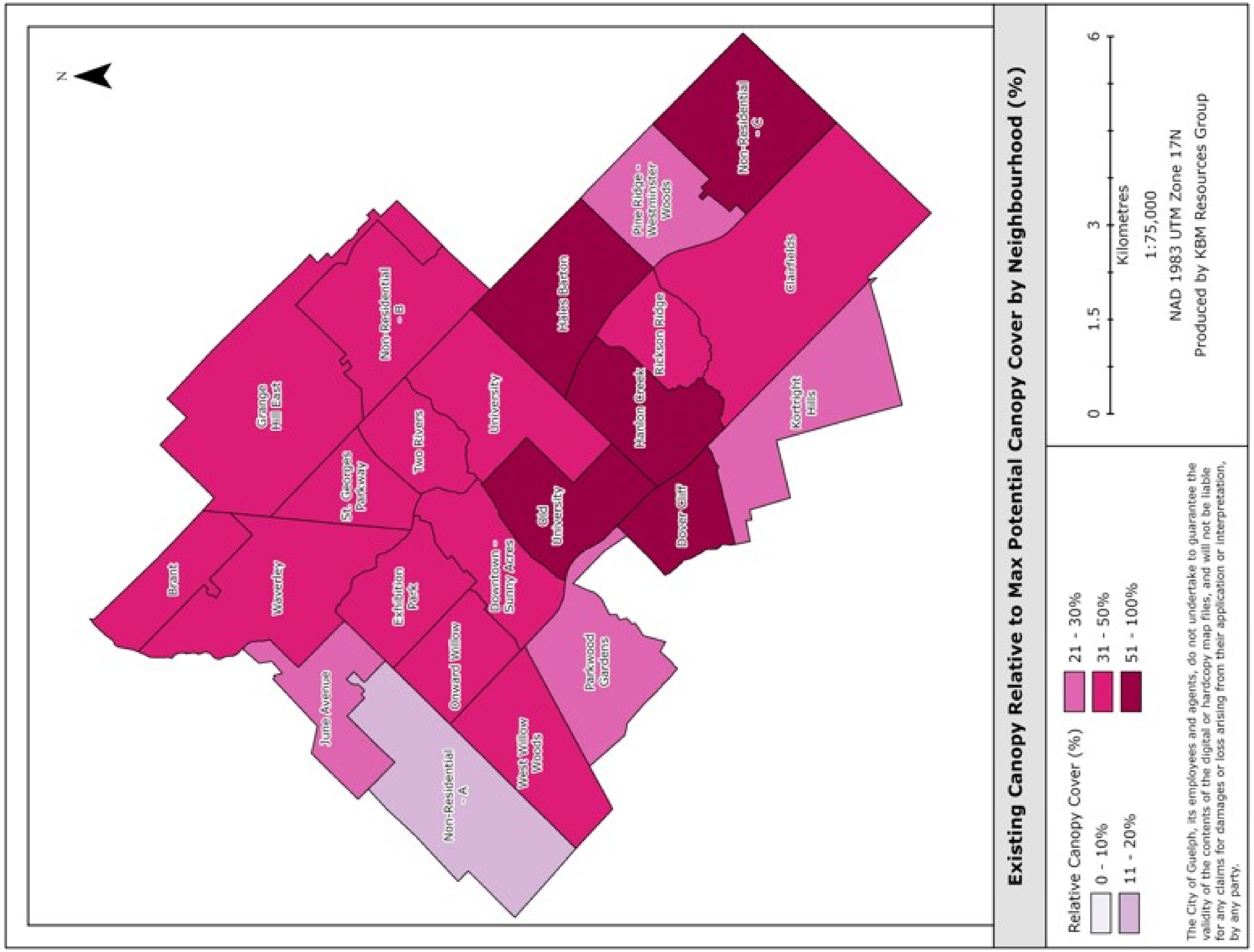
AVERAGE CANOPY COVER BY NEIGHBOURHOOD (PER CENT)

SOURCE: 2019 URBAN FOREST STUDY, LAND COVER DATA



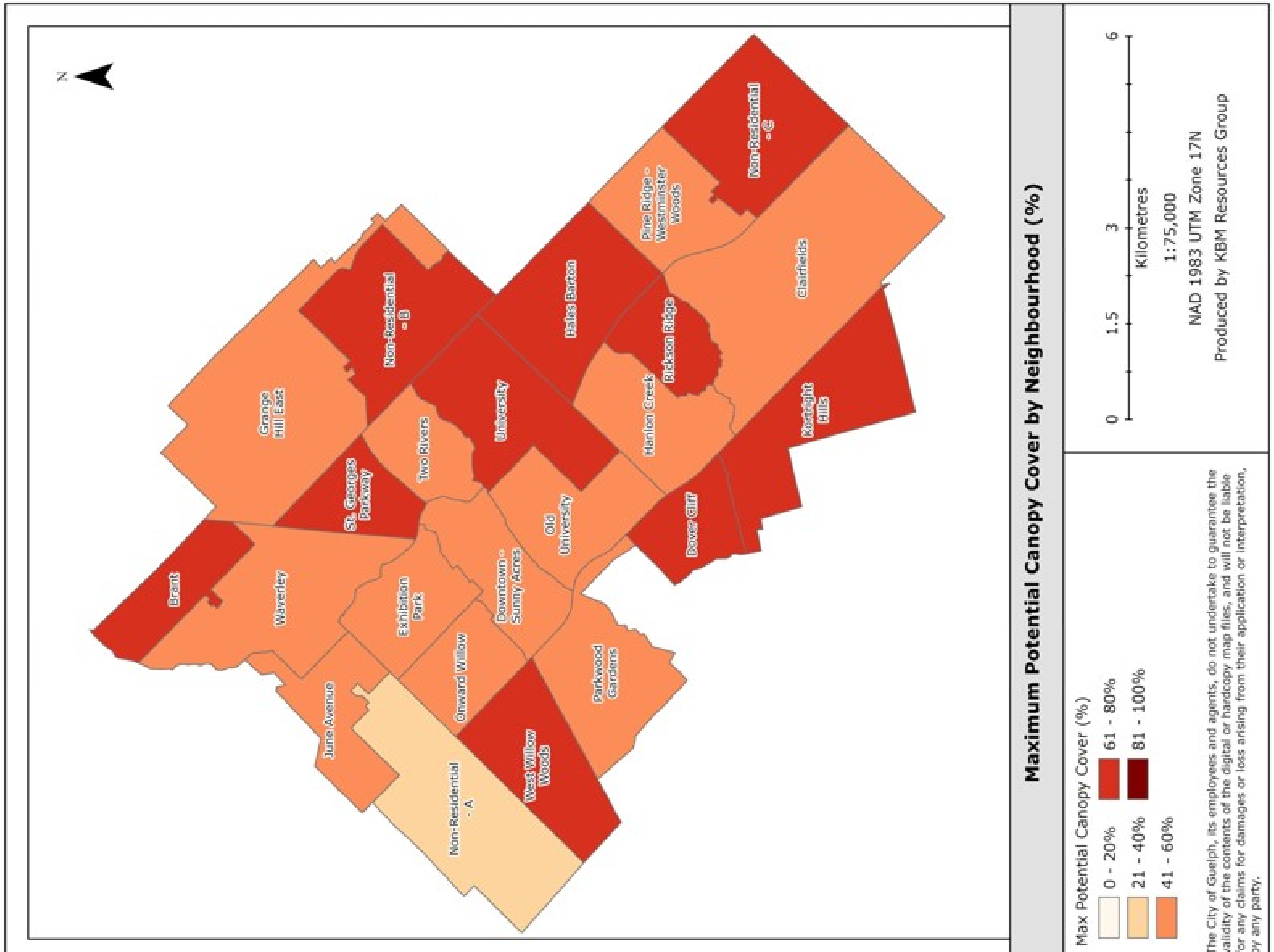
Relative per cent Canopy Cover by neighbourhood (Existing Compared to Maximum)

Source: 2019 Urban Forest study, land cover data



Maximum Potential Canopy cover by Neighbourhood

Source: 2019 Urban Forest Study, land cover data



PER CENT CANOPY COVER BY PARCEL (SHOWING CANOPY HEIGHT >20M)

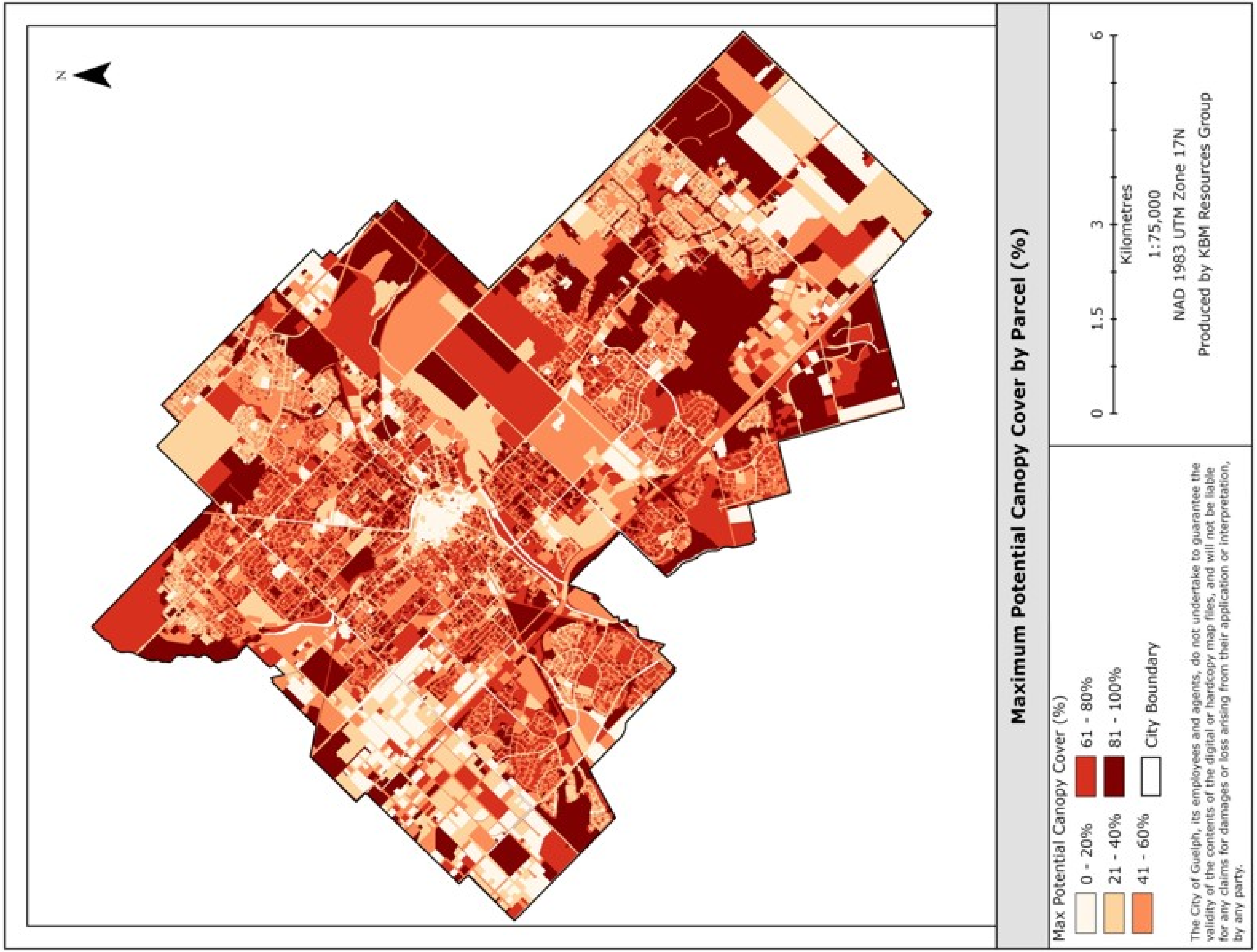
SOURCE: 2019 URBAN FOREST STUDY, LAND COVER MAPPING

Relative per cent Canopy Cover by parcel (Existing Compared to Maximum)

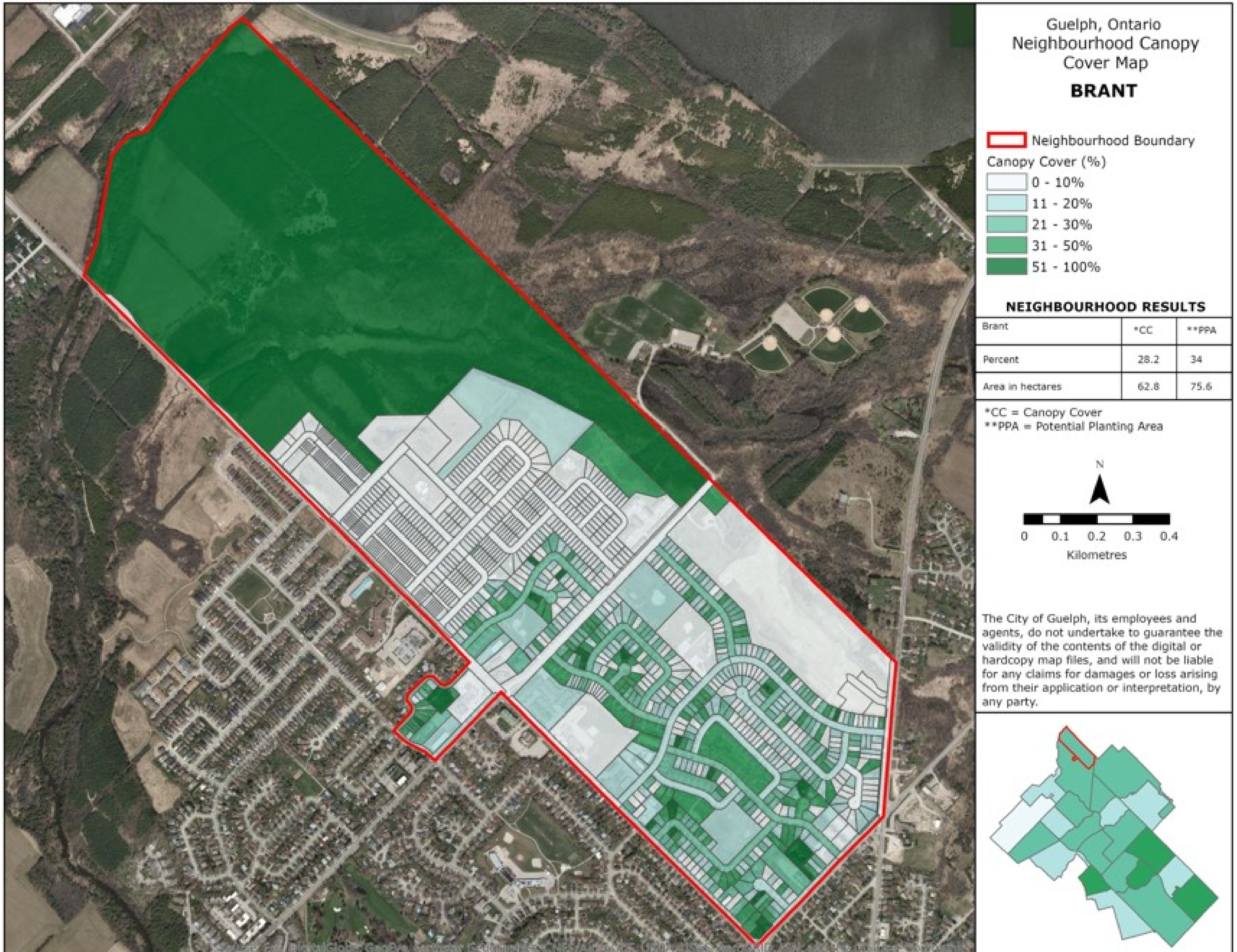
Source: 2019 Urban Forest study, land cover data

Maximum Potential Canopy cover by parcel

Source: 2019 Urban Forest Study, land cover data



Appendix F: City of Guelph Neighbourhood Canopy Cover Maps


Guelph, Ontario
Neighbourhood Canopy Cover Map
BRANT
Neighbourhood Boundary
Canopy Cover (%)
0 - 10%
11 - 20%
21 - 30%
31 - 50%
51 - 100%
NEIGHBOURHOOD RESULTS
Brant | *CC | **PPA
Percent | 28.2 | 34
Area in hectares | 62.8 | 75.6
*CC = Canopy Cover
**PPA = Potential Planting Area
N
0 0.1 0.2 0.3 0.4
Kilometres
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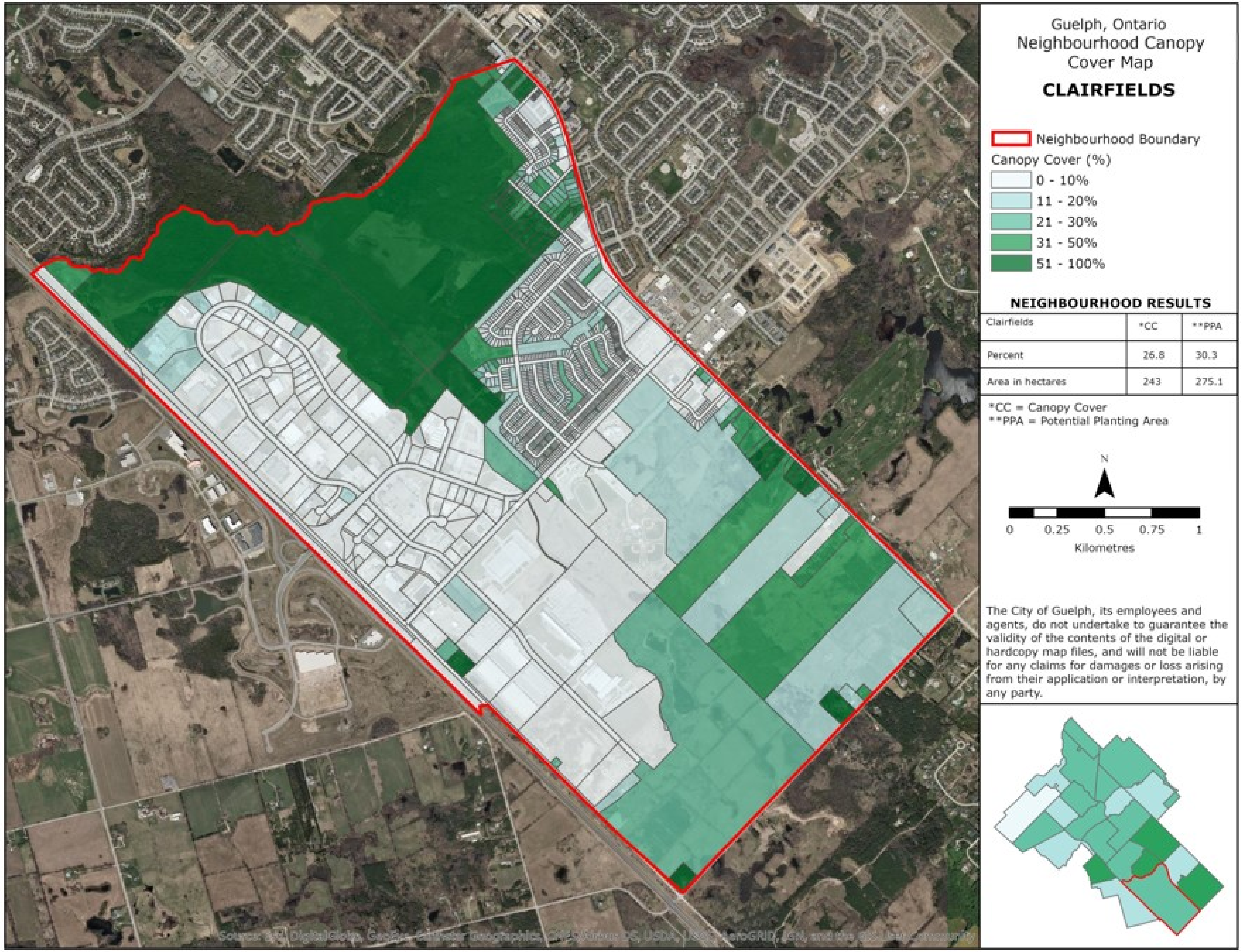
Guelph, Ontario
Neighbourhood Canopy Cover Map
CLAIRFIELDS
Neighbourhood Boundary
Canopy Cover (%)
0 - 10%
11 - 20%
21 - 30%
31 - 50%
51 - 100%
NEIGHBOURHOOD RESULTS
Clairfields | *CC | **PPA
Percent | 26.8 | 30.3
Area in hectares | 243 | 275.1
*CC = Canopy Cover
**PPA = Potential Planting Area
N
0 0.25 0.5 0.75 1
Kilometres
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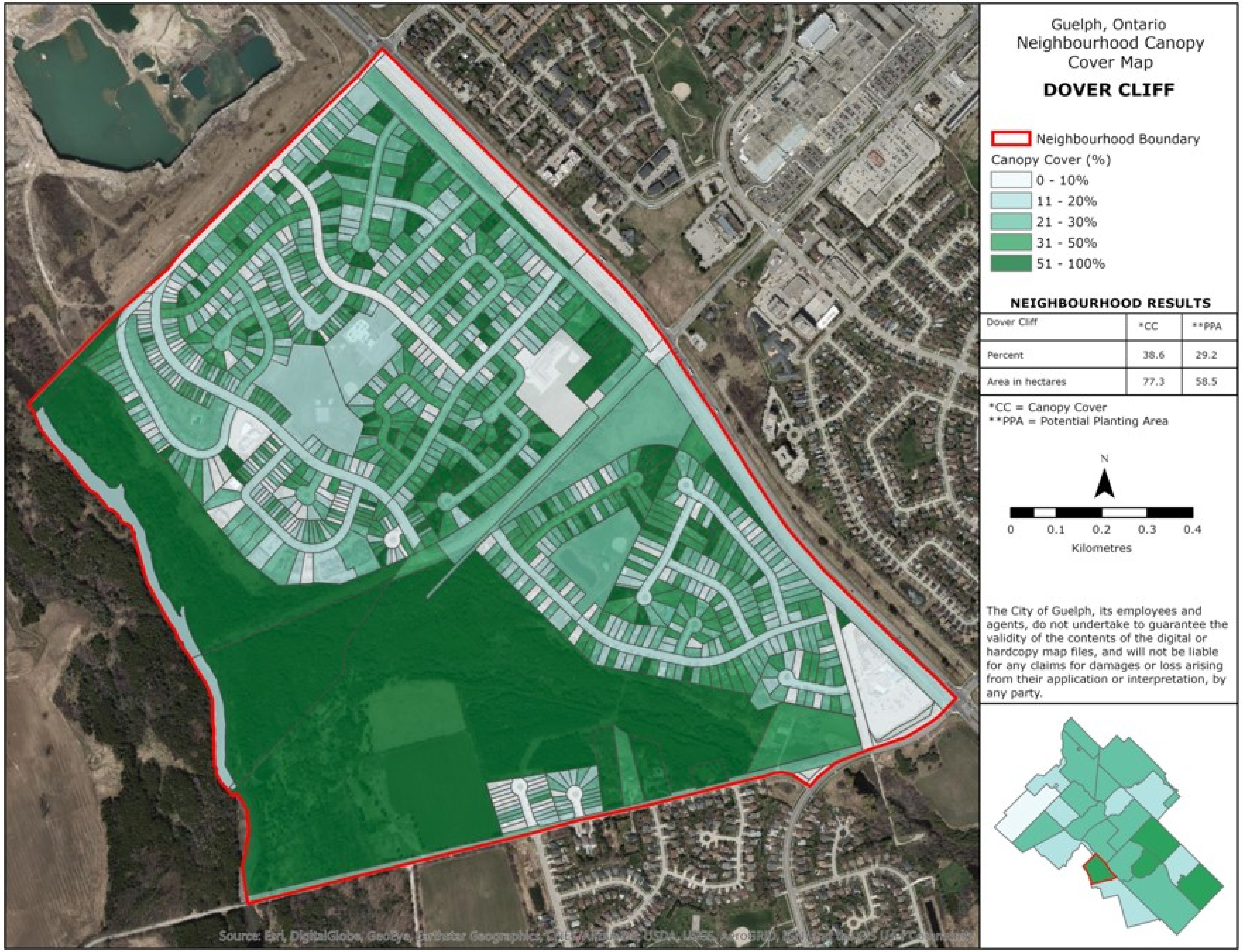
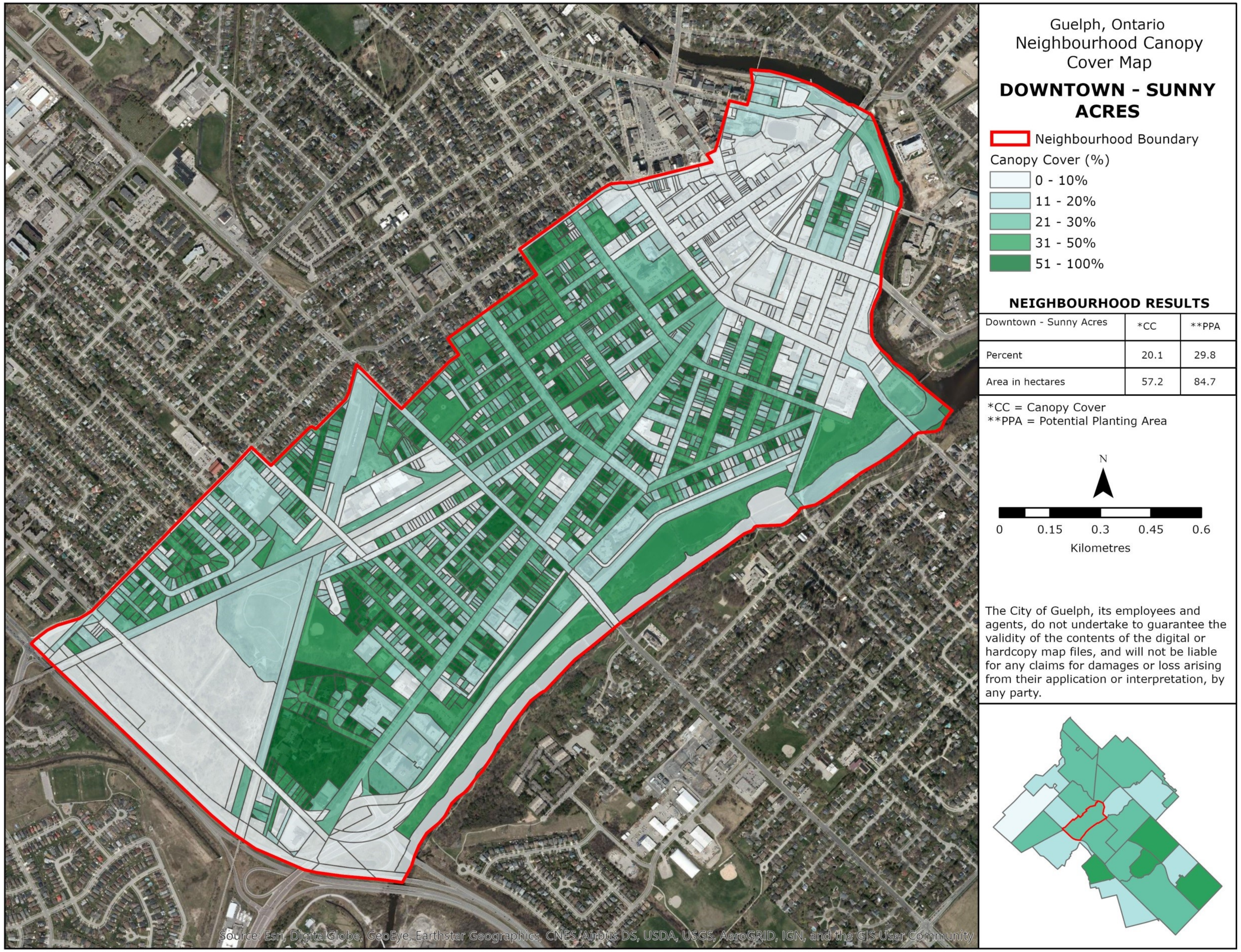


Dover Cliff	*CC	**PPA
Percent	38.6	29.2
Area in hectares	77.3	58.5


Guelph, Ontario
Neighbourhood Canopy Cover Map
DOWNTOWN - SUNNY ACRES
Neighbourhood Boundary
Canopy Cover (%)
0 - 10%
11 - 20%
21 - 30%
31 - 50%
51 - 100%
NEIGHBOURHOOD RESULTS
Downtown - Sunny Acres | *CC | **PPA
Percent | 20.1 | 29.8
Area in hectares | 57.2 | 84.7
*CC = Canopy Cover
**PPA = Potential Planting Area
N
0 0.15 0.3 0.45 0.6
Kilometres
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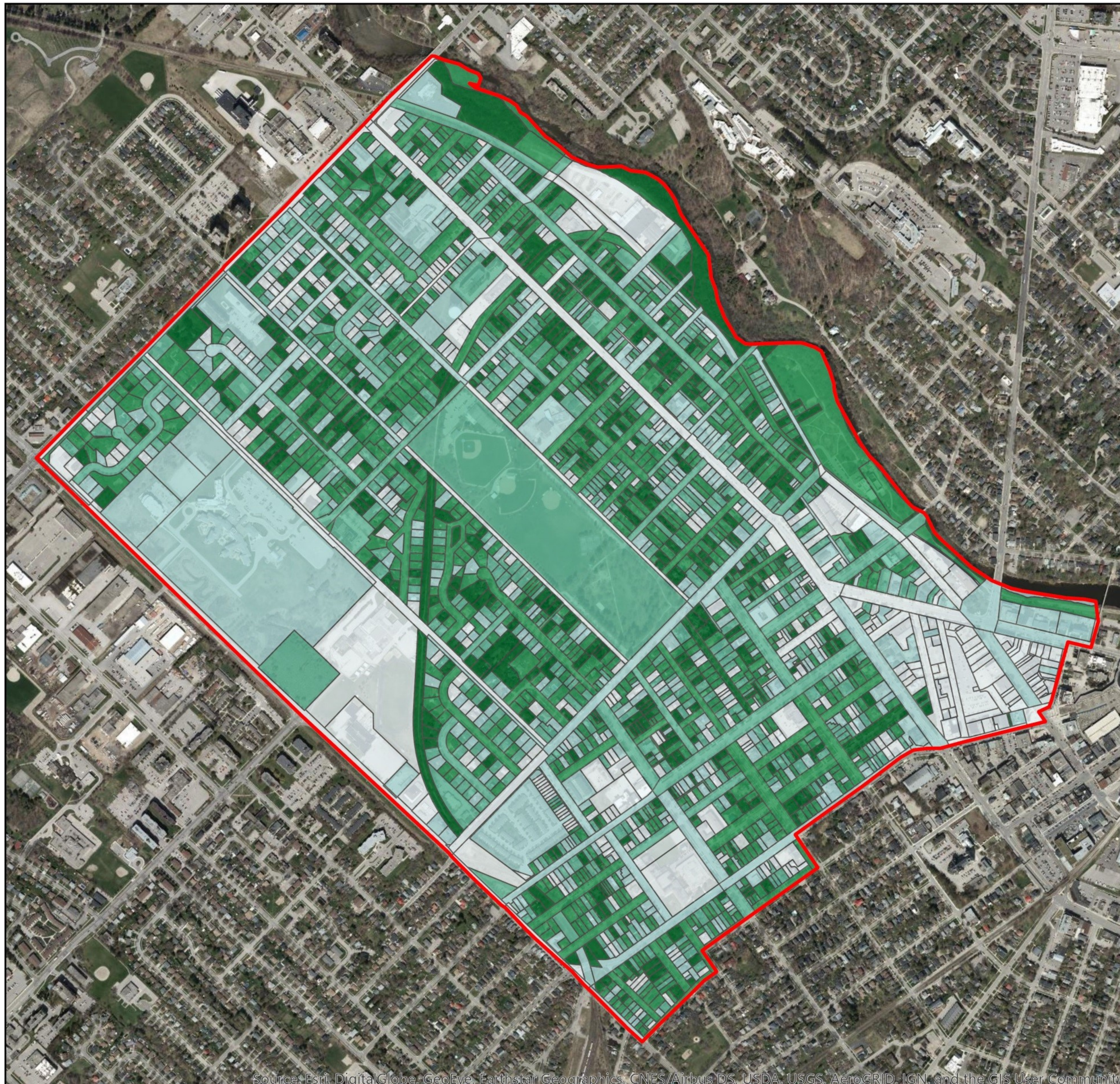
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community



Guelph, Ontario
Neighbourhood Canopy Cover Map

EXHIBITION PARK

Neighbourhood Boundary

Canopy Cover (%)

- 0 - 10%
- 11 - 20%
- 21 - 30%
- 31 - 50%
- 51 - 100%

NEIGHBOURHOOD RESULTS

Exhibition Park	*CC	**PPA
Percent	25.8	30.9
Area in hectares	67.8	81

*CC = Canopy Cover
**PPA = Potential Planting Area

N

0 0.1 0.2 0.3 0.4
Kilometres

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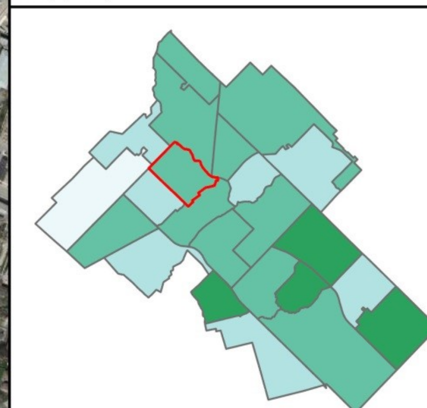
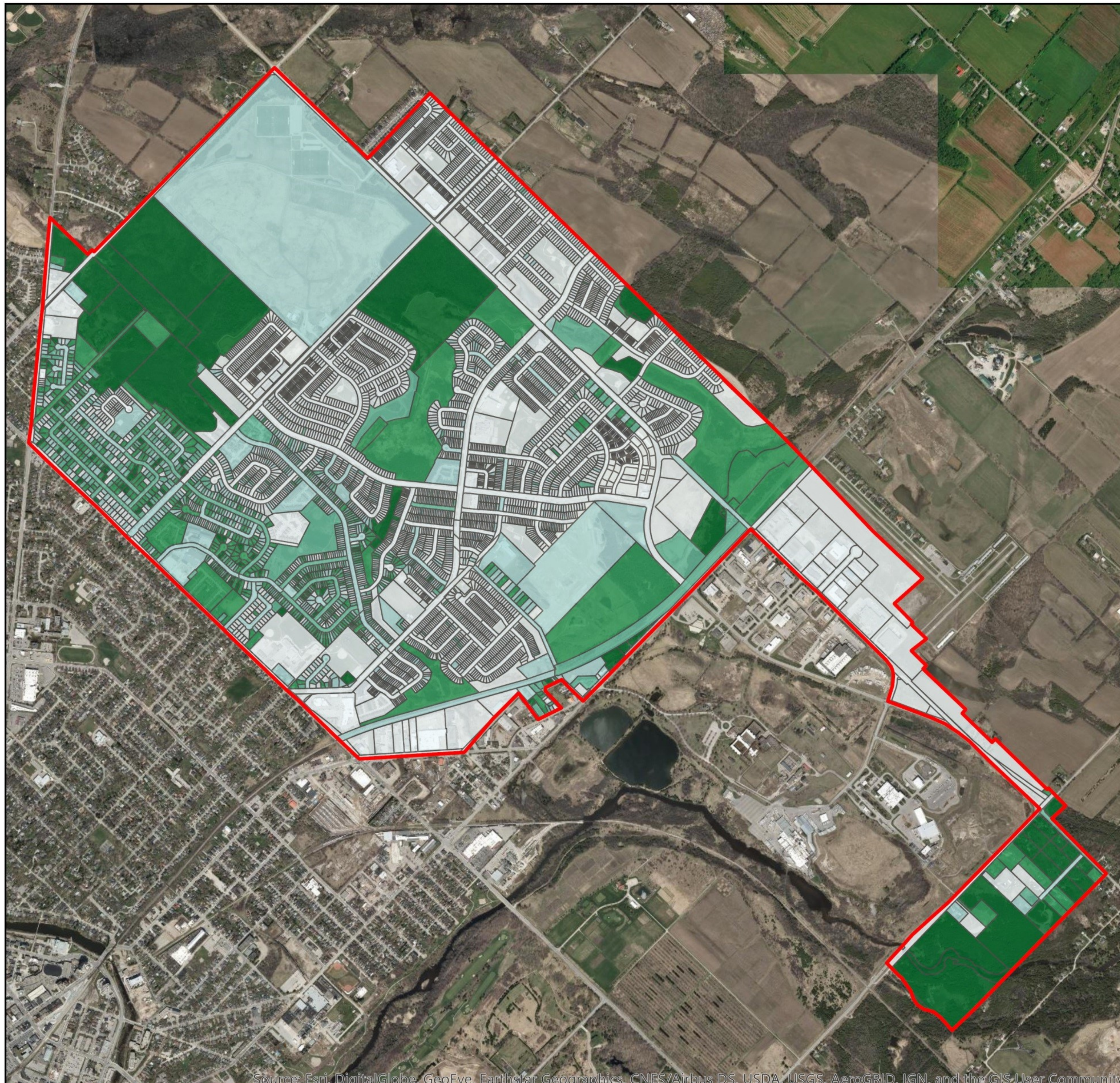




Guelph, Ontario
Neighbourhood Canopy Cover Map

GRANGE HILL EAST

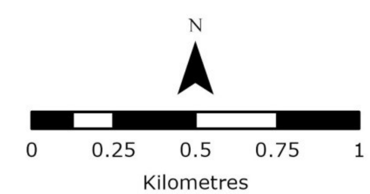
Neighbourhood Boundary

Canopy Cover (%)
- 0 - 10%
- 11 - 20%
- 21 - 30%
- 31 - 50%
- 51 - 100%

NEIGHBOURHOOD RESULTS

Grange Hill East	*CC	**PPA
Percent	20.5	35.7
Area in hectares	163.3	284.8

*CC = Canopy Cover
**PPA = Potential Planting Area



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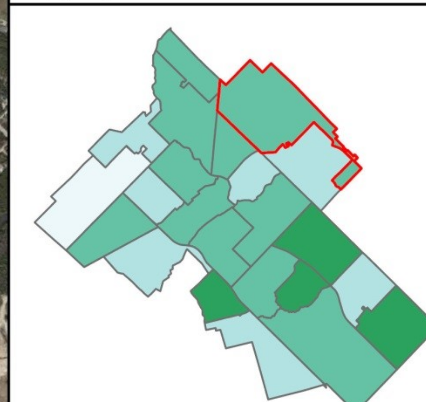

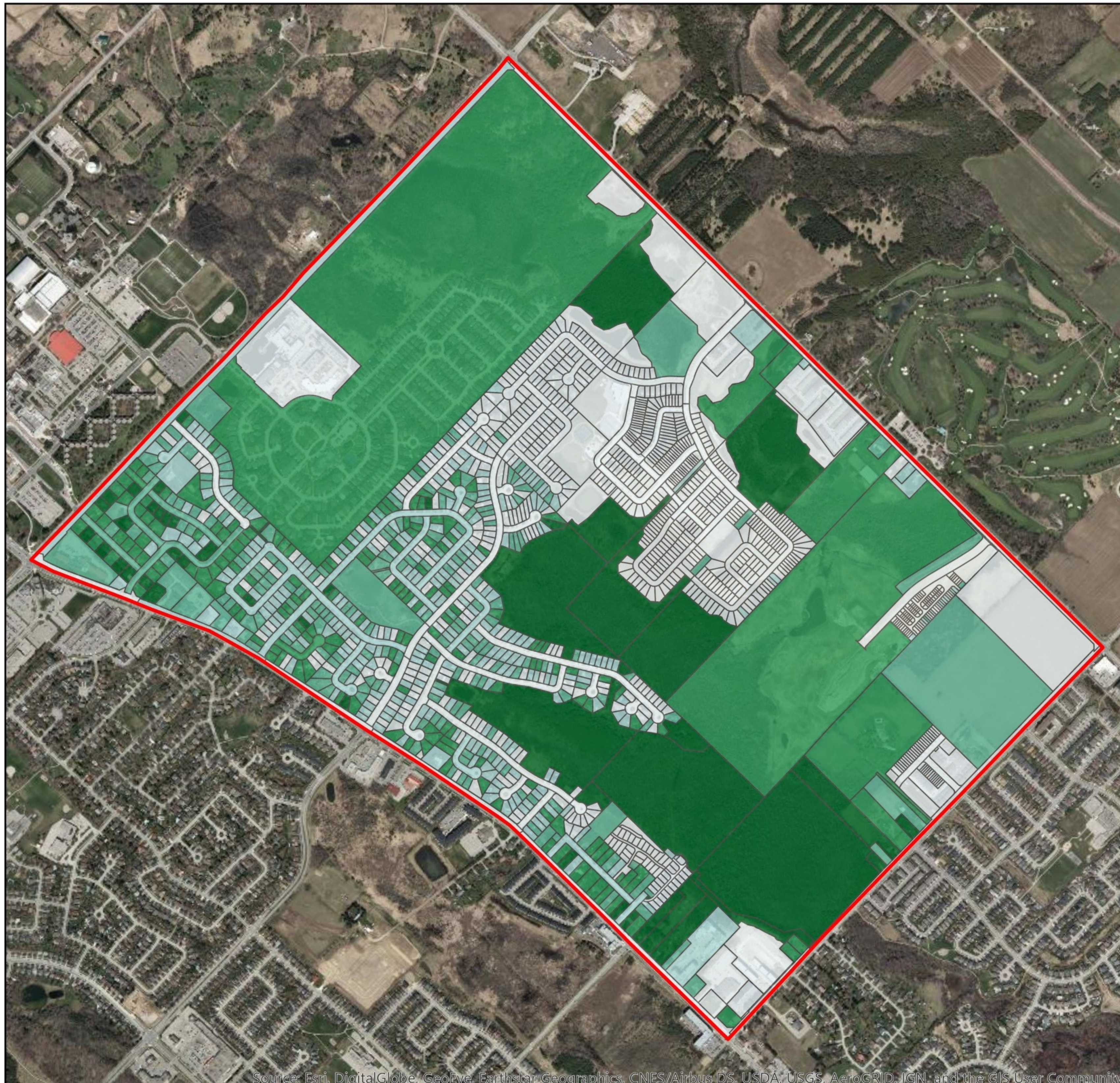

Guelph, Ontario
Neighbourhood Canopy Cover Map

HALES BARTON

Neighbourhood Boundary

Canopy Cover (%)

- 0 - 10%
- 11 - 20%
- 21 - 30%
- 31 - 50%
- 51 - 100%

NEIGHBOURHOOD RESULTS

Hales Barton	*CC	**PPA
Percent	32.1	30.5
Area in hectares	136.5	129.8

*CC = Canopy Cover
**PPA = Potential Planting Area

N

0 0.15 0.3 0.45 0.6
Kilometres

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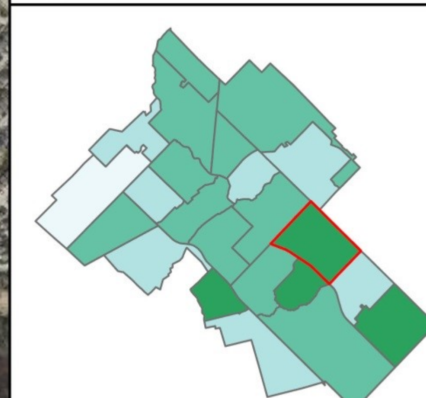

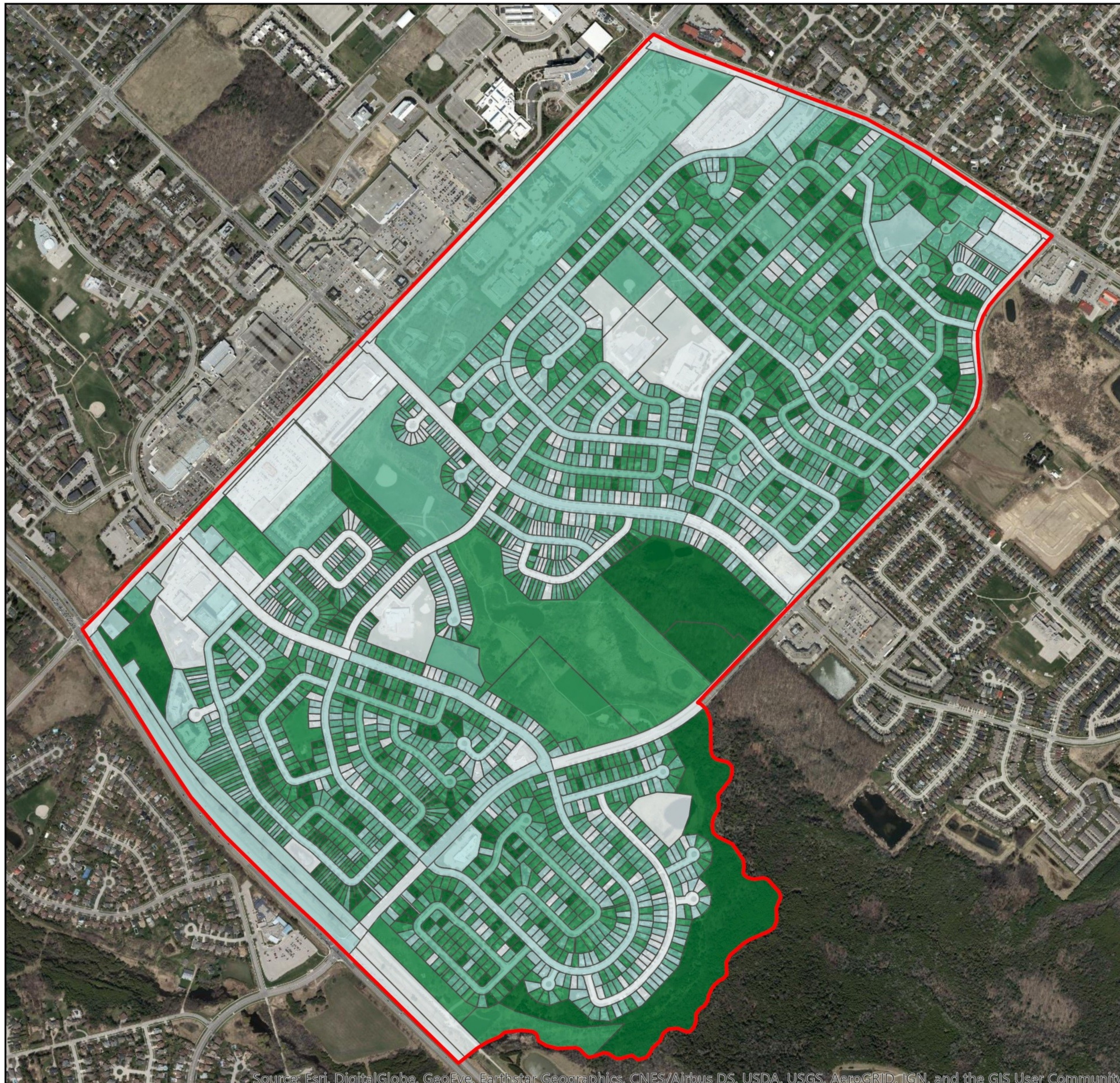

Guelph, Ontario
Neighbourhood Canopy Cover Map

HANLON CREEK

Neighbourhood Boundary

Canopy Cover (%)

- 0 - 10%
- 11 - 20%
- 21 - 30%
- 31 - 50%
- 51 - 100%

NEIGHBOURHOOD RESULTS

Hanlon Creek	*CC	**PPA
Percent	27.9	27.5
Area in hectares	90.1	88.8

*CC = Canopy Cover
**PPA = Potential Planting Area

N

0 0.15 0.3 0.45 0.6
Kilometres

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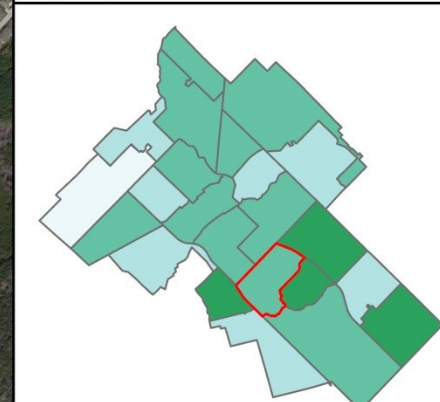

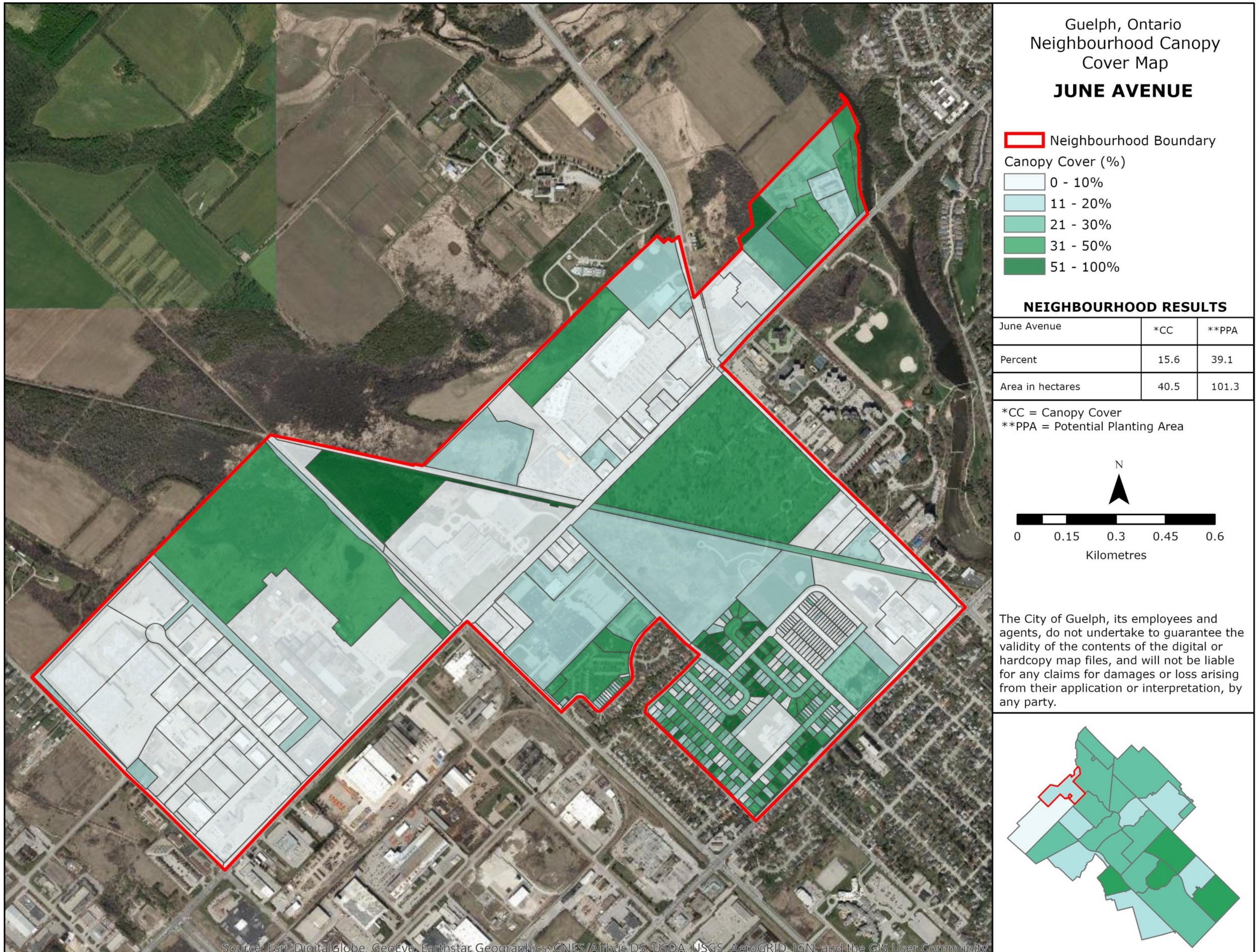

NEIGHBOURHOOD RESULTS

June Avenue	*CC	**PPA
Percent	15.6	39.1
Area in hectares	40.5	101.3

*CC = Canopy Cover
**PPA = Potential Planting Area

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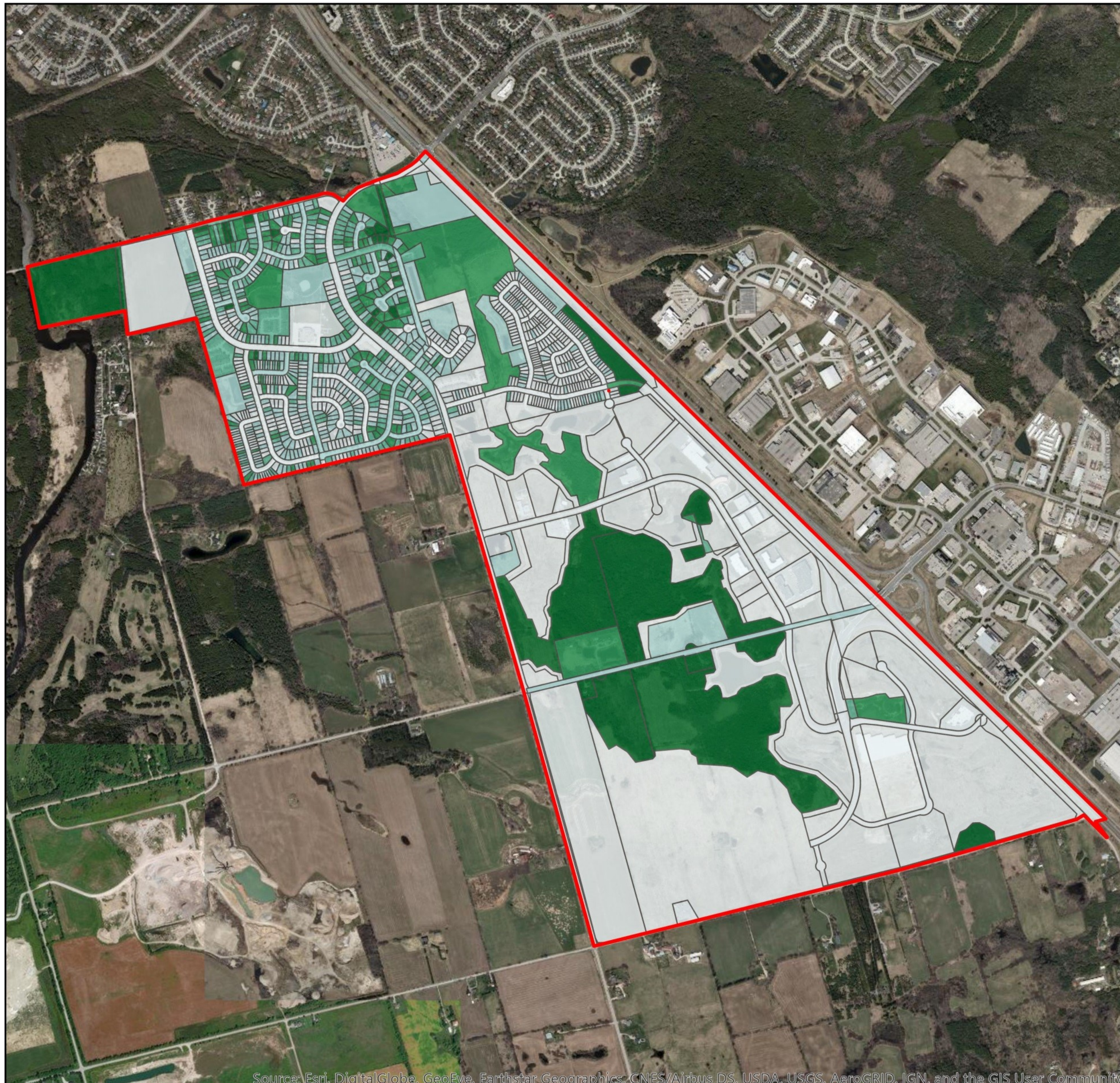


Guelph, Ontario
Neighbourhood Canopy
Cover Map

KORTRIGHT HILLS

Neighbourhood Boundary

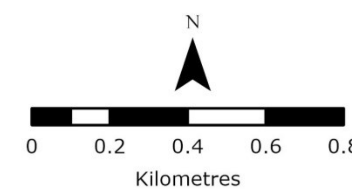
Canopy Cover (%)

- 0 - 10%
- 11 - 20%
- 21 - 30%
- 31 - 50%
- 51 - 100%

NEIGHBOURHOOD RESULTS

Kortright Hills	*CC	**PPA
Percent	17.6	51.3
Area in hectares	81.2	236.4

*CC = Canopy Cover
**PPA = Potential Planting Area



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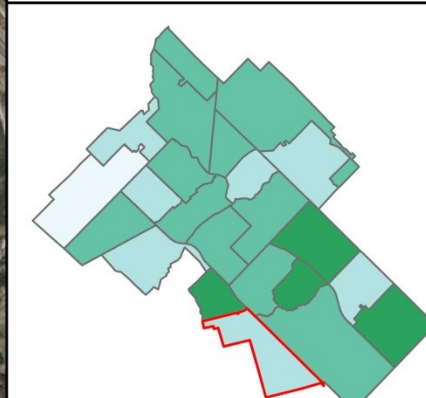

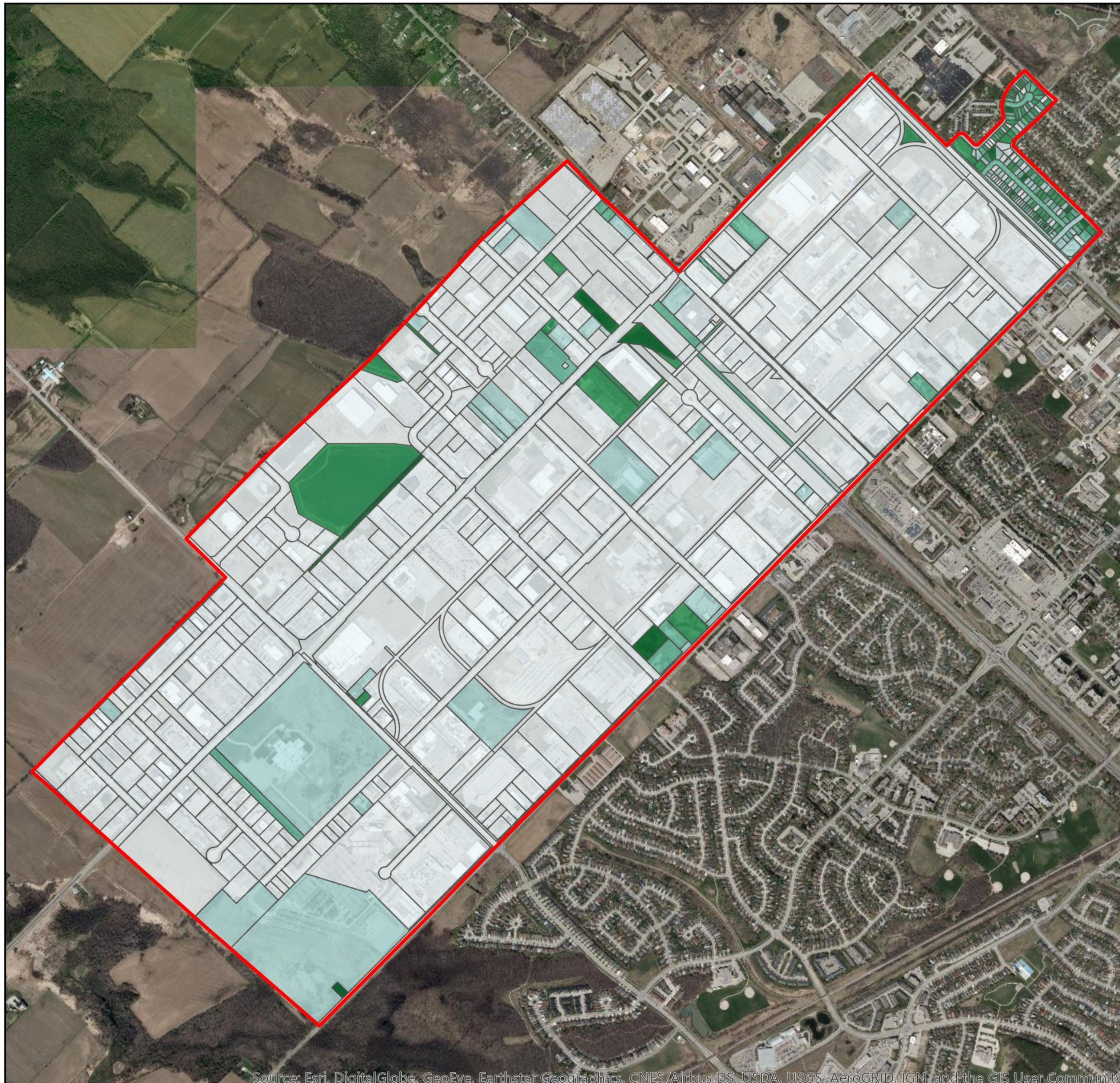

Guelph, Ontario
Neighbourhood Canopy Cover Map

NON-RESIDENTIAL - A

Neighbourhood Boundary

Canopy Cover (%)
- 0 - 10%
- 11 - 20%
- 21 - 30%
- 31 - 50%
- 51 - 100%

NEIGHBOURHOOD RESULTS

Non-Residential - A	*CC	**PPA
Percent	5.7	33.6
Area in hectares	34.8	206.1

*CC = Canopy Cover
**PPA = Potential Planting Area

N

0 0.2 0.4 0.6 0.8
Kilometres

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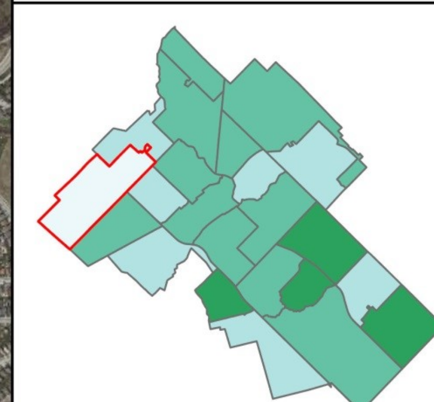

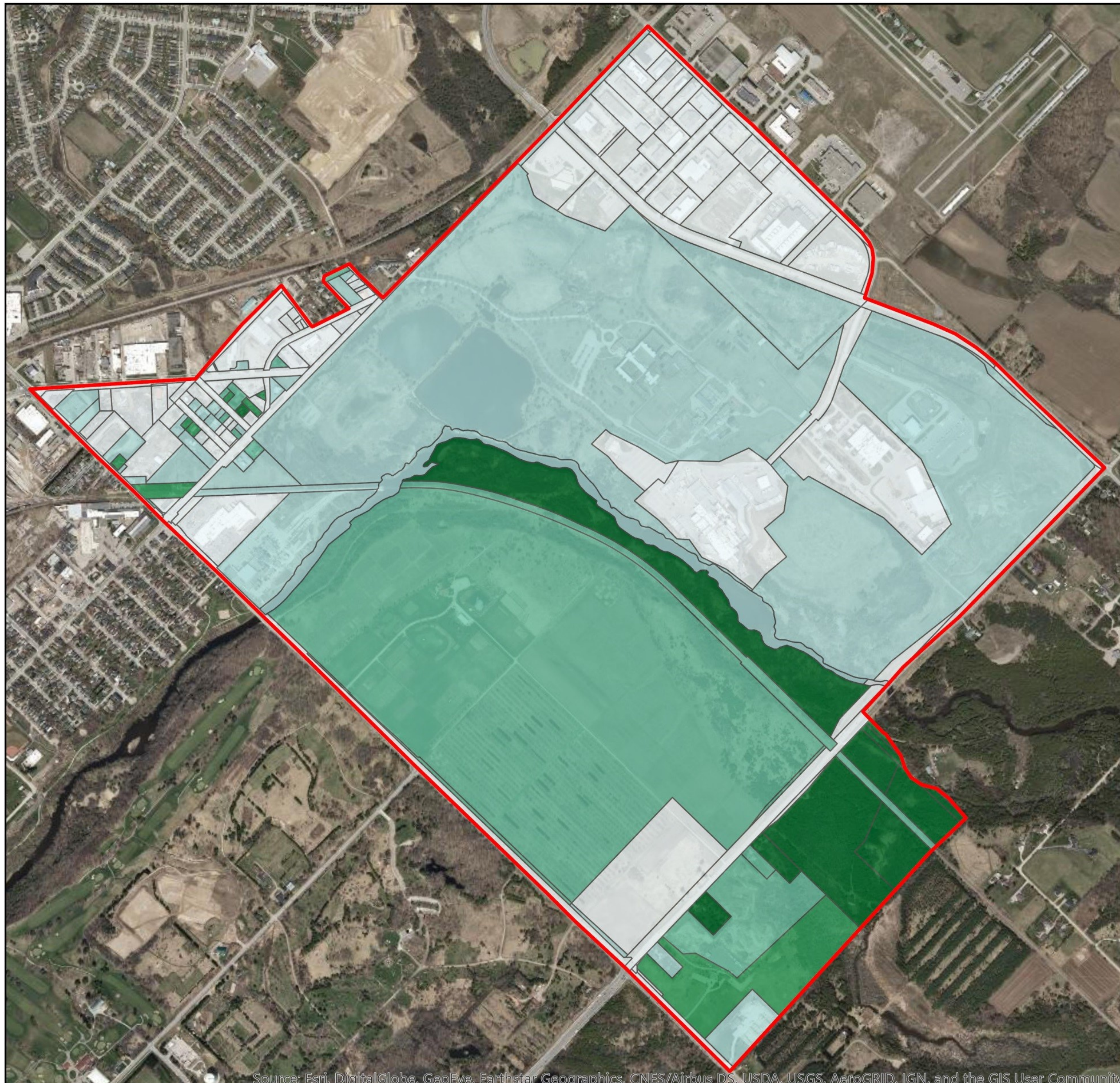

Guelph, Ontario
Neighbourhood Canopy Cover Map

NON-RESIDENTIAL - B

Neighbourhood Boundary
Canopy Cover (%)
0 - 10%
11 - 20%
21 - 30%
31 - 50%
51 - 100%

NEIGHBOURHOOD RESULTS

Non-Residential - B	*CC	**PPA
Percent	19	41.8
Area in hectares	85.8	188.6

*CC = Canopy Cover
**PPA = Potential Planting Area

N

0 0.15 0.3 0.45 0.6
Kilometres

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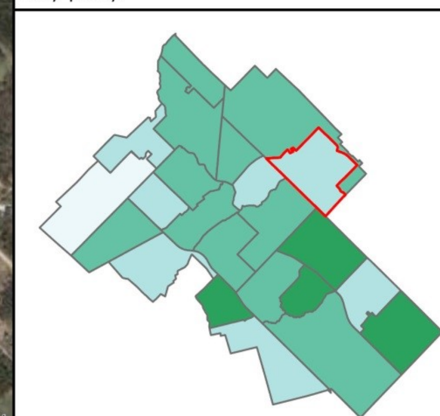

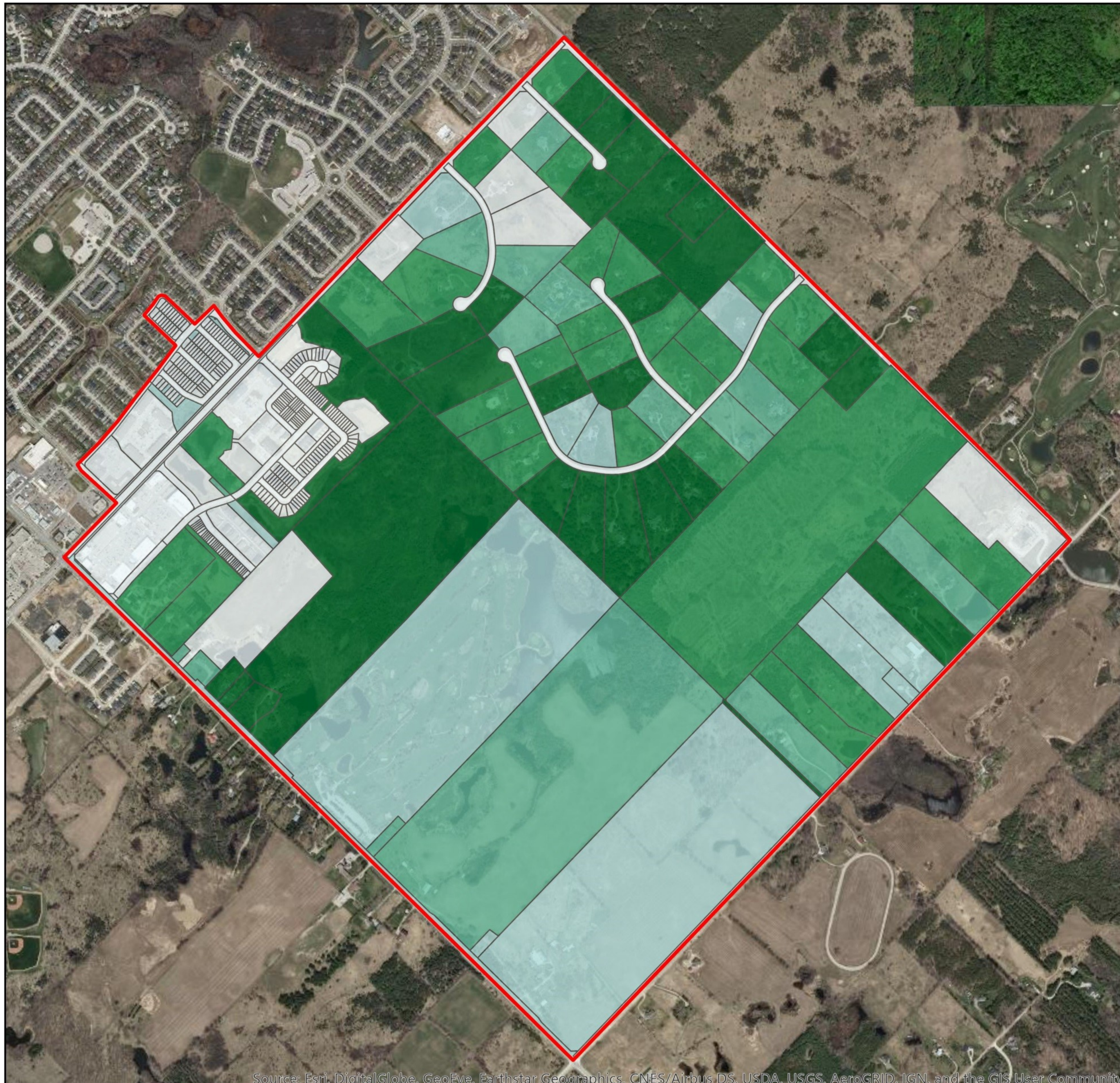

Guelph, Ontario
Neighbourhood Canopy Cover Map

NON-RESIDENTIAL - C

Neighbourhood Boundary

Canopy Cover (%)

- 0 - 10%
- 11 - 20%
- 21 - 30%
- 31 - 50%
- 51 - 100%

NEIGHBOURHOOD RESULTS

Non-Residential - C	*CC	**PPA
Percent	33.9	26.3
Area in hectares	146.8	114

*CC = Canopy Cover
**PPA = Potential Planting Area

N

0 0.15 0.3 0.45 0.6
Kilometres

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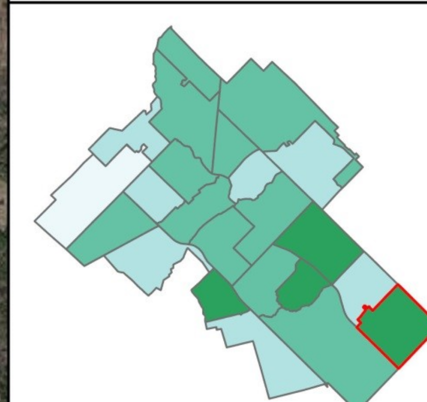

Guelph, Ontario
Neighbourhood Canopy Cover Map

OLD UNIVERSITY

Neighbourhood Boundary

Canopy Cover (%)
- 0 - 10%
- 11 - 20%
- 21 - 30%
- 31 - 50%
- 51 - 100%

NEIGHBOURHOOD RESULTS

Old University	*CC	**PPA
Percent	27.1	26.6
Area in hectares	87.7	86.1

*CC = Canopy Cover
**PPA = Potential Planting Area

N

0 0.15 0.3 0.45 0.6
Kilometres

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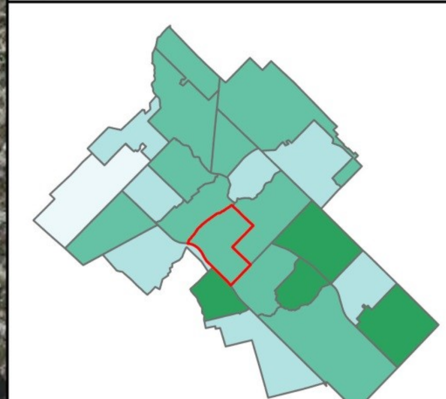

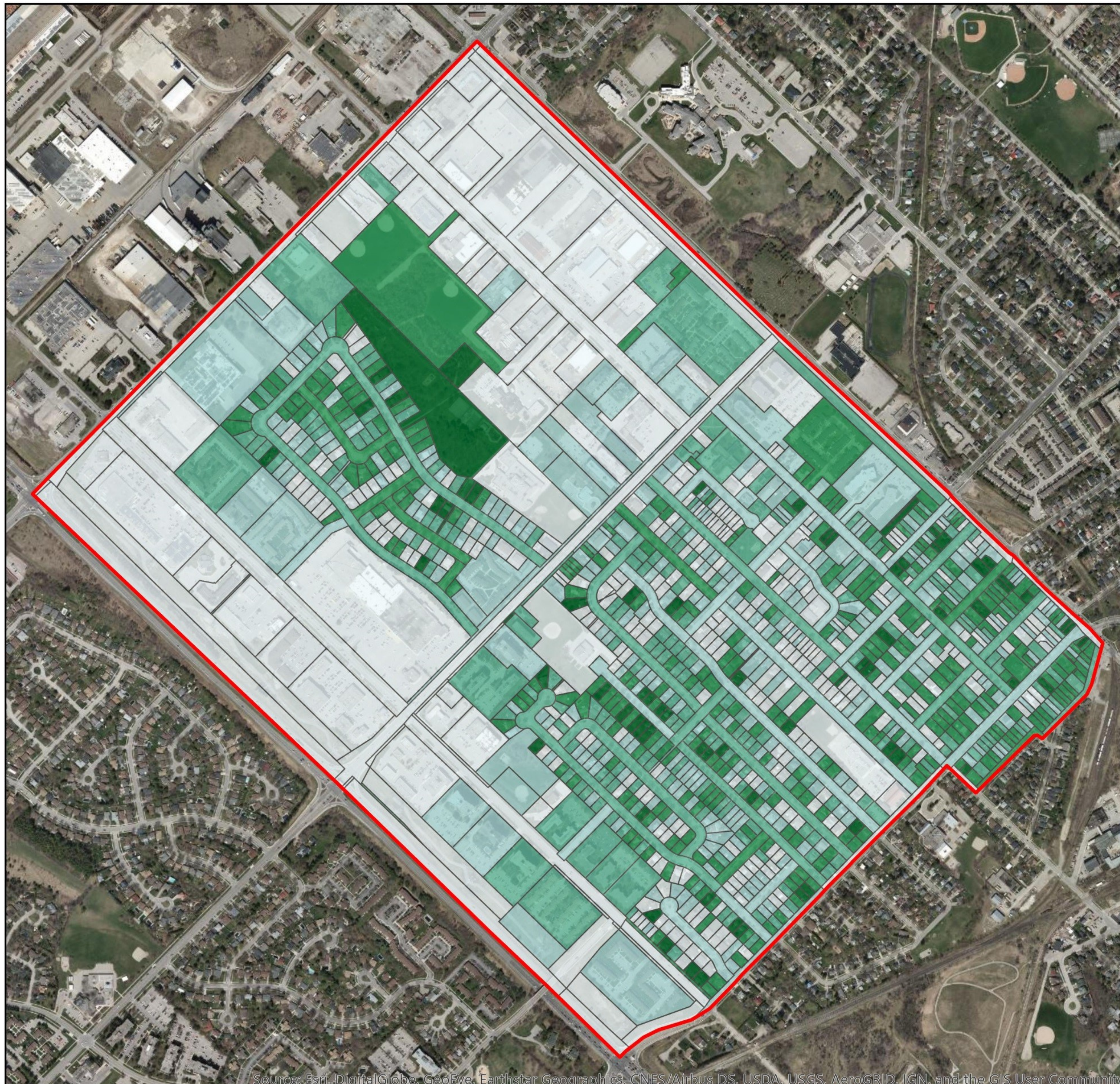

Guelph, Ontario
Neighbourhood Canopy Cover Map

ONWARD WILLOW

Neighbourhood Boundary

Canopy Cover (%)
- 0 - 10%
- 11 - 20%
- 21 - 30%
- 31 - 50%
- 51 - 100%

NEIGHBOURHOOD RESULTS

Onward Willow	*CC	**PPA
Percent	16.3	31.2
Area in hectares	35.3	67.4

*CC = Canopy Cover
**PPA = Potential Planting Area

N

0 0.1 0.2 0.3 0.4
Kilometres

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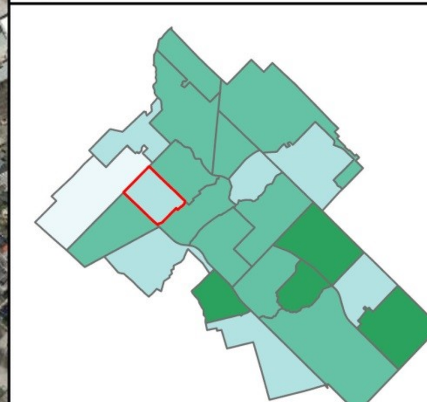

Guelph, Ontario
Neighbourhood Canopy Cover Map

PARKWOOD GARDENS

Neighbourhood Boundary

Canopy Cover (%)

- 0 - 10%
- 11 - 20%
- 21 - 30%
- 31 - 50%
- 51 - 100%

NEIGHBOURHOOD RESULTS

Parkwood Gardens	*CC	**PPA
Percent	13.8	39.4
Area in hectares	51.5	146.6

*CC = Canopy Cover
**PPA = Potential Planting Area

N

0 0.2 0.4 0.6 0.8
Kilometres

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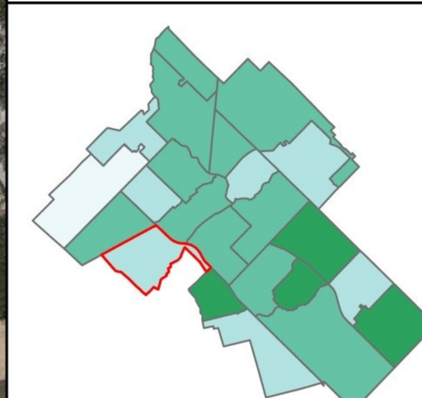
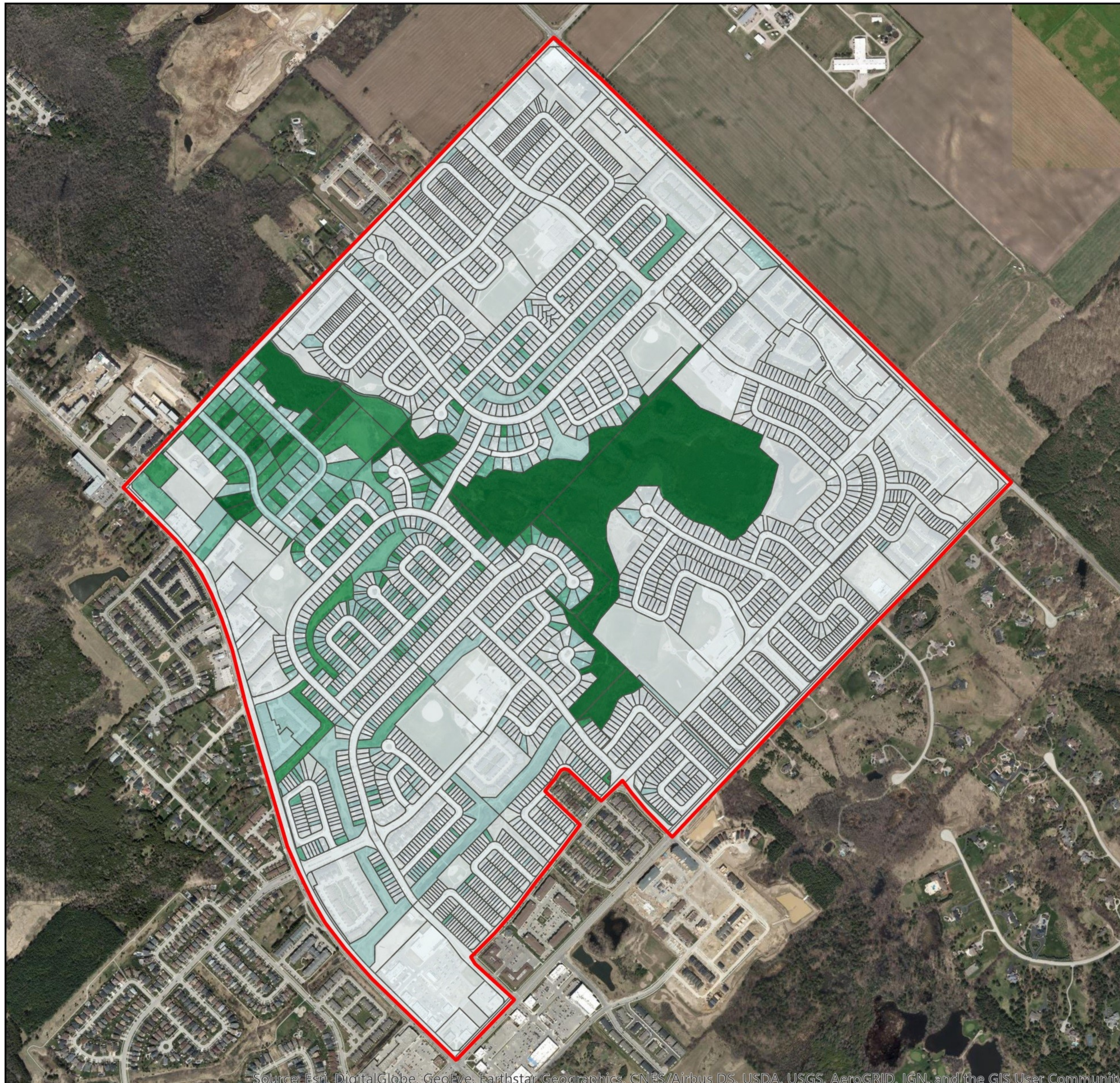




Guelph, Ontario
Neighbourhood Canopy Cover Map

PINE RIDGE - WESTMINSTER WOODS

Neighbourhood Boundary

Canopy Cover (%)

- 0 - 10%
- 11 - 20%
- 21 - 30%
- 31 - 50%
- 51 - 100%

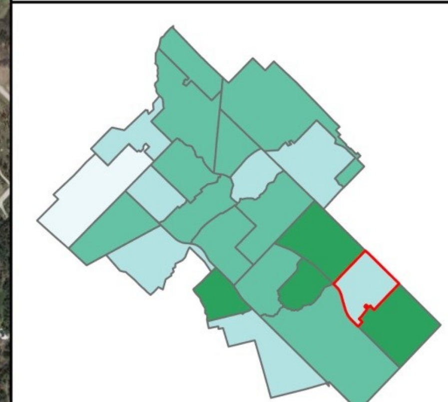
NEIGHBOURHOOD RESULTS

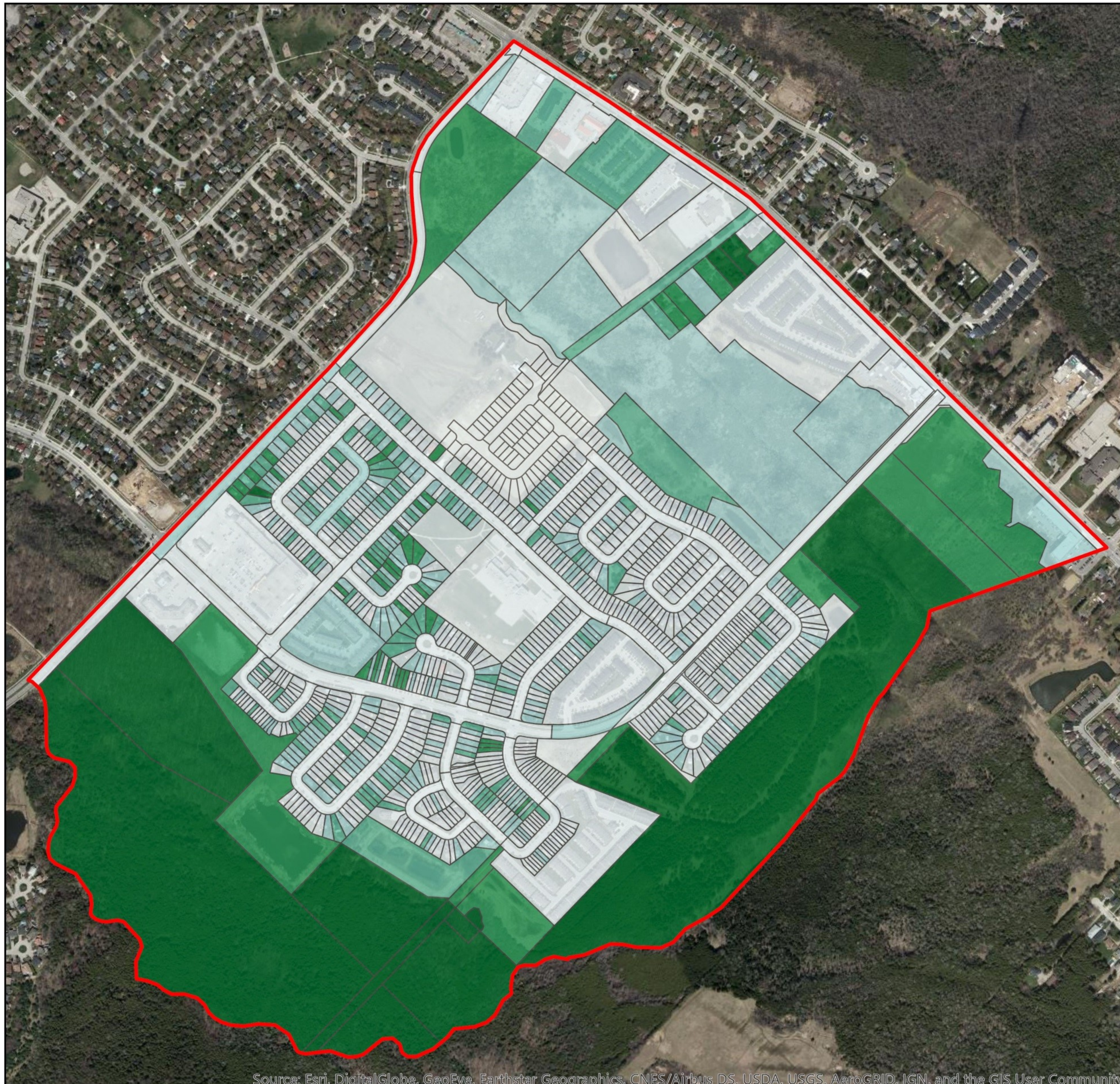
Pine Ridge - Westminster Woods	*CC	**PPA
Percent	11.2	38.6
Area in hectares	33.1	114.4

*CC = Canopy Cover
**PPA = Potential Planting Area

N

0 0.15 0.3 0.45 0.6
Kilometres





Guelph, Ontario
Neighbourhood Canopy Cover Map

RICKSON RIDGE

Neighbourhood Boundary

Canopy Cover (%)

- 0 - 10%
- 11 - 20%
- 21 - 30%
- 31 - 50%
- 51 - 100%

NEIGHBOURHOOD RESULTS

Rickson Ridge	*CC	**PPA
Percent	32.8	38.8
Area in hectares	63	74.6

*CC = Canopy Cover
**PPA = Potential Planting Area

N

0 0.1 0.2 0.3 0.4
Kilometres

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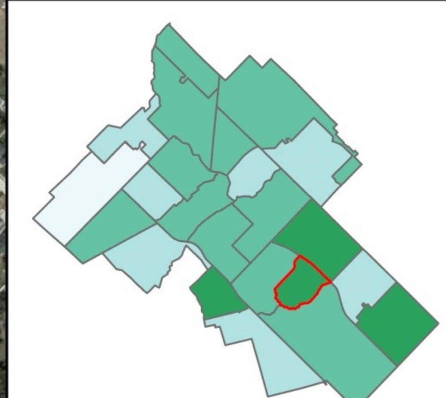

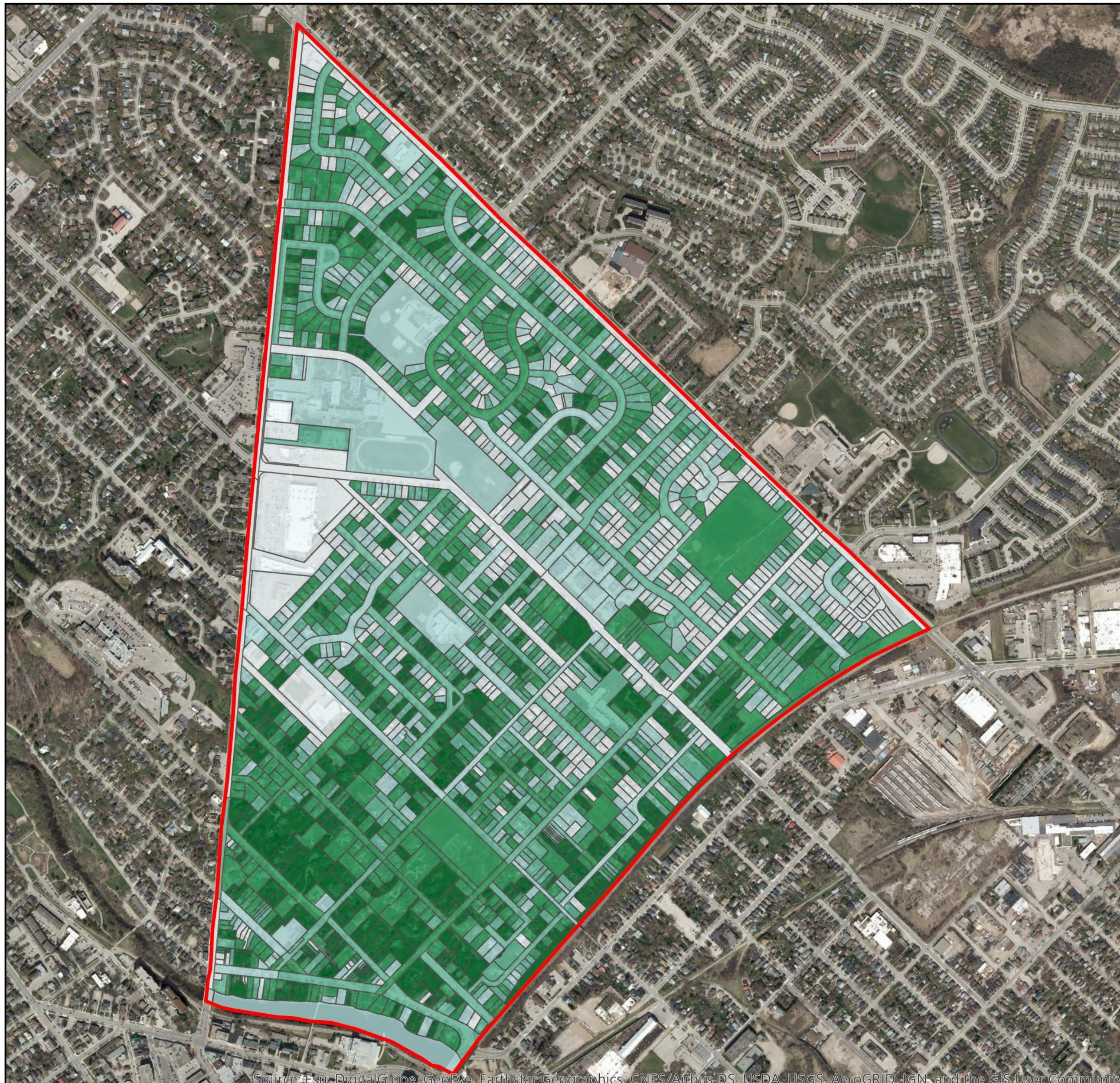

Guelph, Ontario
Neighbourhood Canopy Cover Map

ST. GEORGES PARKWAY

Neighbourhood Boundary

Canopy Cover (%)

- 0 - 10%
- 11 - 20%
- 21 - 30%
- 31 - 50%
- 51 - 100%

NEIGHBOURHOOD RESULTS

St. Georges Parkway	*CC	**PPA
Percent	27.1	33.2
Area in hectares	55.5	67.9

*CC = Canopy Cover
**PPA = Potential Planting Area

N

0 0.1 0.2 0.3 0.4
Kilometres

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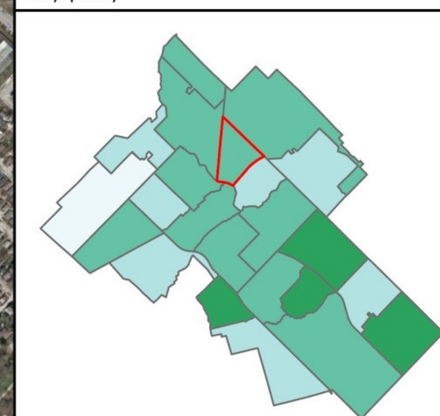

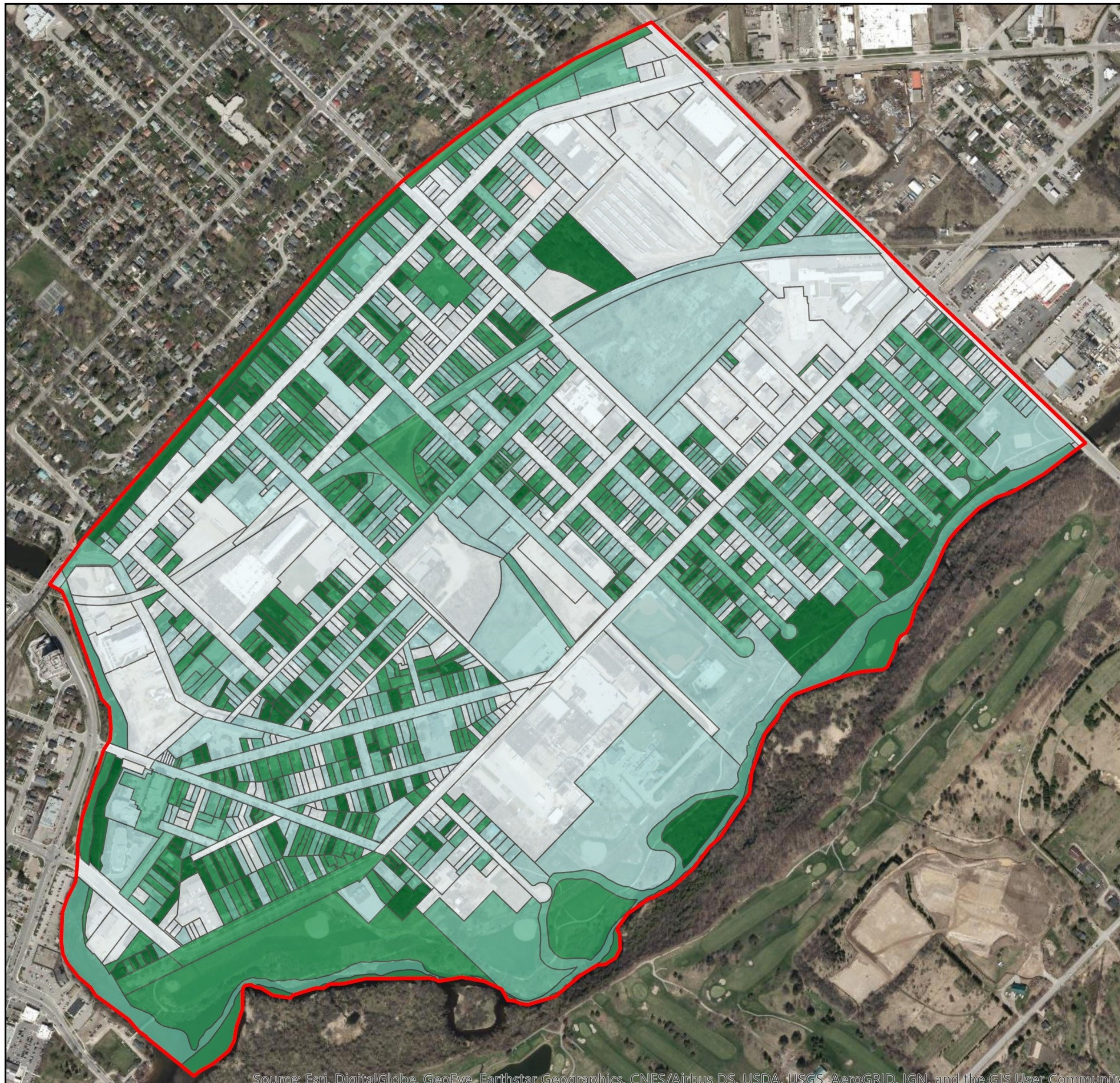

Guelph, Ontario
Neighbourhood Canopy Cover Map

TWO RIVERS

Neighbourhood Boundary

Canopy Cover (%)
- 0 - 10%
- 11 - 20%
- 21 - 30%
- 31 - 50%
- 51 - 100%

NEIGHBOURHOOD RESULTS

Two Rivers	*CC	**PPA
Percent	18.7	32.1
Area in hectares	37.5	64.5

*CC = Canopy Cover
**PPA = Potential Planting Area

N

0 0.1 0.2 0.3 0.4
Kilometres

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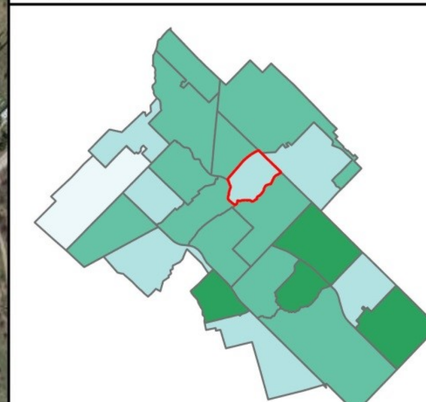

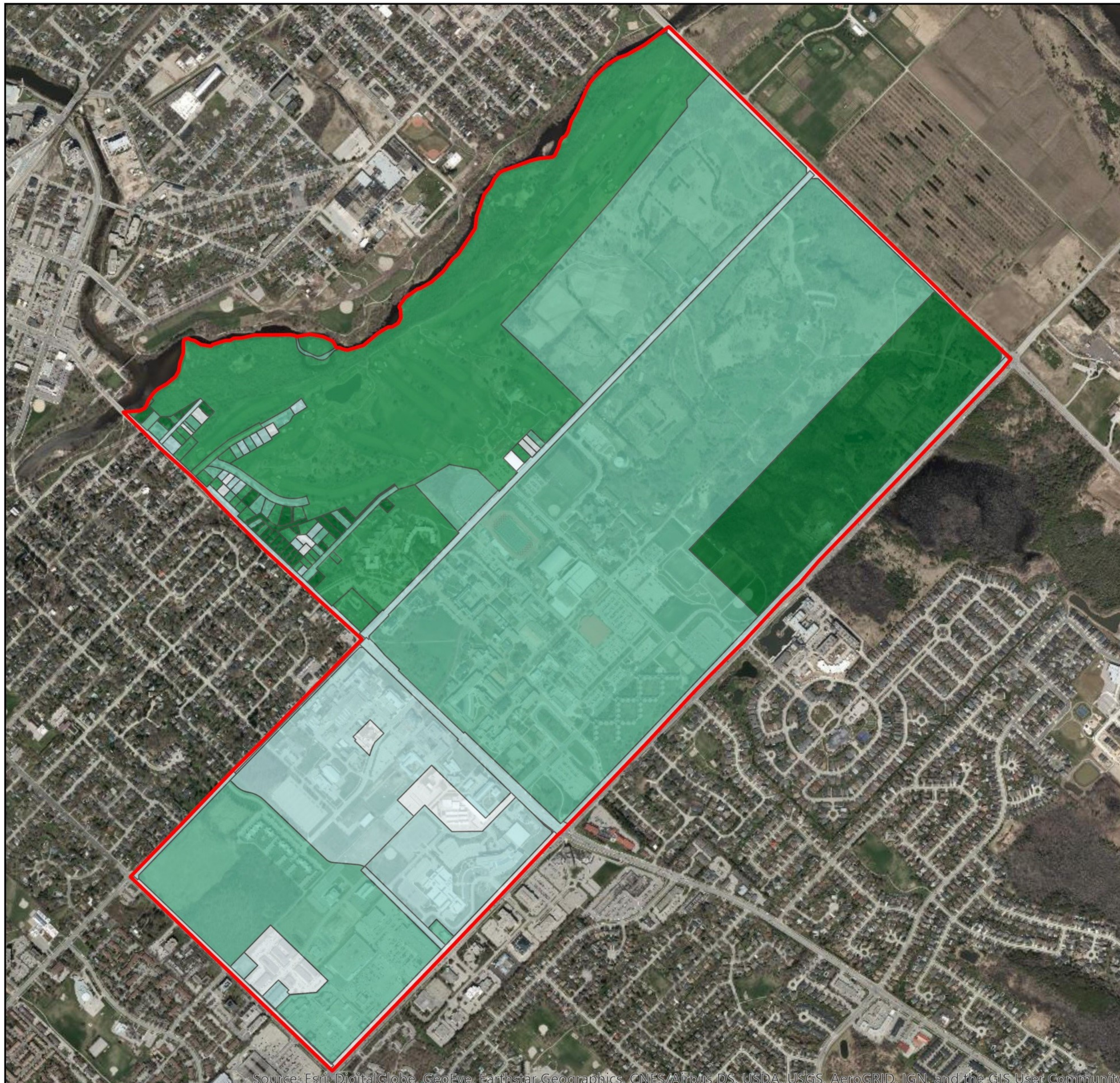

Guelph, Ontario
Neighbourhood Canopy Cover Map

UNIVERSITY

Neighbourhood Boundary

Canopy Cover (%)

- 0 - 10%
- 11 - 20%
- 21 - 30%
- 31 - 50%
- 51 - 100%

NEIGHBOURHOOD RESULTS

University	*CC	**PPA
Percent	28.6	31.8
Area in hectares	121	134.3

*CC = Canopy Cover
**PPA = Potential Planting Area

N

0 0.15 0.3 0.45 0.6
Kilometres

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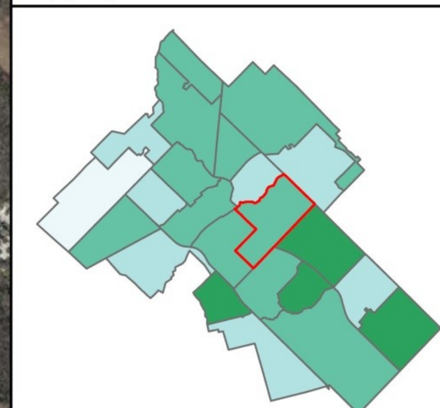

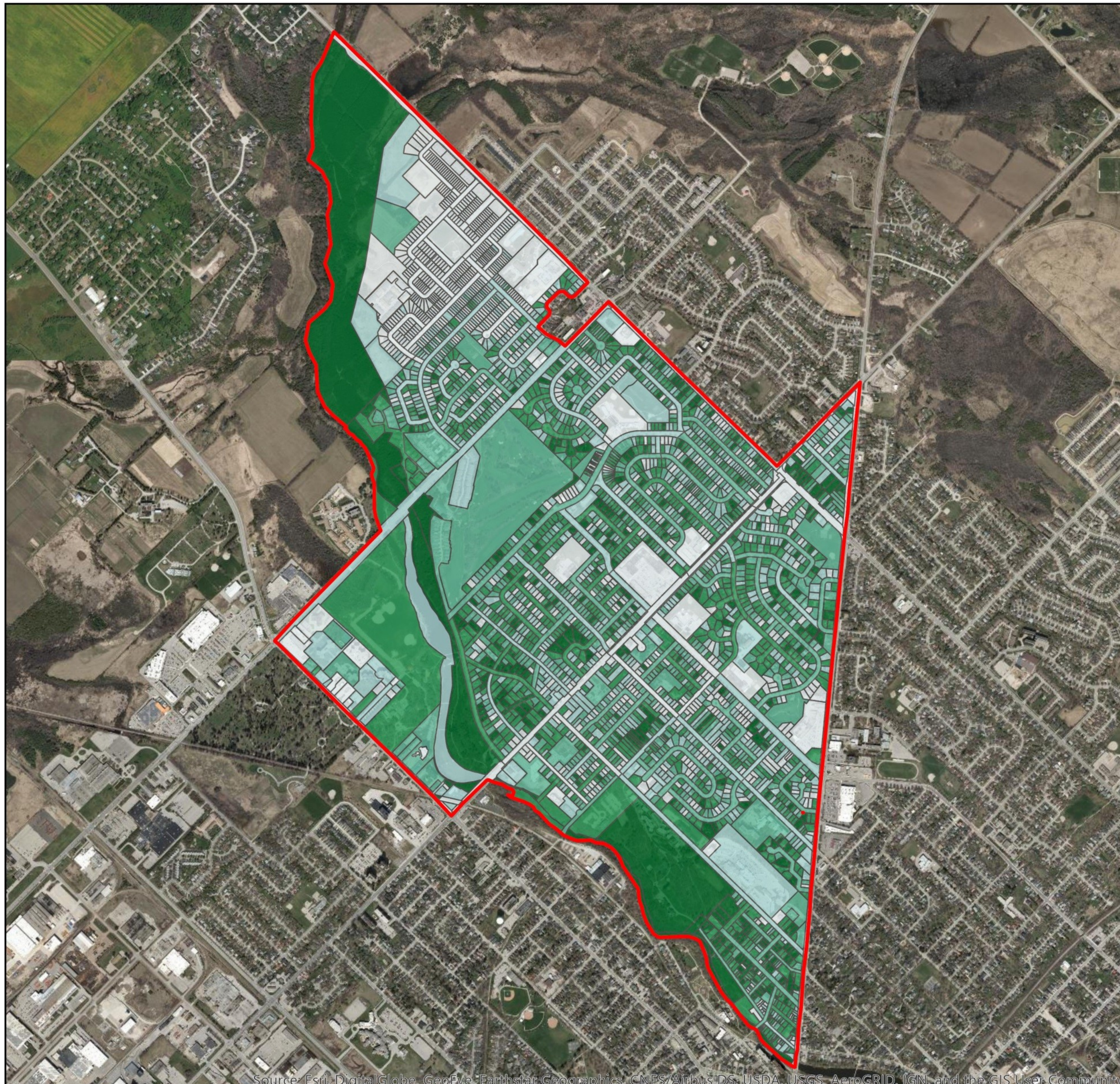

Guelph, Ontario
Neighbourhood Canopy Cover Map

WAVERLEY

Neighbourhood Boundary

Canopy Cover (%)

- 0 - 10%
- 11 - 20%
- 21 - 30%
- 31 - 50%
- 51 - 100%

NEIGHBOURHOOD RESULTS

Waverley	*CC	**PPA
Percent	28.7	29.5
Area in hectares	151.2	155.4

*CC = Canopy Cover
**PPA = Potential Planting Area

N

0 0.25 0.5 0.75 1
Kilometres

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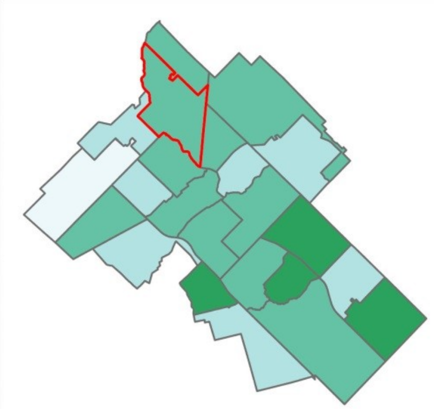

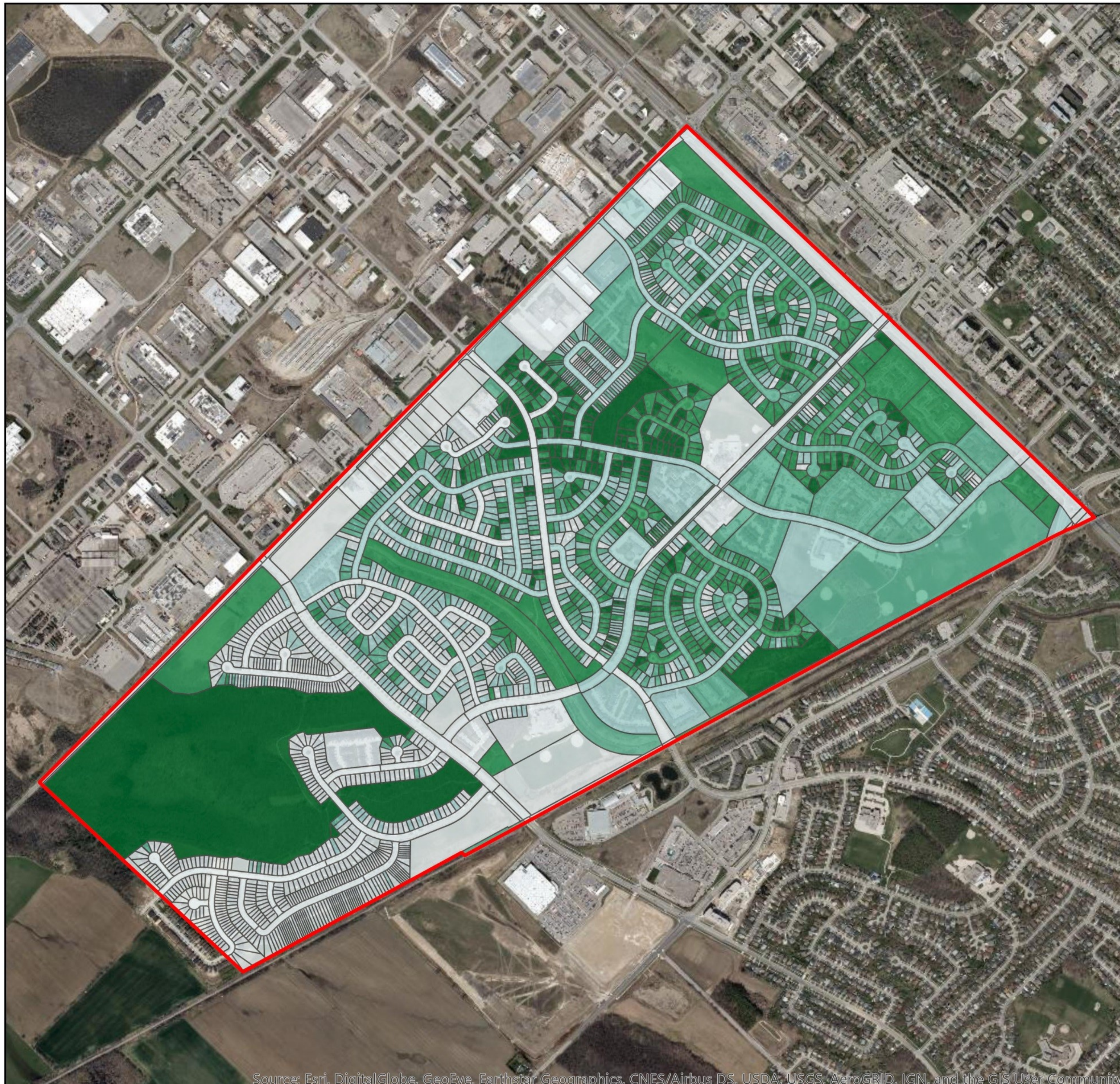

Guelph, Ontario
Neighbourhood Canopy Cover Map

WEST WILLOW WOODS

Neighbourhood Boundary

Canopy Cover (%)
- 0 - 10%
- 11 - 20%
- 21 - 30%
- 31 - 50%
- 51 - 100%

NEIGHBOURHOOD RESULTS

West Willow Woods	*CC	**PPA
Percent	28.4	34.3
Area in hectares	102.5	123.7

*CC = Canopy Cover
**PPA = Potential Planting Area

N

0 0.15 0.3 0.45 0.6
Kilometres

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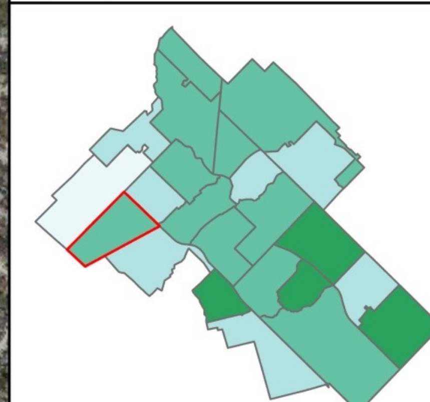


Appendix G: Tree Planting Prioritization Tool Input Layer (Potential Planting Area Net Down)

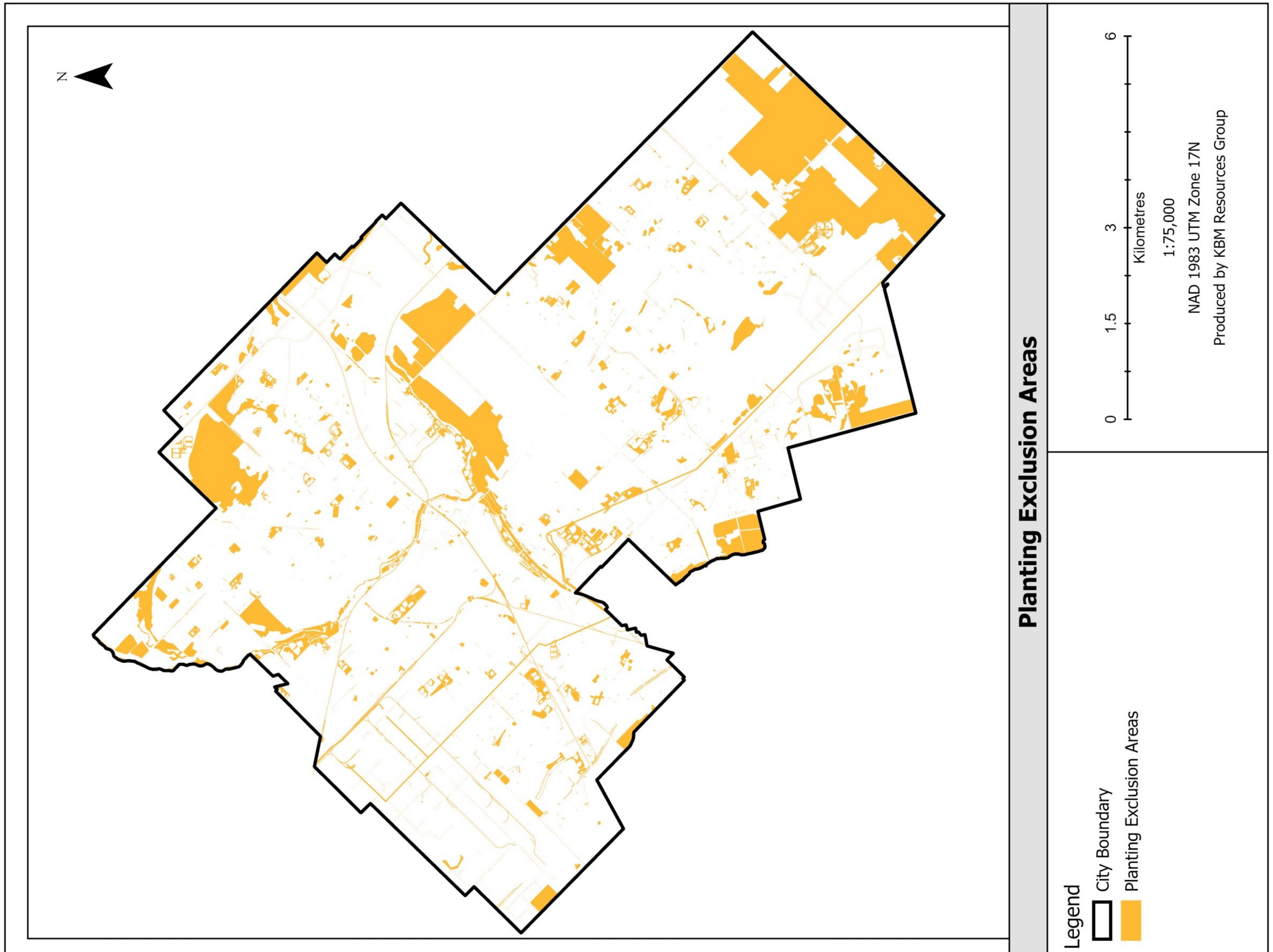
LIST OF DATASETS USED TO NET DOWN PLANTABLE AREA IN GUELPH (EXCLUSIONS)

Note: Plantable area is defined as pervious soil and non-canopy vegetation land cover types – this area has been netted down in the TPPT model to reflect known land use constraints and available datasets to describe these. The netting down process results in a more realistic estimate of what land areas could accommodate trees. The resulting map is useful for strategic and tactical planning – operational planning will further identify other constraints at the site level.

Category	Source
SportsFields and Courts (A separate layer extracted from parks mowing layer – the rest of mowing area is included as plantable area)	Park_Mowing_Areas_FieldsandCourtsRemoved.shp
Community Gardens	Parks.gdb/_Park_Community_Gardens
Tennis Courts	Merged Park_Courts TENNIS classification with UGDSB_Courts TENNIS classification, output: Parks_Courts_UGDSB_Courts_TennisCourts.shp
Splashpads	Parks.gdb/_Park_Splash_Pads.shp
Park Playgrounds	Parks.gdb/_Park_Playgrounds
Wading pools	Parks.gdb/_Park_Wading_Pools
Skateboard Facility	Parks.gdb/_Park_Skateboard_Facility
Park pervious surface	Parks.gdb/_Park_Pervious_Surfaces
Golf Courses	Property_parcels_Golf.shp pulled from property_parcels layer where Golf Course point intersected

Category	Source
Hydro one corridor	HydroCorridor.gdb\Hydro_Corridor
School sports fields	_UGDSB_Fields.shp
Agricultural lands	Merged agricultural land from EcologicalLandClassification with Landuse_Farm (output EcologicalLandClassifications_Agricultural_Landuse_Farm.shp)
City facilities	Eastview road landfill site, Landuse_Former_Eastview_Road_Landfill_site.shp
ELC site: Meadow Marsh	EcologicalLandClassifications_MeadowMarsh.shp
ELC Site: Shallow Marsh	EcologicalLandClassifications_ShallowMarsh.shp
ELC Site: Open Aquatic	EcologicalLandClassifications_OpenAquatic.shp
Median Islands	TransportationNetwork.gdb/_RoadMediansIslands.shp

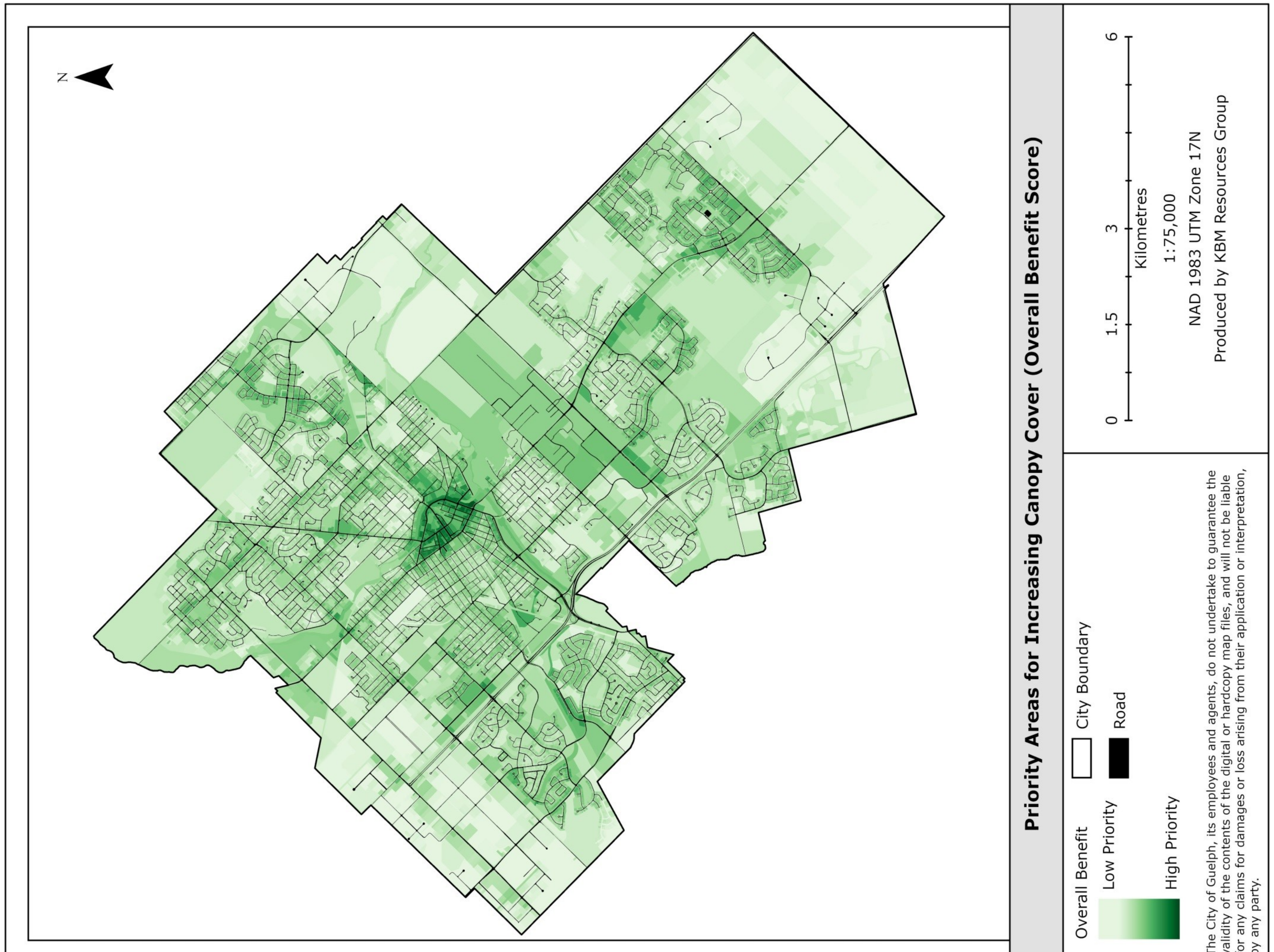
The following map shows the areas that are excluded as possible planting locations based on these known land use constraints.


Planting Exclusion Areas
N
0
1.5
3
6
Kilometres
1:75,000
NAD 1983 UTM Zone 17N
Produced by KBM Resources Group
Legend
City Boundary
Planting Exclusion Areas

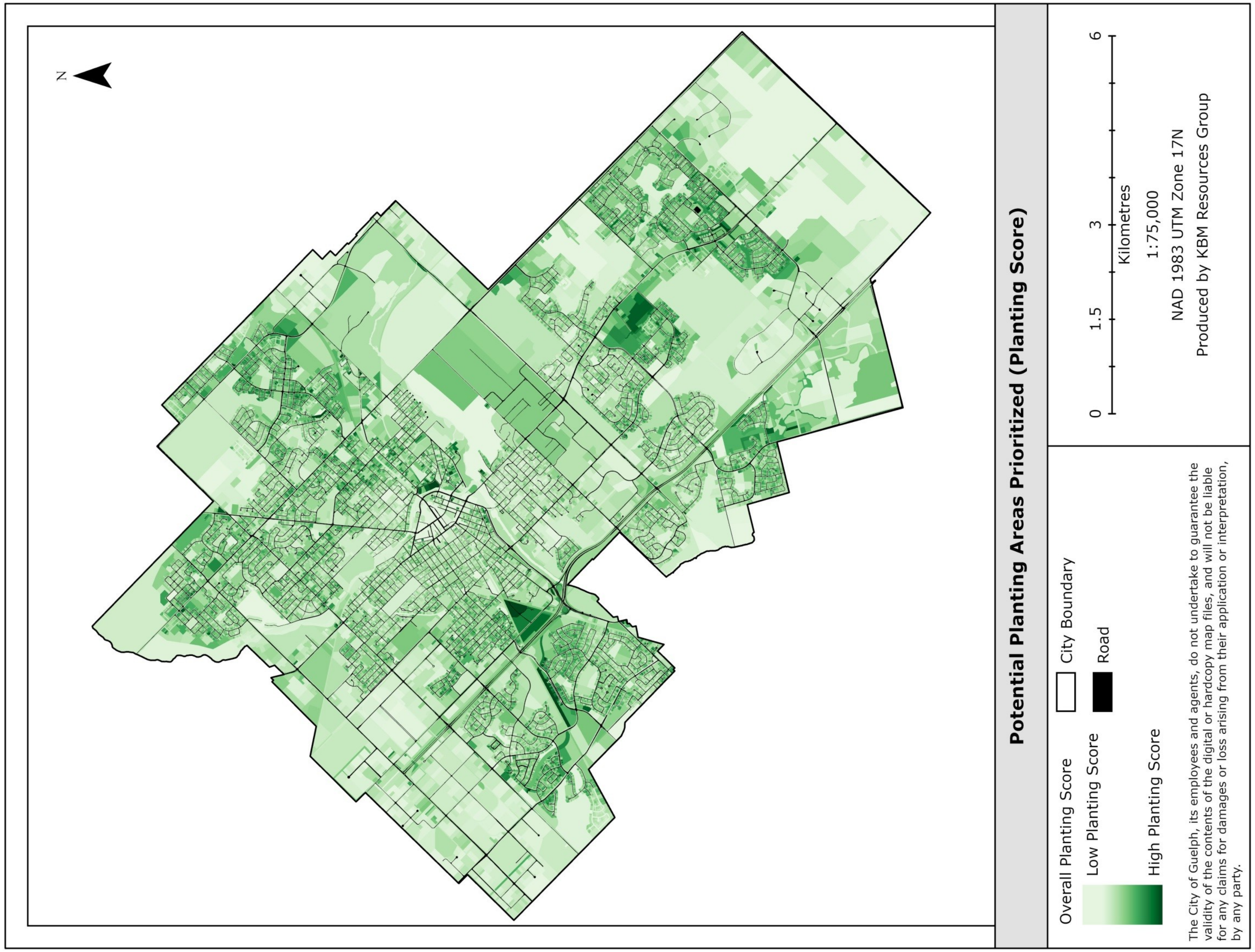
Appendix H: Planting Priotization Indices (maps)

OVERALL BENEFIT AND PLANTING SCORE MAPS

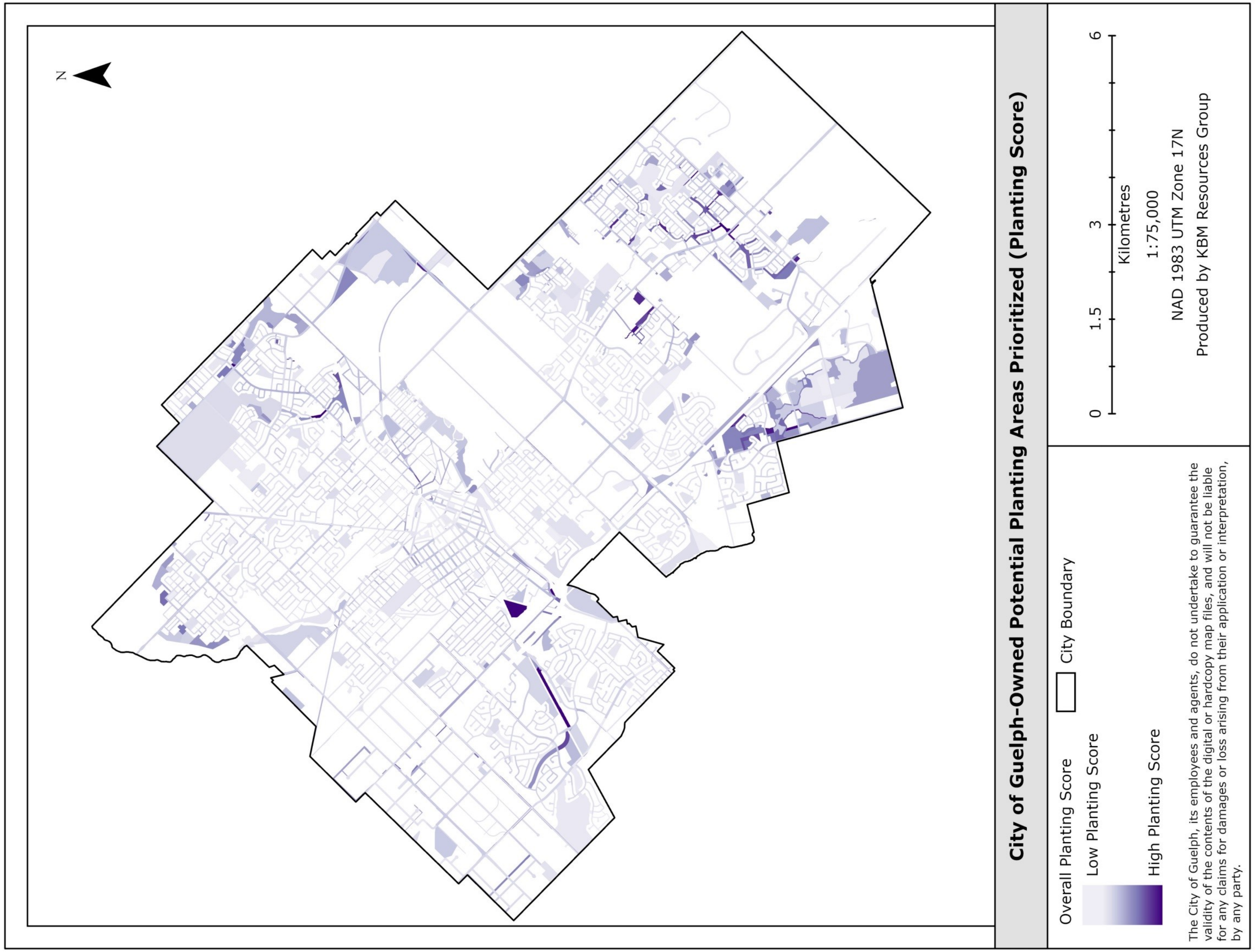
OVERALL BENEFIT MAP (BASED ON 12 TARGET BENEFITS)



Overall Planting Score (based on 12 Target Benefits and available planting area)



Overall Planting Score for City-Owned Lands only (based on 12 Target Benefits and available planting area)



Appendix I: Parcel Level Mapping for Individual Target Benefits (Overall Benefit Scores)

TREE PLANTING FOR MITIGATING AIR POLLUTION

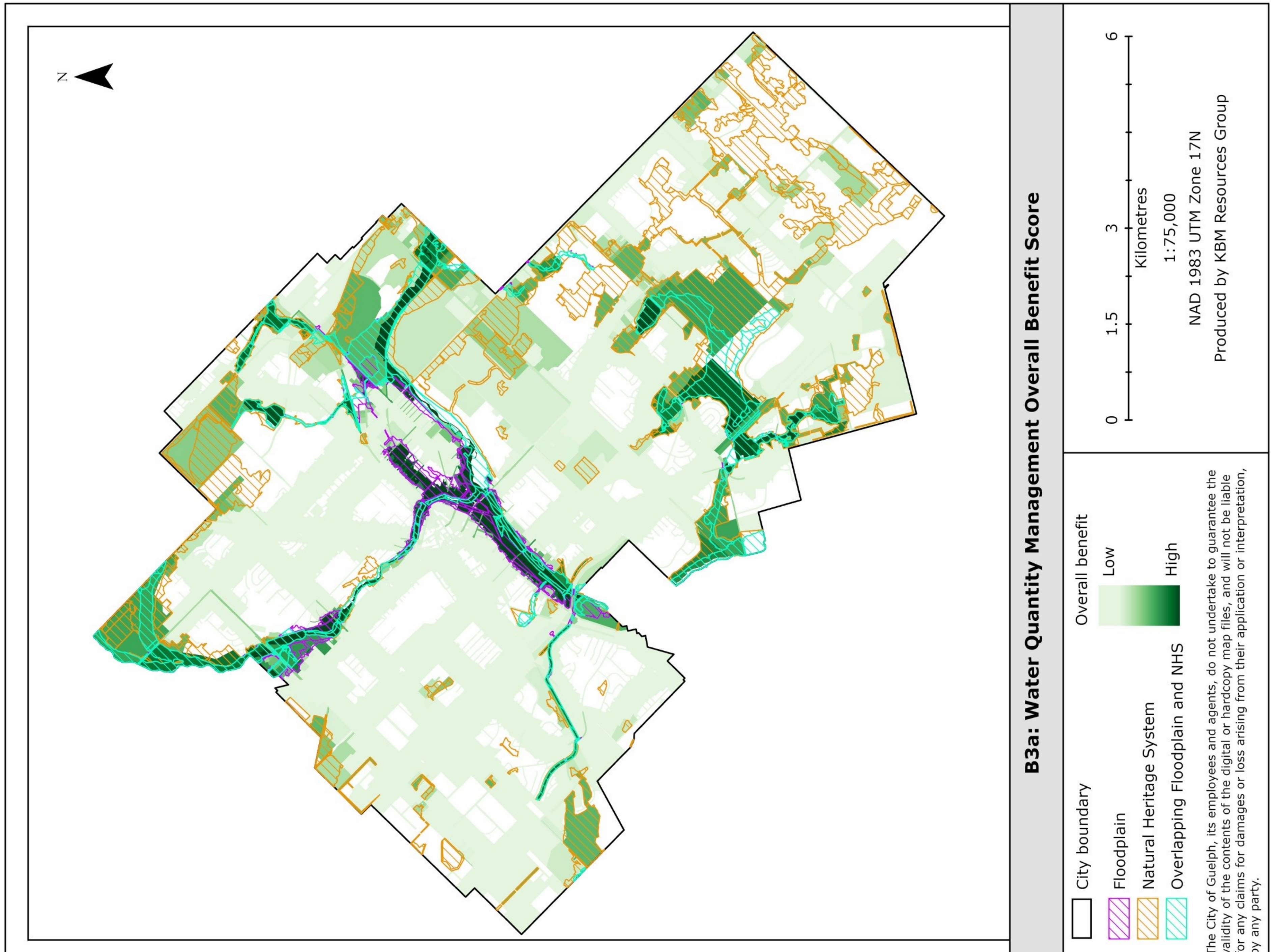
Opportunity Zone (Air Pollution Mitigation Near High Traffic Roads): Areas within 500m of provincial highways, 200m of major roads and 200m of truck routes.

TREE PLANTING FOR MITIGATING URBAN HEAT ISLAND (UHI) EFFECT

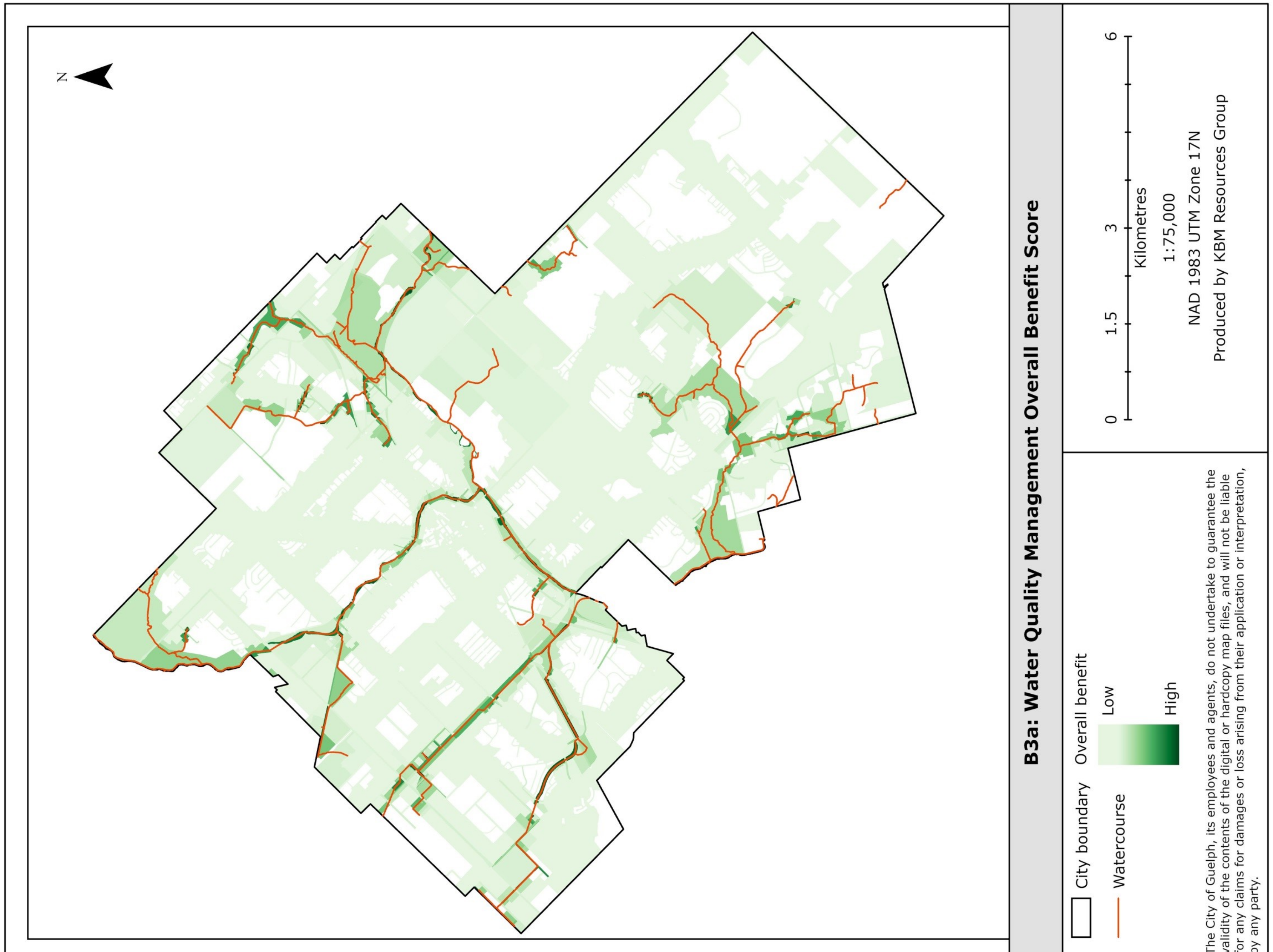
Opportunity Zone (Cooling Where UHI Effects are Greatest): Areas with surface temperature of 31°C or greater.

TREE PLANTING FOR CONTRIBUTING TO MANAGEMENT OF SURFACE WATER QUANTITY AND QUALITY

Opportunity Zone 3a (Contributing to Local Water Quantity Management): Areas without built stormwater management (SWM) facilities.



Opportunity Zone 3b (Contributing to Local Water Quality Management): Areas within 30m of watercourses (both sides).



TREE PLANTING FOR MAINTAINING AND ENHANCING NATURAL HERITAGE

Opportunity Zone 4a (Maintaining and enhancing the NHS): Untreed areas within the NHS, excluding naturally untreed habitats such as marshes, as defined by Ecological Land Classification for Ontario).

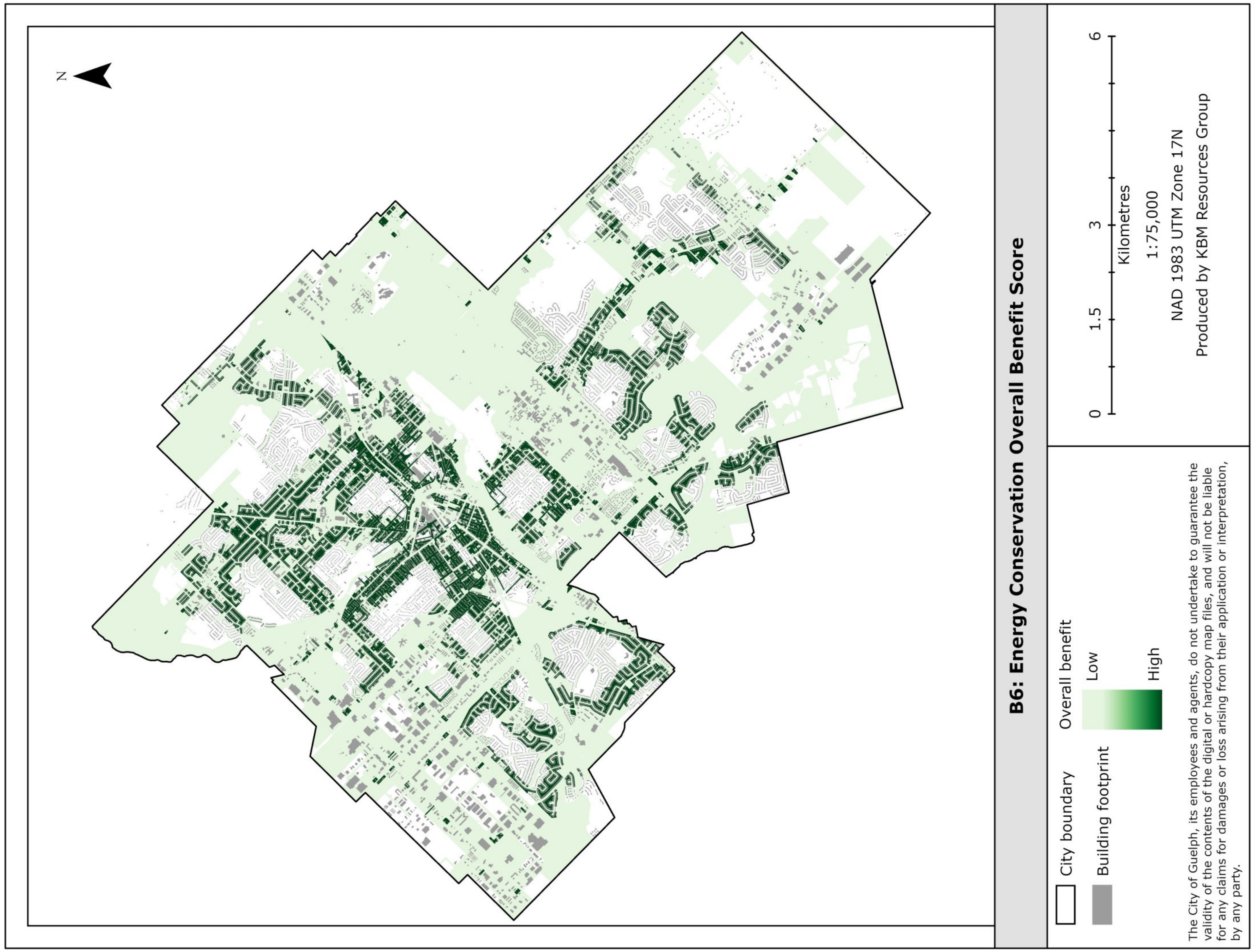
Opportunity Zone 4b (Maintaining and Enhancing Lands Adjacent to the NHS): Areas within 100m of the NHS (NHS adjacent lands).

TREE PLANTING FOR ENHANCING ECONOMIC VALUE

Opportunity Zone (Enhanced Commercial Activity): Commercial nodes and neighbourhoods within 10 minutes walking distance of commercial nodes.

TREE PLANTING FOR PROVIDING DIRECT COST SAVINGS

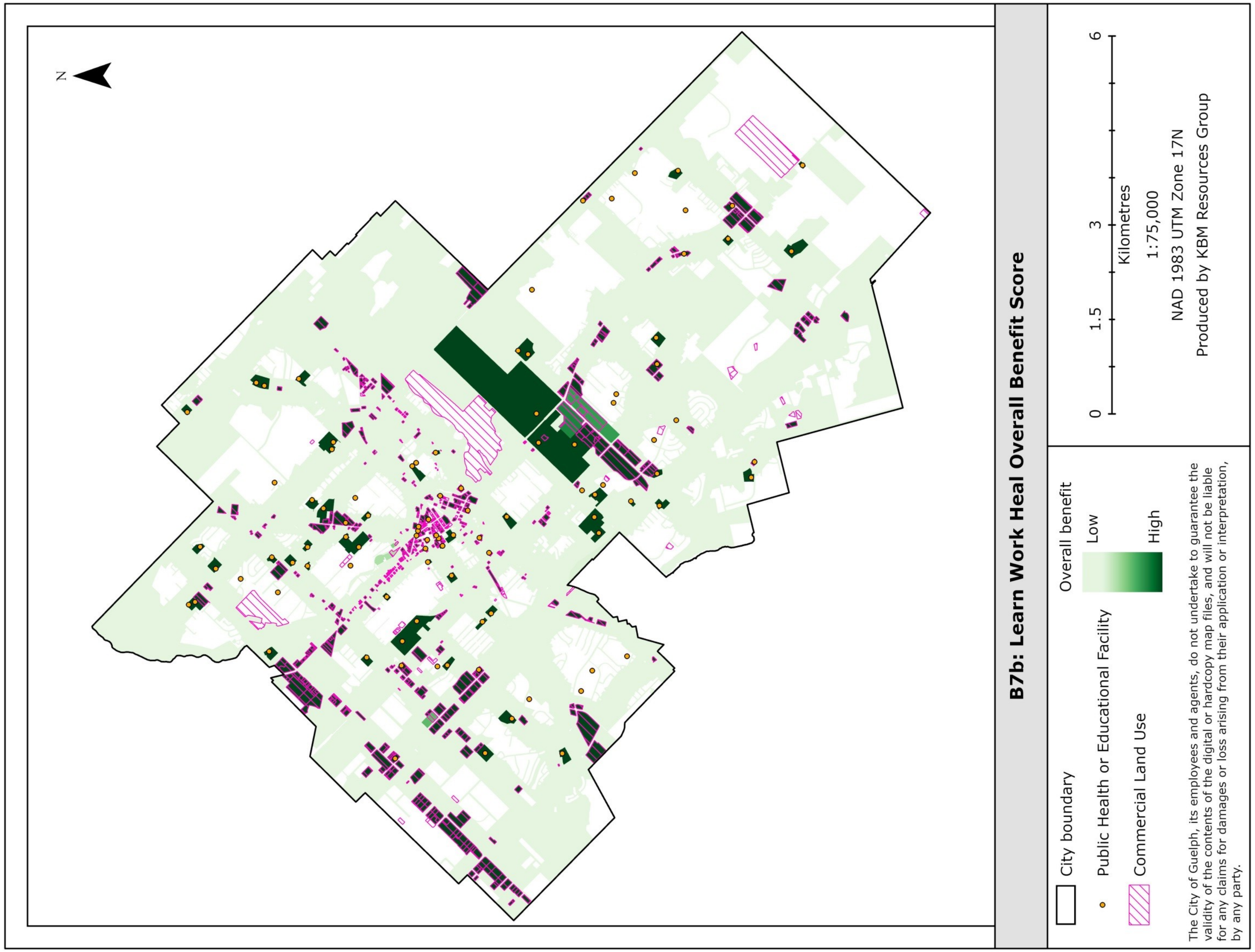
Opportunity Zone (Contributing to Local Energy Conservation): Areas within parcels less than 0.81ha (2 acres) that contain buildings between 69m2 (750 ft2) and 279m2 (3000 ft2).



TREE PLANTING FOR SUPPORTING IMPROVED PHYSICAL HEALTH AND EMOTIONAL WELL-BEING

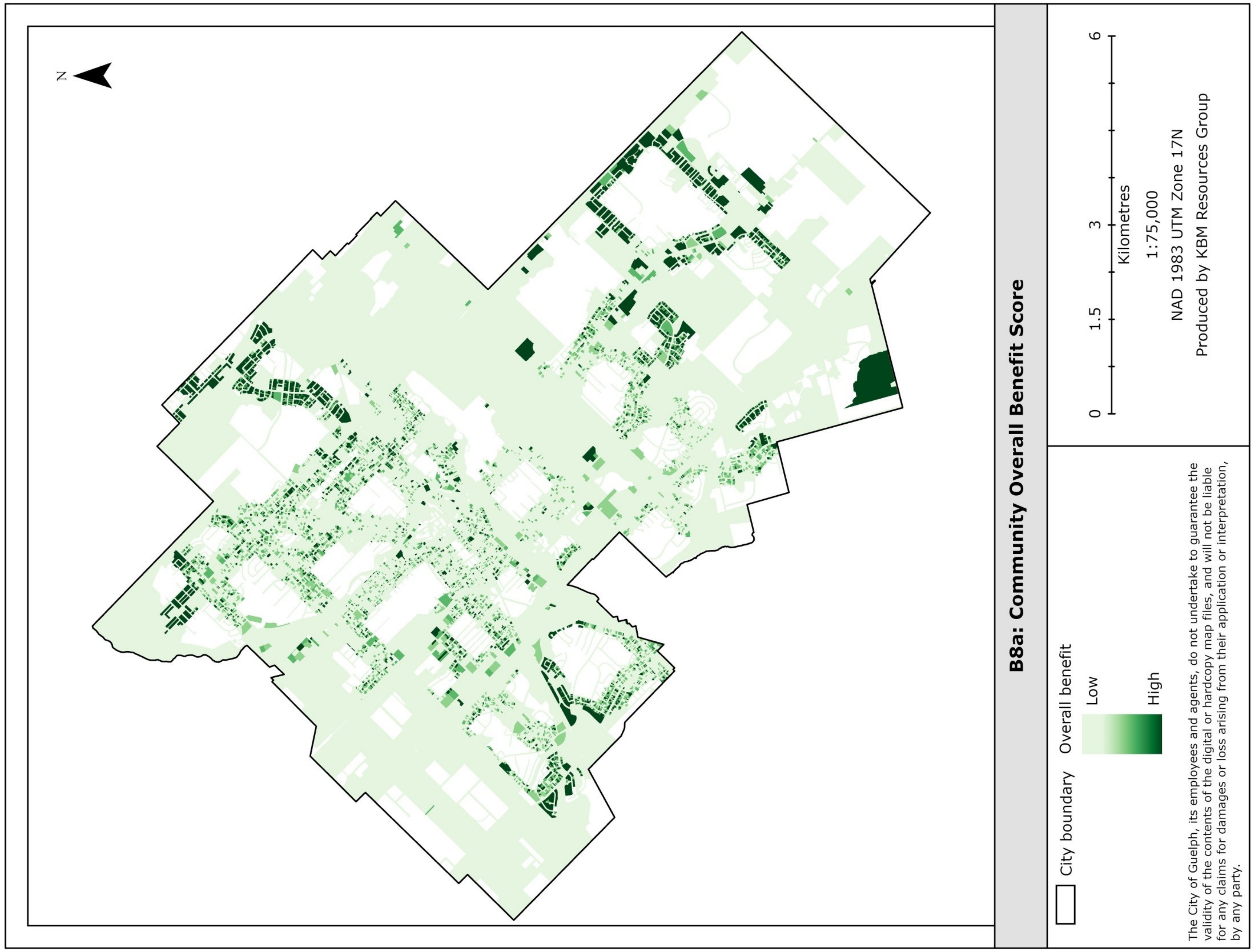
Opportunity Zone 7a (Walkability and Outdoor Recreation): Public parks, areas within 30m of trails (including paved and unpaved trails and active transportation routes), along routes within 10 minutes (800m) from schools.

Opportunity Zone 7b (Improving Environments for Learning, Working, Healing): Properties of institutions for learning, working, youth, the elderly and health care.

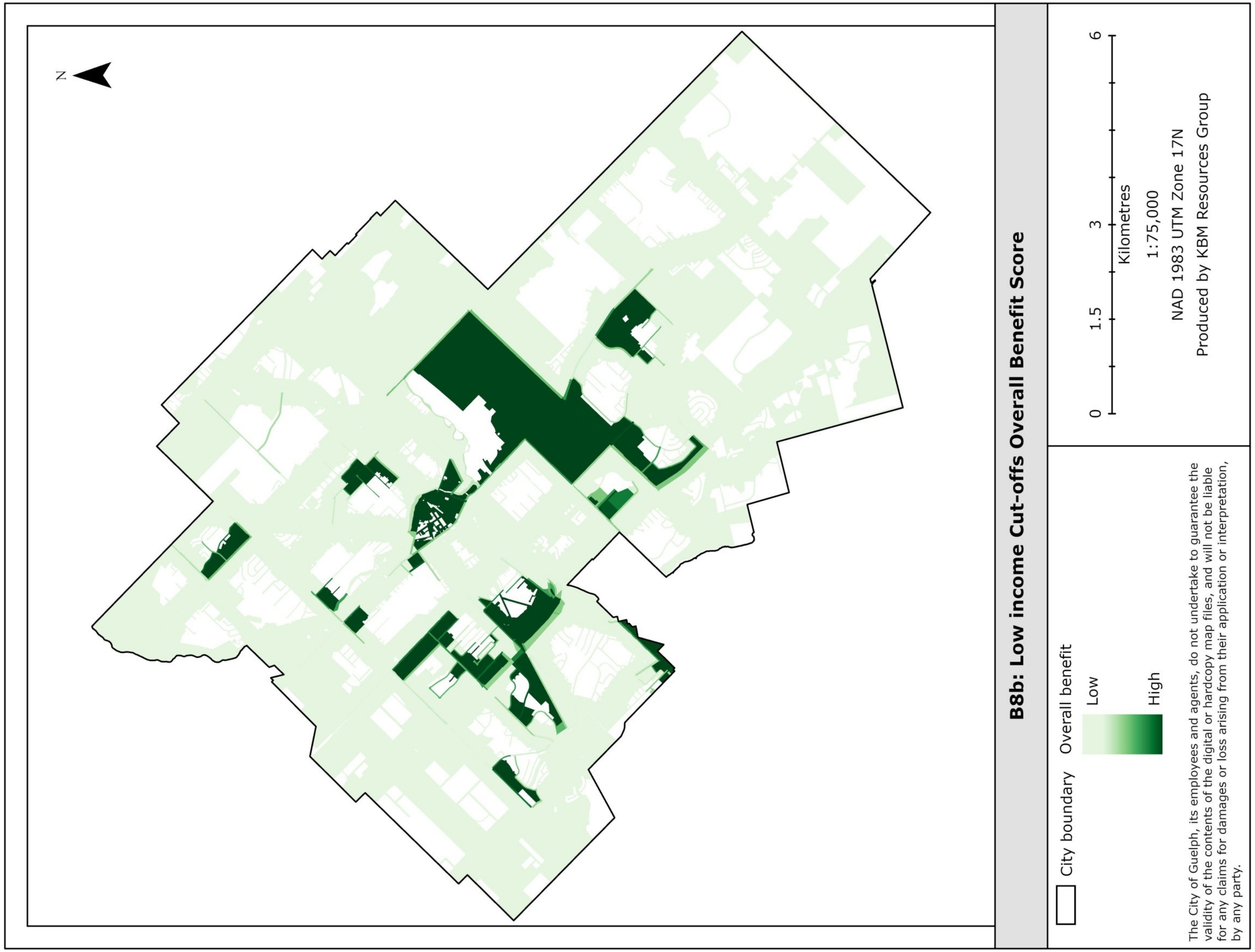


TREE PLANTING FOR CONTRIBUTING TO STRONGER COMMUNITIES AND ENHANCING SOCIAL EQUITY

Opportunity Zone 8a (Strengthening Communities Through Better Canopy Cover): Residential areas that have below average canopy cover.



Opportunity Zone 8b (Enhancing Lower Income Neighbourhoods Through Better Canopy Cover): Areas with relatively high ratios (20 per cent or more) of "low income" households.



Appendix J: i-Tree Eco Field Survey Results and Report

I-TREE ECO FIELD SURVEY

METHODOLOGY

PLOT SELECTION

The i-Tree Eco protocol recommends a minimum of 200 random plots to derive a statistically relevant sample of a study area. In May, 2019, BioForest and KBM, in collaboration with the City of Guelph, established 226 random plots on public and private land across Guelph. Plots were stratified according to land use in order to derive a representative sample from each land use with an acceptable margin of error. A minimum of 20 plots were generated for each land use class, in accordance with i-Tree Eco protocols, with at least one plot created in reserve, in case access issues arose. Land use classes that comprised a relatively larger share of land in Guelph were assigned more plots than land uses that represented a small amount of land. However, the distribution of plot numbers is not in exact proportion to the amount of land area represented by each land use class, as the number of plots required to accomplish this would entail a very large project beyond the scope of the urban forest study. Table 21 lists the number of plots generated for each land use class and the number of plots that were assessed during the study.

Table 21: Distribution of plots by land use created for the 2019 Guelph Urban Forest Study.

Land Use Class	Area (ha)	Number of Plots	Number of Plots Assessed
Commercial	544.26	22	21
Farm	438.24	22	20
Industrial	1,096.00	28	27
Institutional	610.66	22	20
Multi-Residential	94.81	21	21
Residential	2,471.73	50	44
Special and Exempt	249.51	21	20
Vacant	1,907.38	40	35

Total	**7,412.59**	**226**	**208**

During field surveys, field crews were denied permission to access properties in 6 residential plots and one commercial plot. Physical impediments to access plot centre prevented data collection in one Farm plot, one Institutional plot, one Special and Exempt plot, and one Vacant plot. A total of 208 plots were assessed during the field surveys. The remaining incomplete plots were held as reserve plots for future reassessments, if necessary.[55]

LANDOWNER CONTACT

In order to secure permission from landowners whose properties were included in i-Tree plots, BioForest drafted a letter, in collaboration with the City of Guelph, addressed to property owners explaining the project purpose and requesting permission for field crews to access their property. BioForest staff mailed the letters, along with pre-paid return envelopes, to landowners in spring, 2019. BioForest received all replies to the letters and tracked landowner permissions. BioForest staff conducted in-person follow-up visits to properties whose owners did not return a reply to the initial letters. Additional permissions were obtained in this manner, and BioForest field crews continued to conduct landowner outreach during the data collection period, as necessary. Where permission was denied, field crews refrained from entering the property and ceased contact with the landowner.

I-TREE ECO FIELD METHODOLOGY

All 208 circular plots measuring 0.04 hectares were assessed in leaf-on conditions in 2019. A field crew of two BioForest staff conducted data collection under the supervision of a project manager and a project coordinator. Field crew training and orientation took place on June 12 at various plots across the City of Guelph, with city staff in attendance. Field crews collected data independently from June 13 to October 4, 2019. Field crews recorded data on paper or electronically, using digital tablets. At each plot, field crews navigated to plot centre using GPS coordinates and planted a temporary marker at plot centre.

Field crews collected the following data at each plot:

Plot Information

- Plot ID number
- Date of data collection
- Crew
- GPS coordinates of plot centre (NAD 83)
- Plot address/notes
- Reference object descriptions, and distance and compass directions to plot centre
- Tree measuring point, if used, where plot centre was inaccessible
- Per cent tree cover (visual estimate)

[55] Supplement 1 contains an overview map showing the locations of all 226 i-Tree Eco plots created for the 2019 Guelph Urban Forest Study. Supplement 2 contains an example of an i-Tree Eco plot map.

- Per cent shrub cover (visual estimate)
- Per cent plantable space (visual estimate)
- Land use, as observed in the field
- Per cent of plot within each land use (visual estimate, based on field map)
- Per cent ground cover (visual estimate of each cover type)

Shrub Data

- Species ID
- Shrub mass height
- Shrub mass per cent of total shrub area (visual estimate)
- Shrub mass per cent missing (visual estimate of the percentage of shrub's volume not occupied by leaves)

Tree Data

- Tree ID number
    - Trees receive a numerical ID, starting at 1, moving clockwise around the plot from North.
- Tree status
    - Planted, ingrowth, or unknown
- Compass direction and distance from plot centre (or tree measuring plot, if using)
- Land use in which tree is rooted
- Species ID
- Diameter at breast height (1.37 m) for up to six stems, if tree is multi-stemmed
- Tree height
- Live crown height
- Height to crown base
- Crown width (two measurements, in East-West and North-South directions)
- Per cent canopy missing (visual estimate)
- Per cent dieback (visual estimate)
- Per cent impervious surface area under the canopy of the tree (visual estimate)
- Per cent shrub area under the canopy of the tree (visual estimate)
- Crown light exposure (number of sides of the tree's crown that are exposed to direct sunlight)
- Distance and direction to residential buildings, for trees at least 6 metres in height, and within 18 metres of a residential building
- Tree site (street tree or not)
- Ownership (public or private)

Materials

- Clipboard
- Pencils
- Paper data sheets
- Rangefinder
- Digital clinometer
- 30 metre measuring tape
- DBH tape
- Compass

- GPS unit
- Samsung Galaxy Note or Galaxy Tab A tablet
- Flagging tape
- Pigtail pegs
- Chalk

QUALITY CONTROL AUDITS

The i-Tree Eco protocol outlines methods for ensuring quality and accuracy of the data collected by field crews during the survey. Hot checks are procedures in which an auditor works along with the field crew as they collect data at an i-Tree plot to ensure that the crews have a good understanding of the protocol. Errors are corrected in person, and these checks are typically included in the initial field crew training sessions. Cold checks are procedures in which an auditor makes follow-up visits to plots where the field crew has already collected data. The auditor verifies the crew's data to ensure that it is accurate and complete. Plots selected for cold checks are chosen at random, and ideally include a variety of settings.

BioForest staff completed hot checks at three plots during the training and orientation sessions and cold checks at 6 plots in the week following training. Thus, a total of 9 plots were audited, which represents 4.3 per cent of plots.

Cold check procedures varied slightly based on the number of trees present in a plot. For plots with 5 trees or less, each tree was audited. The species ID, DBH, height, crown width, and building interaction (if applicable) were confirmed by the auditor. The land use, as reported by field crews, plot tree cover, and number of trees in the plot were verified. For plots with more than 5 trees, the auditor randomly selected 5 trees and confirmed species ID, DBH, height, crown width, and building interaction (if applicable). The auditor also confirmed the land use, plot tree cover, and total tree count, and verified species ID for all trees in the plot. During the audits, auditors encountered only one minor error where a tree species had been misidentified. The auditor followed up with the field crew and insured that the correct identification was included in the plot data.

DATA SUBMISSION AND ANALYSIS

Throughout the data collection period, the field crew used its Samsung tablet to submit data to the i-Tree server, allowing the project coordinator to download and view the data using i-Tree Eco v. 6 on a desktop computer. Data was either inputted directly through the i-Tree web form in the field, or was entered at a later date, when field crews used paper data sheets to record field data. Following the completion of data collection, the project coordinator reviewed the collected data for errors.

Once the final edited version of the 2019 database was prepared, it was submitted for analysis using i-Tree Eco v. 6. The results of the analysis were returned by the i-Tree server on the same day. Results were downloaded from i-Tree Eco and organized into Microsoft Excel databases for further analysis and reporting purposes.

Results are presented as an extrapolation of the field data gathered from the 208 i-Tree plots used in the study. These plots constitute a statistically representative sample of Guelph's urban forest. A study using 200 urban plots in a stratified random sample is expected to yield a standard error of about 10 per cent (USDA 2014). Therefore, the 208 plots used in Guelph's i-Tree survey produce results that fall within the bounds of acceptable standard error. Only a complete inventory would eliminate the possibility of error, but the time requirements, ability to access private properties, and financial cost would make such an undertaking unfeasible.

I-TREE ECO RESULTS

OVERVIEW

Guelph has a tree population of approximately 2,973,000 with a structural value of about $803 million. Most of these trees (53 per cent) are located on private property while the remaining 47 per cent are located on public land, including conservation areas, boulevards, and land owned by provincial and municipal governments (Figure 45).

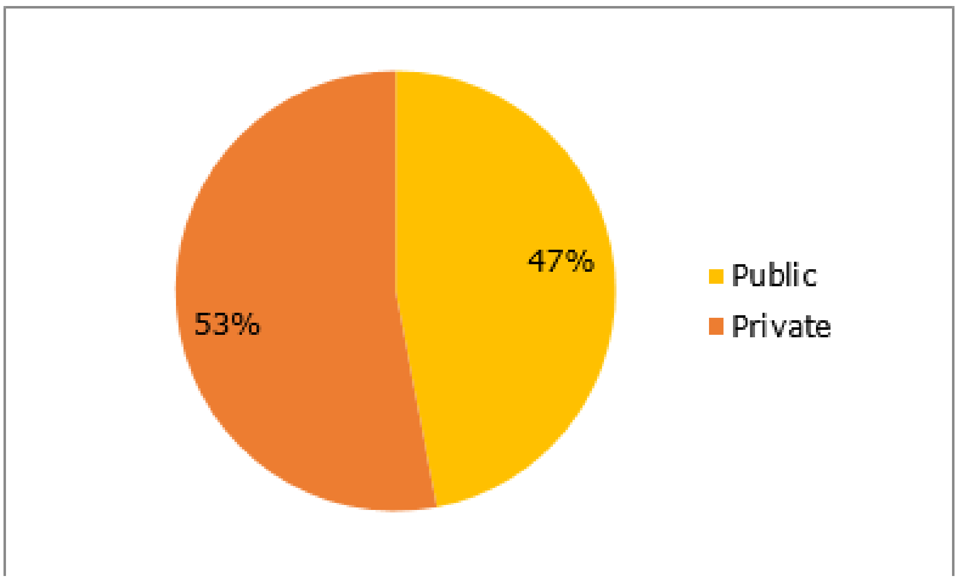


Figure 45: Tree ownership in Guelph in 2019 (Source: 2019 i-Tree Eco data)

Guelph's urban forest stores about 196,894 tonnes of carbon. The total value of this carbon storage is about $22.6 million. Of all the species present in Guelph, sugar maple (*Acer saccharinum*) stores the most carbon, accounting for 13.4 per cent of total carbon storage.

About 71.4 per cent of Guelph's trees measure 15.2 cm in diameter at breast height (DBH) and under. Less than half (42.6 per cent) of Guelph's trees currently belong to the smallest diameter class (7.6 cm and under), while 7 per cent of trees measure more than 30.5 cm DBH, and 1 per cent of trees measure more than 61 cm DBH.

The three most common species in Guelph's urban forest are eastern white cedar (*Thuja occidentalis*), common buckthorn (*Rhamnus cathartica*), and green ash (*Fraxinus pennsylvanica*). Eastern white cedar alone accounts for more than 20 per cent of all trees in Guelph. In terms of leaf area, the three dominant species in Guelph's urban forest are eastern white cedar, Norway maple (*Acer platanoides*), and sugar maple.

Invasive species figure prominently in the shrub layer of Guelph's urban forest. The dominant shrub in Guelph is common buckthorn, comprising 23.7 per cent of the total shrub leaf area. About 57 per cent of the common buckthorn leaf area is confined to the Farm and Vacant land uses, where the majority of the natural forests in Guelph are located.

Guelph's urban forest provides valuable ecosystem services each year to Guelph's residents and visitors. Guelph's trees sequester 6,455 tonnes of carbon annually, which has an associated value of about $741,500. Guelph's trees remove about 156 tonnes of pollutants from the air each year, with an associated value of more than $2 million. The canopies of Guelph's trees prevent nearly 400,000 cubic metres of runoff each year, which has an associated value of about $929,700. Guelph's trees also help to save home energy use, a service that has an associated annual value of about $1.9 million.

FOREST COMPOSITION AND STRUCTURE

MOST COMMON TREES

In terms of population, the three most abundant tree species are eastern white cedar, common buckthorn, and green ash (Figure 46). In many cities, an abundance of eastern white cedar points to widespread use of the species in hedges on residential properties. However, Guelph has many forested lands with substantial eastern white cedar components, which contribute significantly to its prominence in the tree population. Eastern white cedar comprises 20.8 per cent of Guelph's trees. It is concerning that the second most abundant tree, the highly invasive common buckthorn, comprises 19.3 per cent of trees in Guelph and was found in each land use.

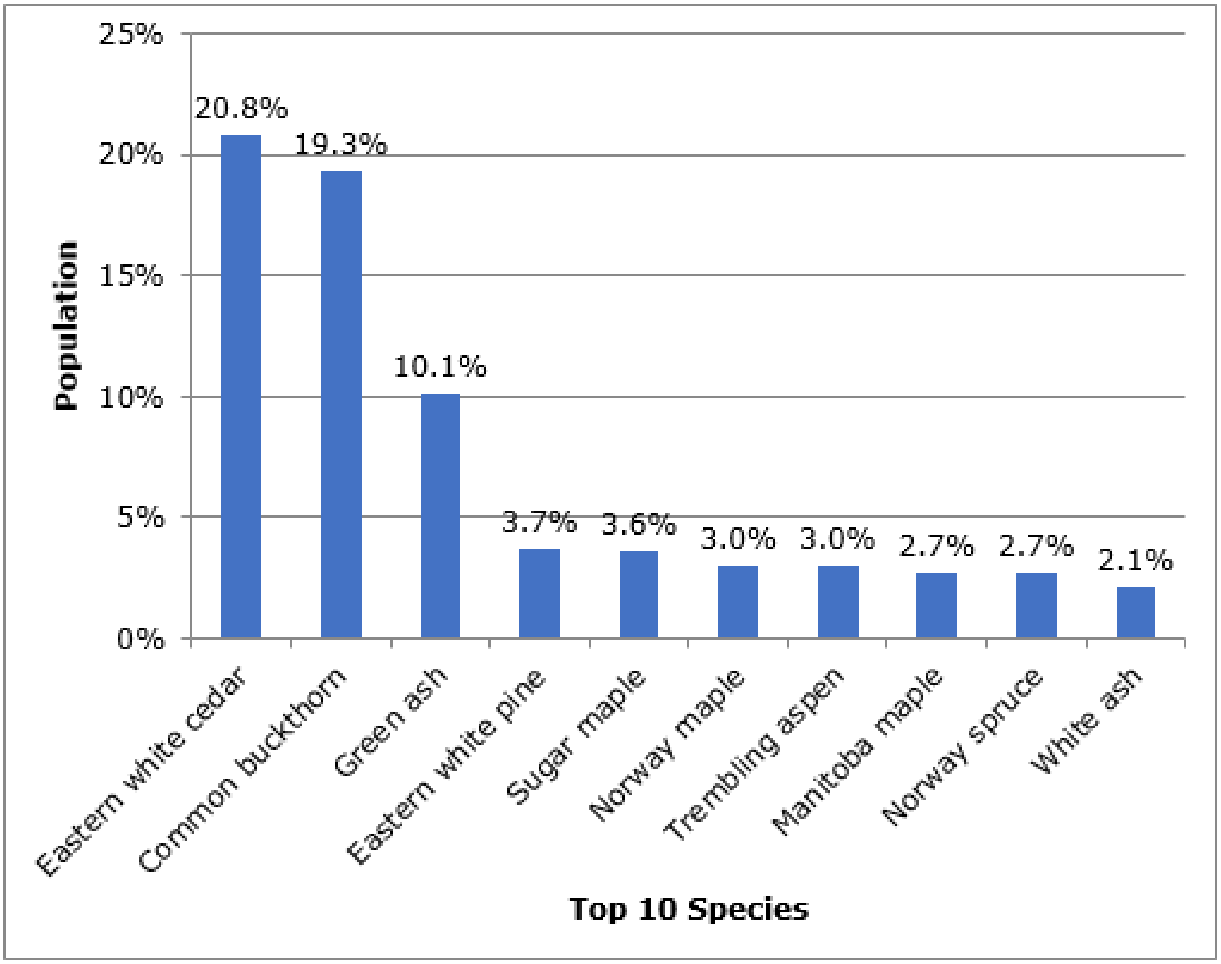


Figure 46: Top 10 tree species by population in 2019 (Source: 2019 i-Tree Eco data)

While tree populations provide insight into the relative abundance of tree species in the city's tree population, measuring the species' abundance by leaf area gives greater insight into which species are making greater contributions to the ecosystem services the urban forest provides. Leaf area is the primary part of a tree's physiology that filters pollution, casts shade, releases oxygen, and provides other valuable benefits. Tree species with a greater potential size at maturity are likely to provide the greatest benefits in the long term, provided conditions exist to support growth to their full biological potential.

When ranked by leaf area, eastern white cedar is also dominant, comprising 16.6 per cent of the leaf area. This also suggests that Guelph's population of eastern white cedar is not merely made up of small trees in hedges, but includes many mature trees in forested settings. Norway maple ranks second in leaf area, followed by sugar maple. It is also notable that common buckthorn ranks sixth in leaf area, considering it typically has a fairly shrubby form and does not attain a large stature (Figure 47). This seems to suggest that Guelph's population of common buckthorn is not only fairly abundant, but that it also contains some fairly large specimens.

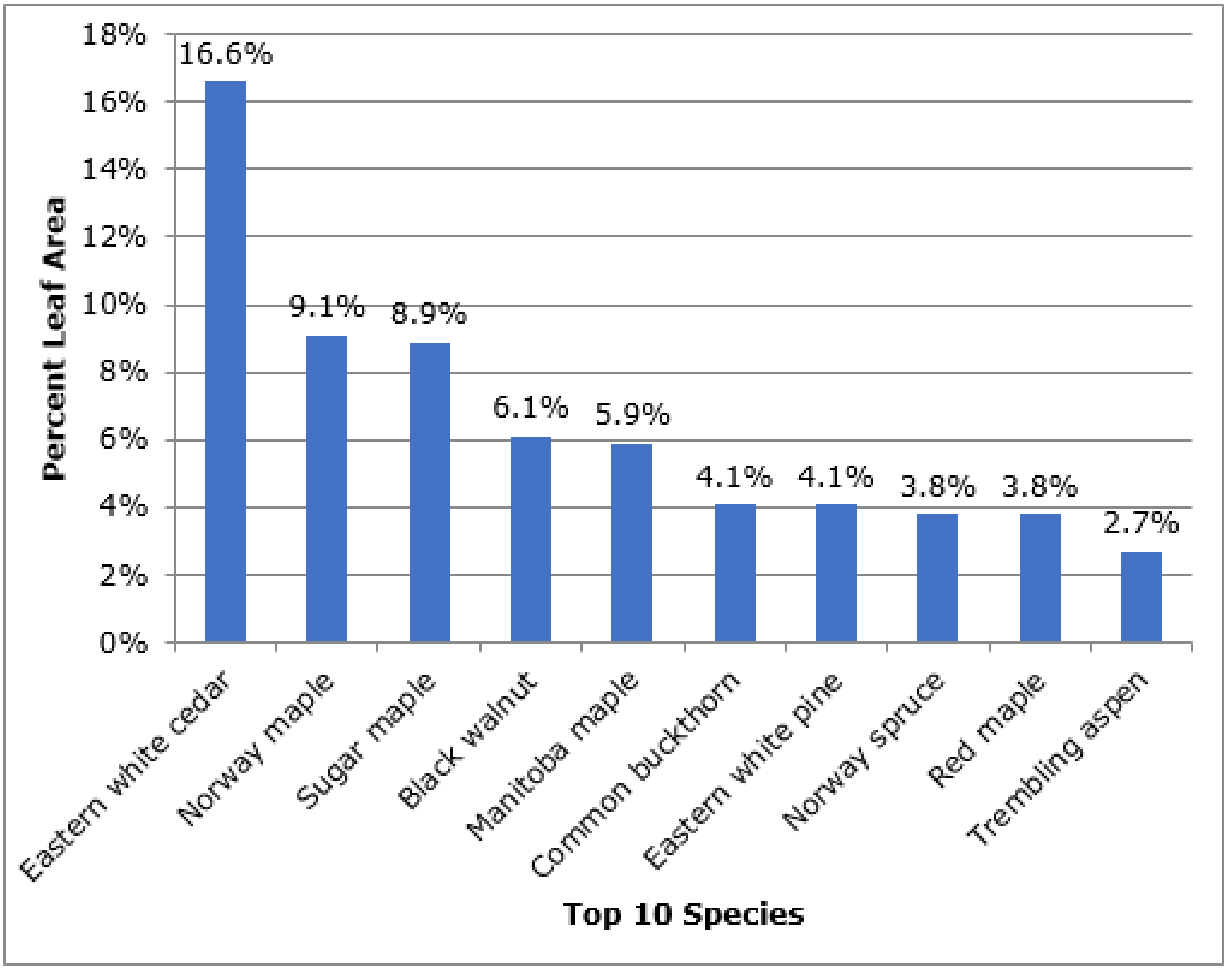


Figure 47: Top 10 tree species by leaf area in 2019 (Source: 2019 i-Tree Eco data)

Guelph's urban forest has a total of 14,400 hectares of leaf area. Table 20 illustrates the distribution of leaf area by land use relative to the percentage of land area each land use represents in the City of Guelph. This is different from canopy cover, which measures the two dimensional coverage of area by foliage when viewed from above. Rather, leaf area is a measurement of the surface area of all the leaves on trees. For example, a large, healthy tree will have a relatively greater leaf area than a small tree due to the greater amount of leaves on the large tree.

The distribution of leaf area illustrated in Table 22 helps to illustrate the impact land use may have on the urban forest. For example, while Industrial lands make up 14.8 per cent of the land in Guelph, they represent only 5 per cent of the total leaf area, due to the nature of the landscape in those lands and the limited tree canopy supported there. By contrast, Vacant lands, which include many of the forested lands in Guelph, account for 25.7 per cent of land but 42.6 per cent of the total leaf area.

Table 22: Distribution of leaf area by land use relative to land area in 2019 (Source: 2019 i-Tree Eco data)

Land Use	Land Area (%)	Leaf Area (%)
Commercial	7.3%	4.5 %
Farm	5.9%	7.3 %
Industrial	14.8%	5.0 %
Institutional	8.2%	8.0 %
Multi-Residential	1.3%	0.6 %
Residential	33.3%	29.2 %
Special and Exempt	3.4%	2.7 %
Vacant Land	25.7%	42.6 %

TREE SIZE DISTRIBUTION

As of 2019, approximately 71.4 per cent of Guelph's trees measure 15.2 cm DBH and under. Less than half (42.6 per cent) of Guelph's trees currently belong to the smallest diameter class (7.6 cm and under), while 7 per cent of trees measure more than 30.5 cm DBH, and 1 per cent of trees measure more than 61 cm DBH (Figure 48).

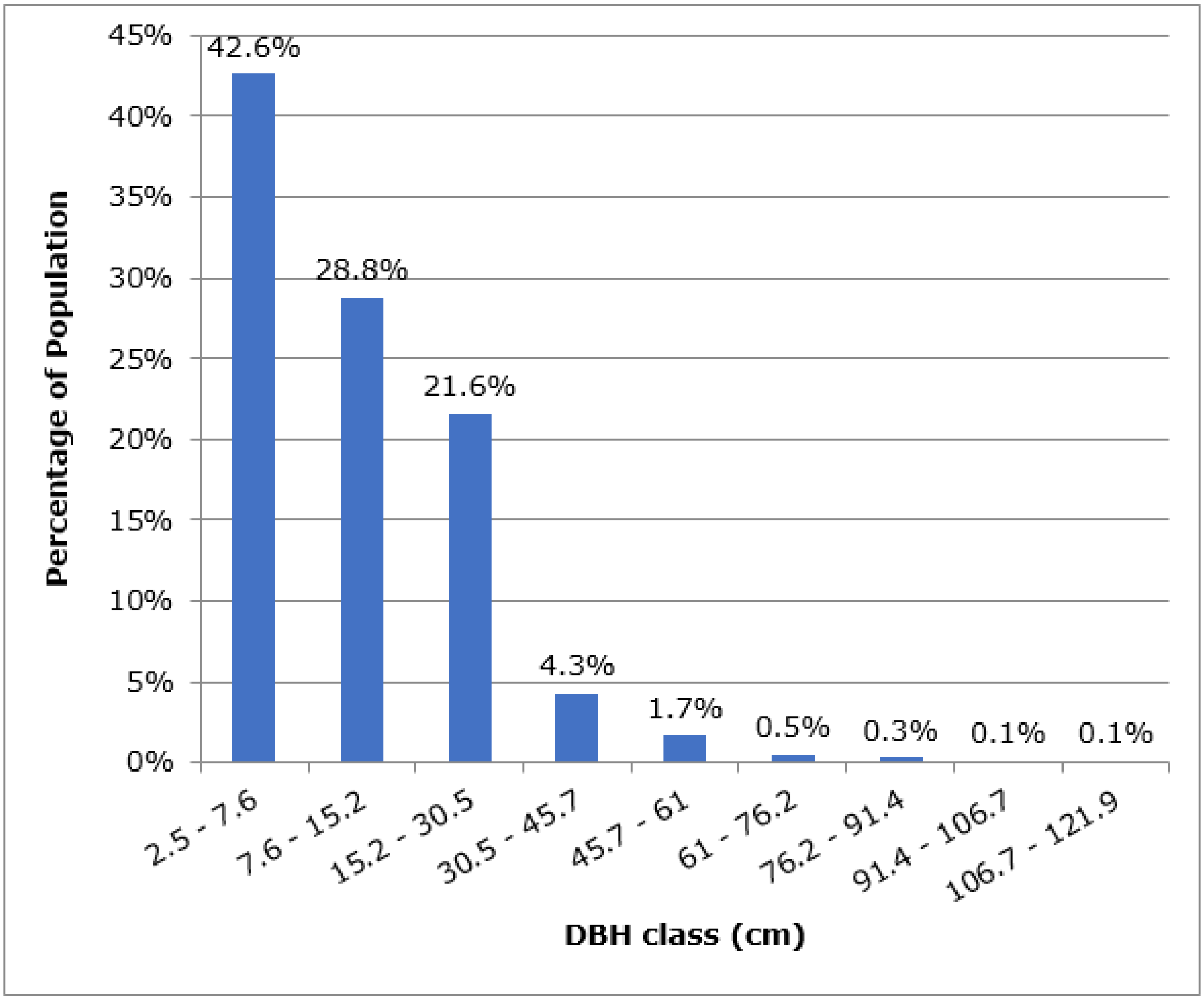


Figure 48: Distribution of Guelph's tree population by DBH class in 2019 (Source: 2019 i-Tree Eco data)

The Multi-Residential land use had the smallest proportion of small diameter trees, with only 28.5 per cent of trees measuring less than 15.3 cm DBH, and the largest proportion of large diameter trees, with 31.4 per cent of trees measuring more than 30.5 cm DBH (Figure 49). However, it should be noted that this land use comprises a small portion of the land in Guelph, so these dynamics do not have a large impact on the distribution of DBH classes across the city.

The Residential land use had the second largest proportion of trees in the largest diameter classes (30.5 cm and above), with 9.3 per cent (Figure 49). This land use has the potential to accommodate many large-diameter trees, given that Residential lands make up 33.3 per cent of Guelph's land and there may be suitable planting space in front and/or back yards.

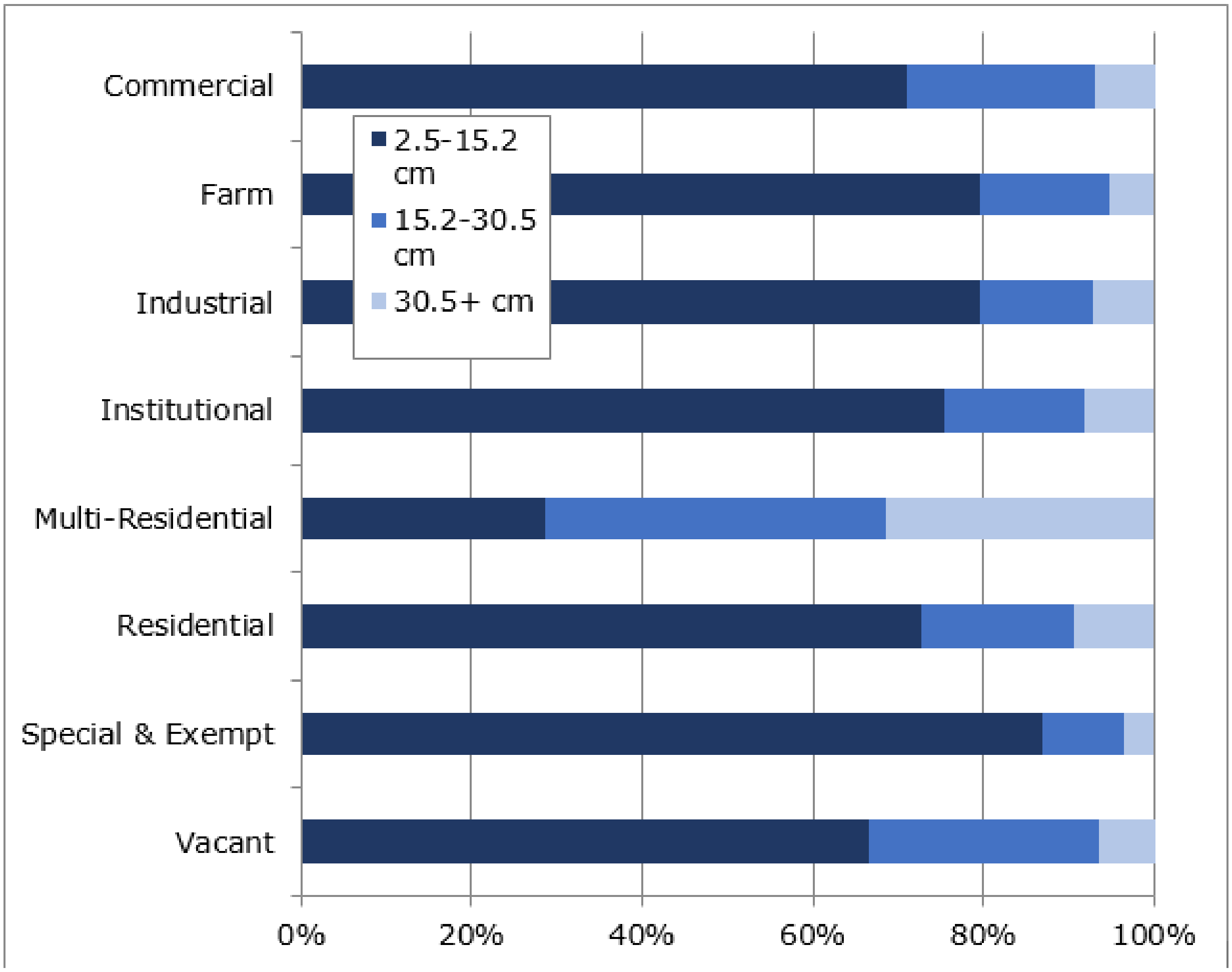


Figure 49: Tree size class distribution by land use (cm diameter at breast height) in 2019 (Source: 2019 i-Tree Eco data)

TREE CONDITION

All trees measured during the i-Tree Eco field survey were assessed for the level of dieback, expressed as the percentage of dead branches located in the live crown. In 2019, approximately 71.1 per cent of trees were estimated to be in excellent or good condition (Figure 50). Trees rated as being in excellent or good condition have less than 10 per cent dieback in the crown. Approximately 16.7 per cent of trees were found to be dead, which is an unusually high number and presents some concern. Many of these dead trees were ash (*Fraxinus* spp.) of various species that had been killed by emerald ash borer and remained standing in forests. For example, dead trees account for 45.8 per cent of the population of green ash, the third most abundant tree in Guelph. It is expected that in the near future, these standing dead ash will fall or be removed and the proportion of dead trees in the overall tree population will be reduced.

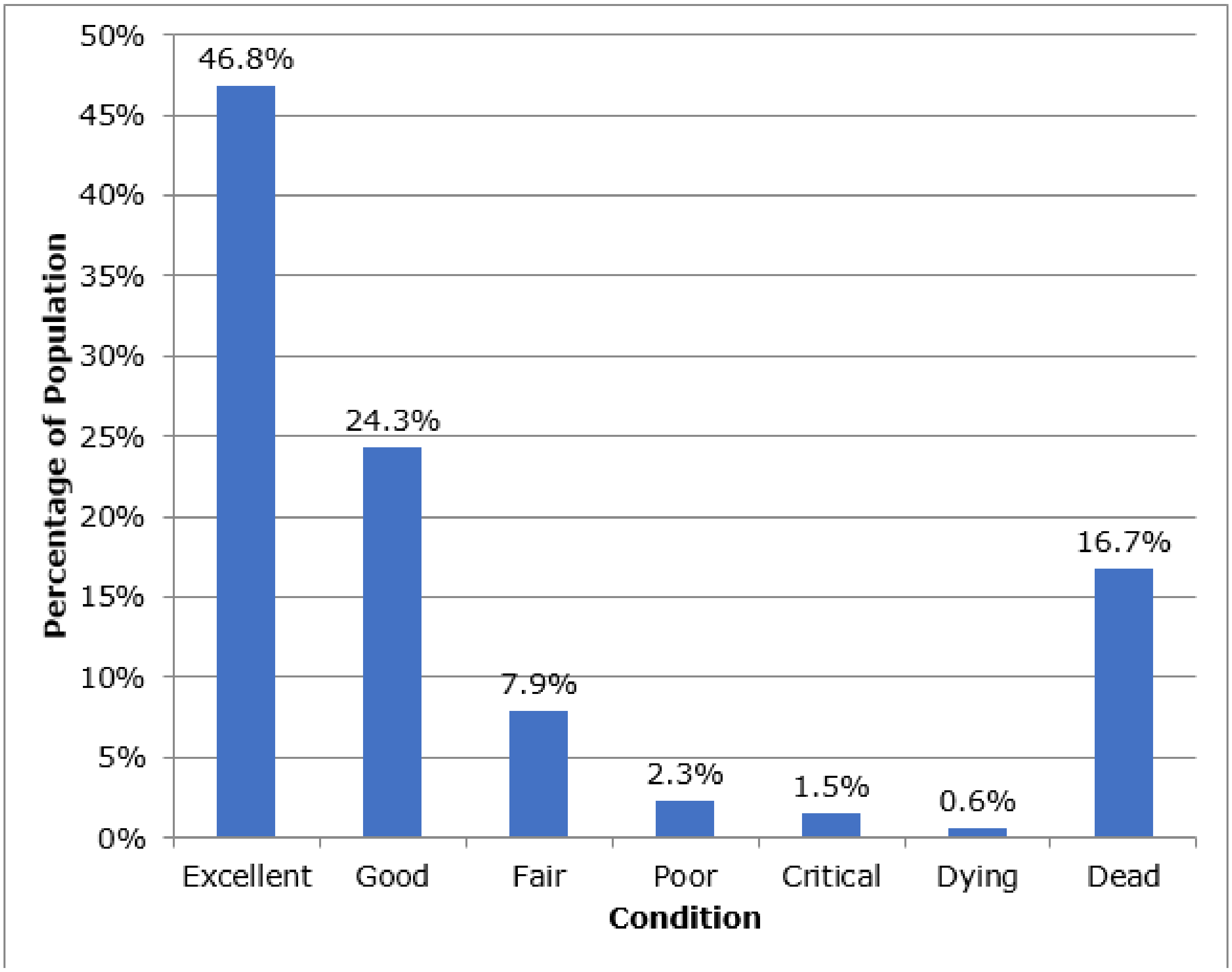


Figure 50: Distribution of tree population by condition rating in 2019 (Source: 2019 i-Tree Eco data)

The Commercial and Multi-Residential land uses were characterized by the best tree condition ratings, with 83 per cent and 82.9 per cent of trees rated as being in excellent or good condition, respectively. The Multi-Residential land use was the only one that contained no dead trees. Trees in the Industrial and Residential land use categories were characterized by very good tree condition, with 78.7 per cent and 76.7 per cent of trees rated as being in excellent or good condition, respectively. The high proportion of trees in good condition or better in these categories is likely due to the active management and pruning of trees on residential and municipal park properties. The Farm land use category was characterized by the worst overall tree condition, with only 61.7 per cent of trees rated as being in excellent or good condition, and 24.7 per cent of trees recorded as being dead (Figure 51).

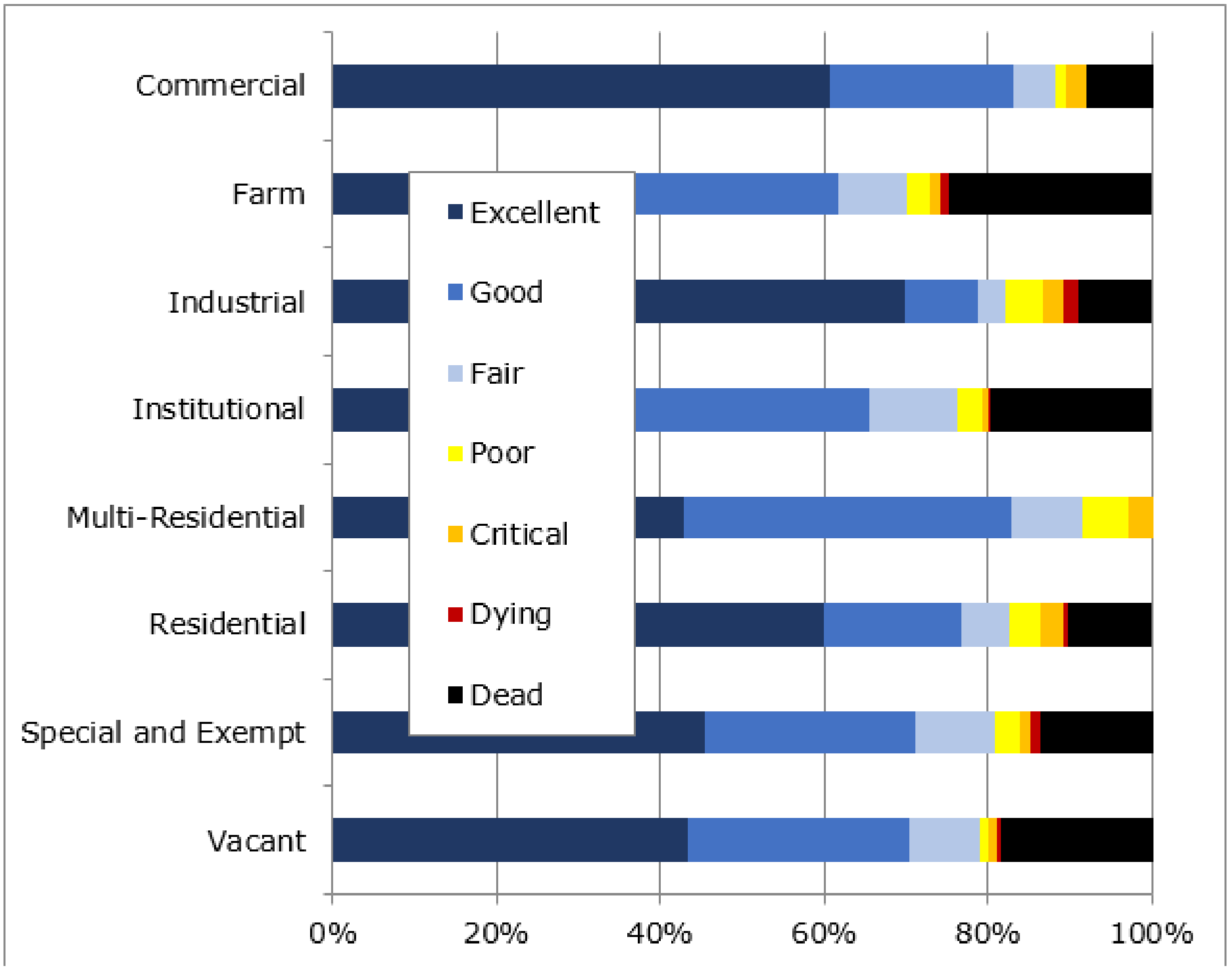


Figure 51: Distribution of tree condition ratings by land use in 2019 (Source: 2019 i-Tree Eco data)

When considering the top ten species by leaf area, black walnut (*Juglans nigra*) and Norway spruce (*Picea abies*) were ranked highest in condition, with 95.2 per cent and 93.1 per cent of trees rated as being in excellent or good condition, respectively. There were also no dead trees recorded in the black walnut population, nor in the population of red maple (*Acer rubrum*). Manitoba maple (*Acer negundo*) was rated lowest in condition among the top ten species by leaf area, with 71.7 per cent of trees rated as being in excellent or good condition. However, of the top ten species by leaf area, the population of eastern white cedar contained the highest amount of dead trees, at 19.6 per cent (Figure 52).

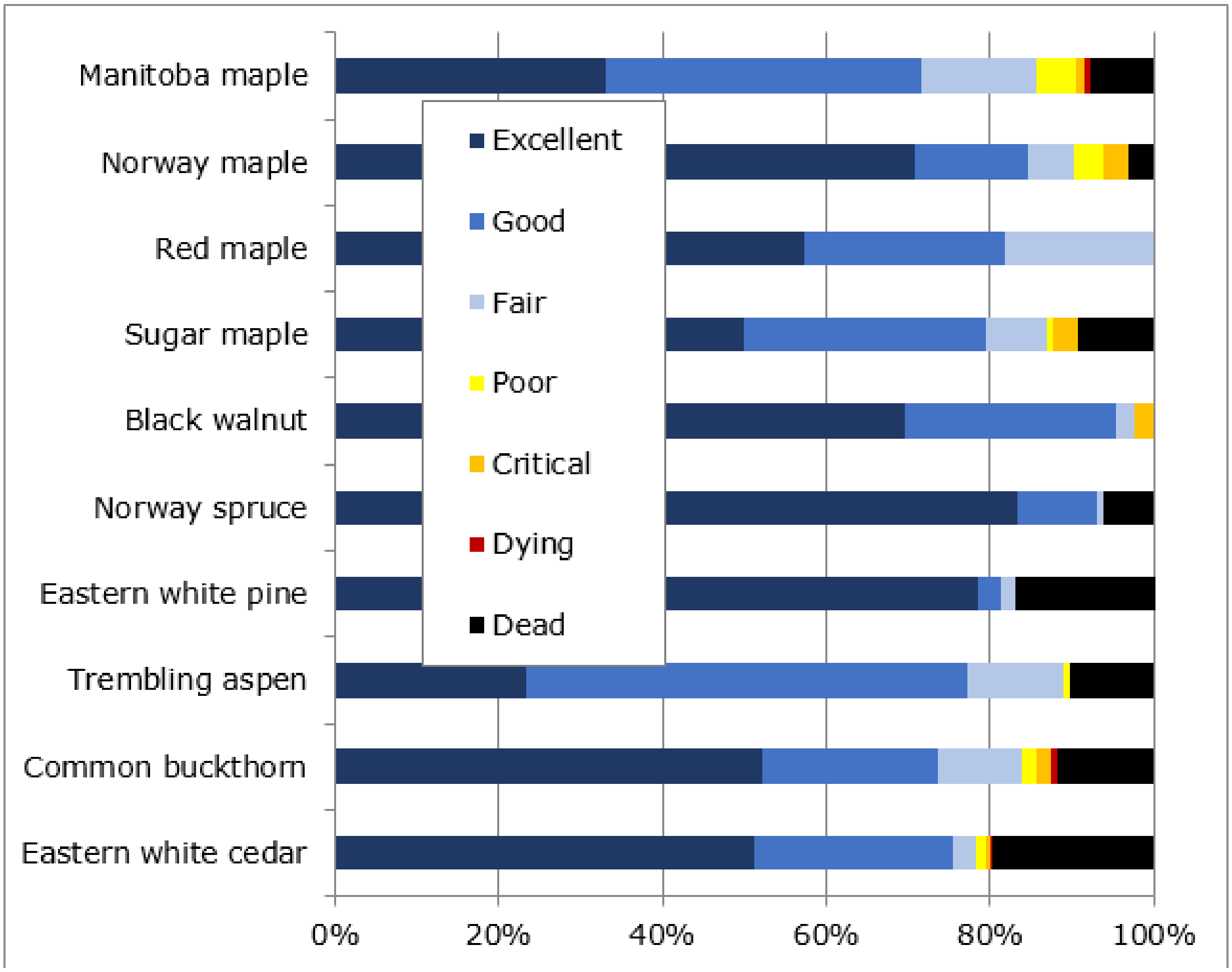


Figure 52: Condition ratings for top 10 species by leaf area in 2019 (Source: 2019 i-Tree Eco data)

PEST SUSCEPTIBILITY

As a city in southern Ontario, Guelph is host to native and non-native forest pests that can inflict damaging effects on the city's urban forest. Some of the most serious insect pests that threaten Guelph's urban forest include the invasive Asian longhorned beetle (*Anoplohora glabripennis*), emerald ash borer (*Agrilus planipennis*), and European gypsy moth (*Lymantria dispar dispar*). Other insect species that pose a threat to Guelph's urban forest include fall and spring cankerworm (*Alsophila pometaria* and *Paleacrita vernata*), hemlock woolly adelgid (*Adelges tsugae*), and beech bark scale (*Cryptococcus fagisuga*). Diseases of concern in Guelph's urban forest include Dutch elm disease (*Ophiostoma* spp.), beech bark disease (*Neonectria faginata* and *N. ditissima*), and oak wilt (*Bretziella fagacearum*).

ASIAN LONGHORNED BEETLE

Asian longhorned beetle (ALHB) was detected along the Toronto-Vaughan border in 2003. The pest was subsequently eradicated through a quarantine program led by the Canadian Food Inspection Agency (CFIA) that resulted in the removal of approximately 13,000 host trees (NRCAN 2018). A new detection in Mississauga in 2013 resulted in the implementation of another quarantine program that is ongoing. ALHB poses a particularly serious threat to Guelph's urban forest because of its wide range of preferred host species, which include maples (*Acer* spp.), birch (*Betula* spp.), willow (*Salix* spp.), poplar (*Populus* spp.), horsechestnut (*Aesculus* spp.), elm (*Ulmus* spp.), and katsura (*Cercidiphyllum* spp.). A total of about 811,000 of Guelph's trees are currently threated by this pest, with an associated structural value of about $349.5 million (Figure 53). These susceptible trees also represent 42 per cent of the total leaf area of Guelph's urban forest.

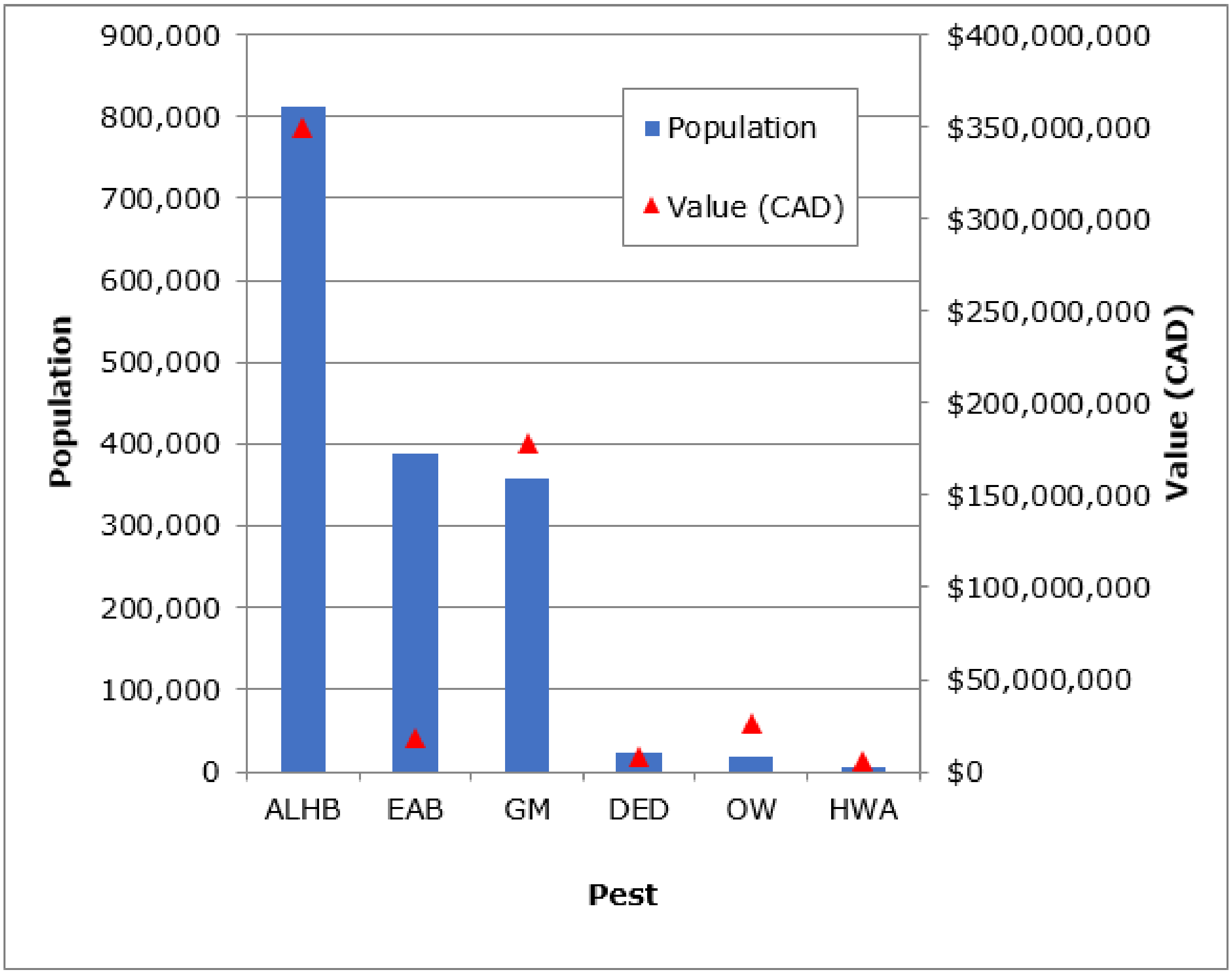


Figure 53: Susceptibility of Guelph's trees to major invasive pests in 2019 (Asian longhorned beetle – ALHB, emerald ash borer – EAB, gypsy moth – GM, Dutch elm disease – DED, oak wilt – OW, hemlock woolly adelgid – HWA (Source: 2019 i-Tree Eco data)

GYPSY MOTH

European gypsy moth (*Lymantria dispar* ssp. *dispar*) has been present on the landscape in southern Ontario for decades. The larval stage of the insect causes defoliating damage to many species of broadleaf trees, but oaks (*Quercus* spp.) are the preferred hosts of gypsy moth. Defoliation can reduce tree vigour and place stress on trees that can exacerbate other tree health issues. Multiple years of repeated severe defoliation can lead to tree mortality. Gypsy moth populations follow cyclical patterns of expansion and decline, so there are periodic threats to urban forest canopies during years when gypsy moth populations are at high levels. A variety of options are available to homeowners and municipalities to manage gypsy moth, including manual egg mass removal, tree injection of systemic insecticides, and aerial insecticide spraying. Approximately 357,000 of Guelph's trees are susceptible to damage by gypsy moth, with an associated structural value of $178 million (Figure 53). These susceptible trees account for about 18 per cent of Guelph's leaf area.

EMERALD ASH BORER

Since emerald ash borer (EAB) was detected in Guelph in 2012, there has been large-scale tree mortality affecting all species of ash (*Fraxinus* spp.), the beetle's host genus. While some trees have been saved through canopy conservation programs using systemic insecticide treatments, the vast majority of untreated trees, including those in natural areas, have succumbed to the effects of the invasive beetle. Approximately 388,000 trees are currently susceptible to EAB infestation, with a structural value of about $18 million (Figure 53). It should be noted that the compensatory value is somewhat low relative to the portion of the tree population that is at risk of infestation. It is also notable that this population of susceptible trees only accounts for 3 per cent of the total leaf area in Guelph. This is likely due to the lingering effects of ash mortality on the landscape, which has seen the decline and mortality of large, mature ash, which, in a healthy state, have relatively high compensatory value and leaf area. As a result of this widespread decline, ash populations are now characterized by relatively smaller, lower value living trees and large-stature standing dead trees.

DUTCH ELM DISEASE

Dutch elm disease (caused by *Ophiostoma ulmi*) has been present on the landscape in Ontario for decades and has resulted in severe declines in the native population of elms (*Ulmus* spp.). As a result, elms occupy a much less significant place in Guelph's urban forest than they once did. There are currently about 23,500 elm trees in Guelph's urban forest that are susceptible to the effects of Dutch elm disease. These trees have a structural value of about $8.5 million (Figure 53).

OAK WILT

Oak wilt, a devastating disease of oaks caused by the fungus *Bretziella fagacearum*, has not yet been detected in Canada. However, the disease is present in 23 states in the US, including several that border Ontario. An infestation on Belle Isle in Detroit, MI, is less than a kilometer from Windsor, ON, making an introduction of this disease into Canada a likely possibility in the near future. All oaks are susceptible to infection by oak wilt, but oaks in the red oak group, including red oak (*Quercus rubra*), pin oak (*Quercus palustris*), and black oak (*Quercus velutina*), are particularly susceptible to rapid mortality.

There are approximately 17,400 trees in Guelph's urban forest that are susceptible to infection by oak wilt. The structural value of these trees is estimated at about $26 million, which is quite high relative to the size of the population at risk (Figure 53). This is likely due to the large stature of many mature oaks in the city's urban forest and the high value those trees represent.

HEMLOCK WOOLLY ADELGID

Hemlock woolly adelgid (*Adelges tsugae*) has been detected and eradicated twice in Ontario, in 2011 and 2013. Two new detections were reported in the Niagara region in 2019 and have not yet been eradicated. It has also been detected elsewhere in Canada, in British Columbia in the 1920s, and in Nova Scotia in 2017, where it remains active. This pest has had devastating impacts on hemlock forests in the eastern United States, where it has been established since the 1950s. While not a large component of Guelph's urban forests, eastern hemlock (*Tsuga canadensis*) is an important native species that forms unique microclimates and it is susceptible to infestation by hemlock woolly adelgid. About 5,000 trees in Guelph's urban forest are susceptible to infestation by this pest, with a structural value of about $5.3 million (Figure 53). These trees are found only in the Farm and Vacant land uses.

BEECH BARK DISEASE

Beech bark disease is a fungal disease caused by two species of fungi (*Neonectria faginata* and *N. ditissima*) that are vectored by a non-native insect, the beech scale (*Cryptococcus fagisuga*). The disease causes dieback and mortality in American beech (*Fagus grandifolia*), an important tree in eastern North American forests that is a significant food source for wildlife. Some trees exhibit resistance to the disease and it is possible to preserve local populations of beech. Only about 500 trees in Guelph's urban forest are susceptible to beech bark disease, with a structural value of about $9,500. These trees are found only in the Farm land use.

SHRUB SPECIES COMPOSITION

Shrubs are an important component of Guelph's urban forest, and they make a valuable contribution to the total ecosystem services the urban forest provides. Overall, Guelph's shrubs constitute about 1,500 hectares of leaf area, which is equivalent to about 10.4 per cent of the leaf area represented by trees. Following i-

Tree Eco protocols, shrubs include all woody vegetation measuring less than 2.5 cm DBH, including immature individuals of tree species.

When measured by leaf area, the dominant shrub species in Guelph's urban forest is common buckthorn, which comprises 23.7 per cent of the total shrub leaf area. The abundance of this species, particularly in natural forests, is a concern for forest health in the long term as it can inhibit regeneration of native species and affect forest succession. Common buckthorn was over-represented in the Farm and Vacant land uses, where the majority of the forests in Guelph are located. Common buckthorn comprised 42.5 per cent and 31.2 per cent of the leaf area in these land uses. Furthermore, about 57 per cent of the common buckthorn leaf area is confined to the Farm and Vacant land uses.

The second and third most abundant shrubs are eastern white cedar and invasive honeysuckles (*Lonicera* spp.), comprising 8.7 per cent and 5.8 per cent of the total shrub leaf area, respectively. Of the top 10 shrub species by leaf area, three are considered invasive – common buckthorn, honeysuckle, and glossy buckthorn (*Frangula alnus*). Combined, these three species constitute about one third of the shrub layer in Guelph's urban forest (Figure 54).

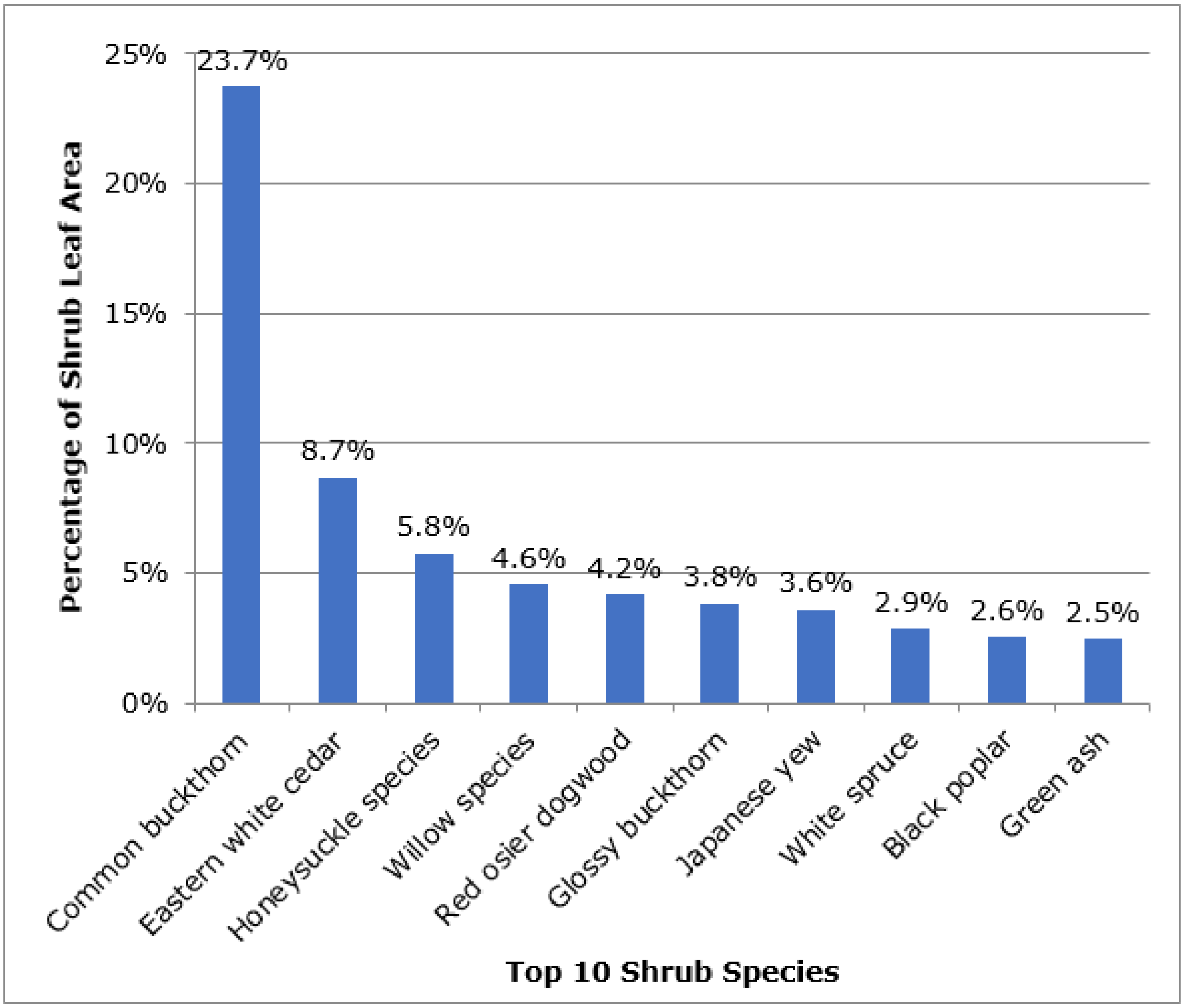


Figure 54: Top 10 shrub species by leaf area in 2019 (Source: 2019 i-Tree Eco data)

SPECIES DIVERSITY

Biodiversity is often upheld as a measure of healthy ecosystems, but it is important to consider the context of individual scenarios. Urban forests may be characterized by an inconsistent distribution of species diversity, as residential and other highly cultivated landscapes may contain a relatively diverse mix of native and non-native species, while natural areas may be relatively less diverse. In this case, less diverse areas may not necessarily be "unhealthy" ecosystems. It is also important to consider the role of invasive plant and tree species, which are a risk associated with a highly diverse urban forest, as well as pest susceptibility, which may be mitigated by greater species diversity.

A total of 106 species were recorded during the 2019 Guelph i-Tree Eco field surveys. The Residential land use had the highest number of species, with 58 species recorded. However, the Farm and Institutional land uses had the highest amount of species per unit area, with 42 species per hectare. The lowest number of species was found in the Industrial land use, with only 19 species recorded (Table 21).

The Shannon Diversity Index is a metric used to measure the diversity of species in a community. Rather than simply tallying the number of species present in a community, the index accounts for the relative abundance of species in the community. The greater the species abundance and evenness in a community, the lower the rating will be for that community on the Shannon Diversity Index (Table 23).

Table 23: Species richness, density, and Shannon Diversity Index ratings by land use in 2019 (Source: 2019 i-Tree Eco data)

Stratum	Species Richness	Species per hectare	Shannon Index
Commercial	22	25.9	2.4
Farm	34	42	2.4
Industrial	19	17.4	2.3
Institutional	34	42	2.6
Multi-Residential	20	23.5	2.8
Residential	58	32.6	2.8
Special and Exempt	28	34.6	2.4
Vacant Land	45	31.8	2.7
Study Area	**106**	**12.6**	**3.2**

SPECIES ORIGINS

Figure 55 illustrates the distribution of the tree population according to the geographical origin of the trees' native range. About 64 per cent of trees in Guelph are native to North America, though not all of these are native to Ontario. Approximately 48 per cent of trees in Guelph are native to southern Ontario, while the remaining 16 per cent native to North America originate in another part of the continent.

The Commercial land use contains the highest proportion of trees native to North America, at 76.6 per cent, followed closely by Vacant lands, at 75.5 per cent. The Special and Exempt land use had the lowest proportion of trees native to North America, at 29.6 per cent, and the highest proportion of trees native to Europe, at 40.4 per cent.

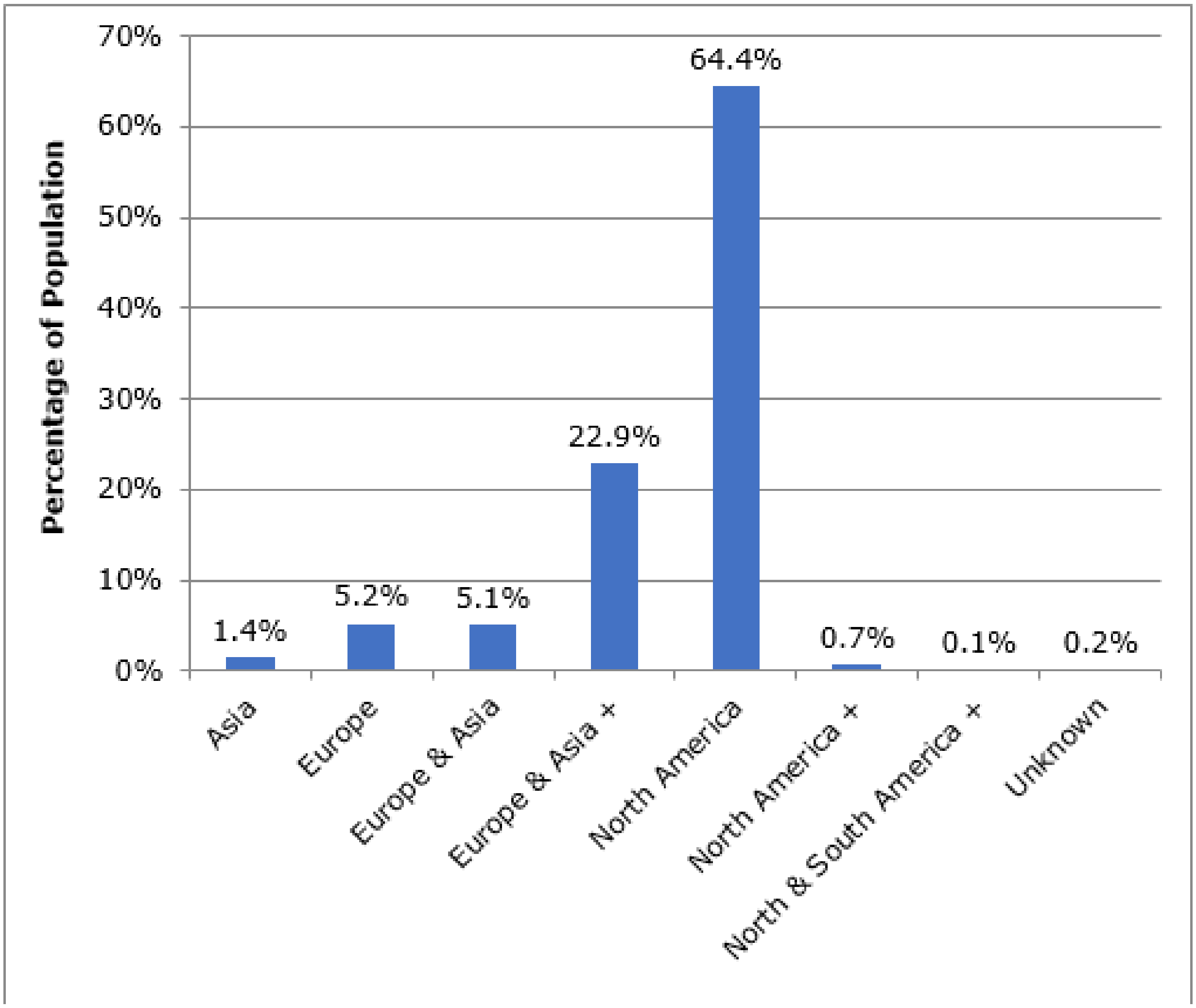


Figure 55: Distribution of tree population by native status in 2019 (Source: 2019 i-Tree data)

ECOSYSTEM SERVICES

As of 2019, Guelph's trees are estimated to provide annual ecosystem services worth more than $5.6 million. These include home energy savings, carbon sequestration, pollution removal, and avoided runoff. Each tree provides an average of $1.88 in benefits each year. These benefits have an annual value of about $42.51 for each resident of the City of Guelph (Table 24). Because these services are typically associated with leaf area and tree health, an analysis of ecosystem services provides additional insight into the functioning of the urban forest and its state of health over time. Furthermore, large stature trees with relatively large leaf area will make disproportionately large per-tree contributions to the ecosystem services provided by the urban forest when compared to smaller stature trees.

Table 24: Annual ecosystem services performed by Guelph's trees in 2019 (Source: 2019 i-Tree Eco data)

Benefits	Total Units	Total (CAD)	CAD/tree	CAD/capita
Energy savings	141,941 MBTUs; 4,428 MWHs	1,882,502	0.63	14.28
Gross Carbon Sequestration	6,455 tonnes	741,515	0.25	5.62
Pollution Removal	156 tonnes	2,051,438	0.69	15.56
Avoided Runoff	399,938 m^3	929,742	0.31	7.05
Total Annual Benefits	**N/A**	**5,605,197**	**1.88**	**42.51**

CARBON STORAGE

As trees grow, they accumulate wood in their stems and branches, which results in the long-term storage of carbon through the tree's life. As such, tree species that attain a large stature at maturity are capable of storing more carbon per tree than tree species that attain only small or medium stature at maturity. When trees lose biomass through injury or decay, or the tree dies, the stored carbon is released into the atmosphere over time, if the tree is able to decay naturally. Reusing or recycling the wood as wood products can maintain the storage of the carbon the tree accumulated during its lifetime.

As of 2019, Guelph's trees store a total of 196,894 tonnes of carbon. The total value of carbon storage by Guelph's urban forest in 2019 is about $22.6 million.

Sugar maple stores the most carbon, about 26,450 tonnes, accounting for 13.4 per cent of carbon stored by Guelph's urban forest, followed by eastern white cedar, which stores 8.8 per cent of the carbon stored by Guelph's urban forest, about 17,400 tonnes (Figure 56).

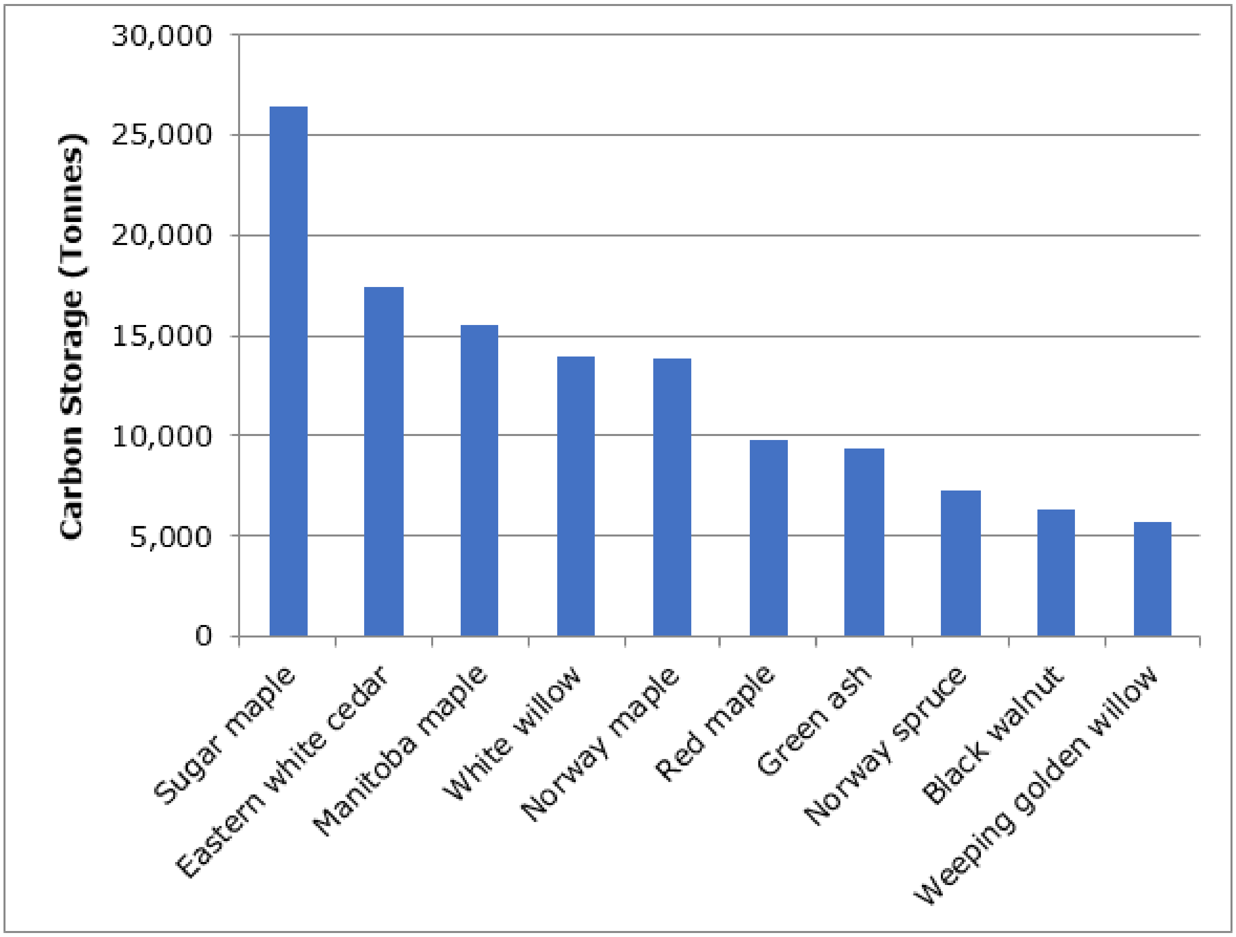


Figure 56: Total carbon stored by top 10 tree species by carbon storage in 2019 (Source: 2019 i-Tree Eco data)

CARBON SEQUESTRATION

During the growing season, when trees are at their most active, they sequester atmospheric carbon through the process of photosynthesis. Carbon is captured through the leaves and deposited into the tree's leaves and wood, and in soils, where it is stored over the longer term. Carbon sequestration is measured in annual amounts, with net carbon sequestration calculated based on the gross amount of carbon sequestered and the amount of carbon released through the decay of biomass and plant respiration.

In 2019, Guelph' trees are estimated to sequester about 6,455 gross tonnes of carbon annually, which has an annual value of $741,500. After accounting for loss of carbon through mortality and decay, Guelph's trees sequester about 4,201 net tonnes of carbon annually. Annual carbon sequestration by trees in Guelph is equivalent to the annual carbon emissions from about 5,000 automobiles.

Sugar maple sequesters the most carbon annually, in gross and net amounts (699.7 tonnes and 483.6 tonnes, respectively). Eastern white cedar sequesters the second most amount of carbon in gross, but is fourth in annual net carbon sequestration behind Norway maple and common buckthorn (Figure 57). Sugar maple sequesters 11.5 per cent of all net carbon annually sequestered by trees in Guelph.

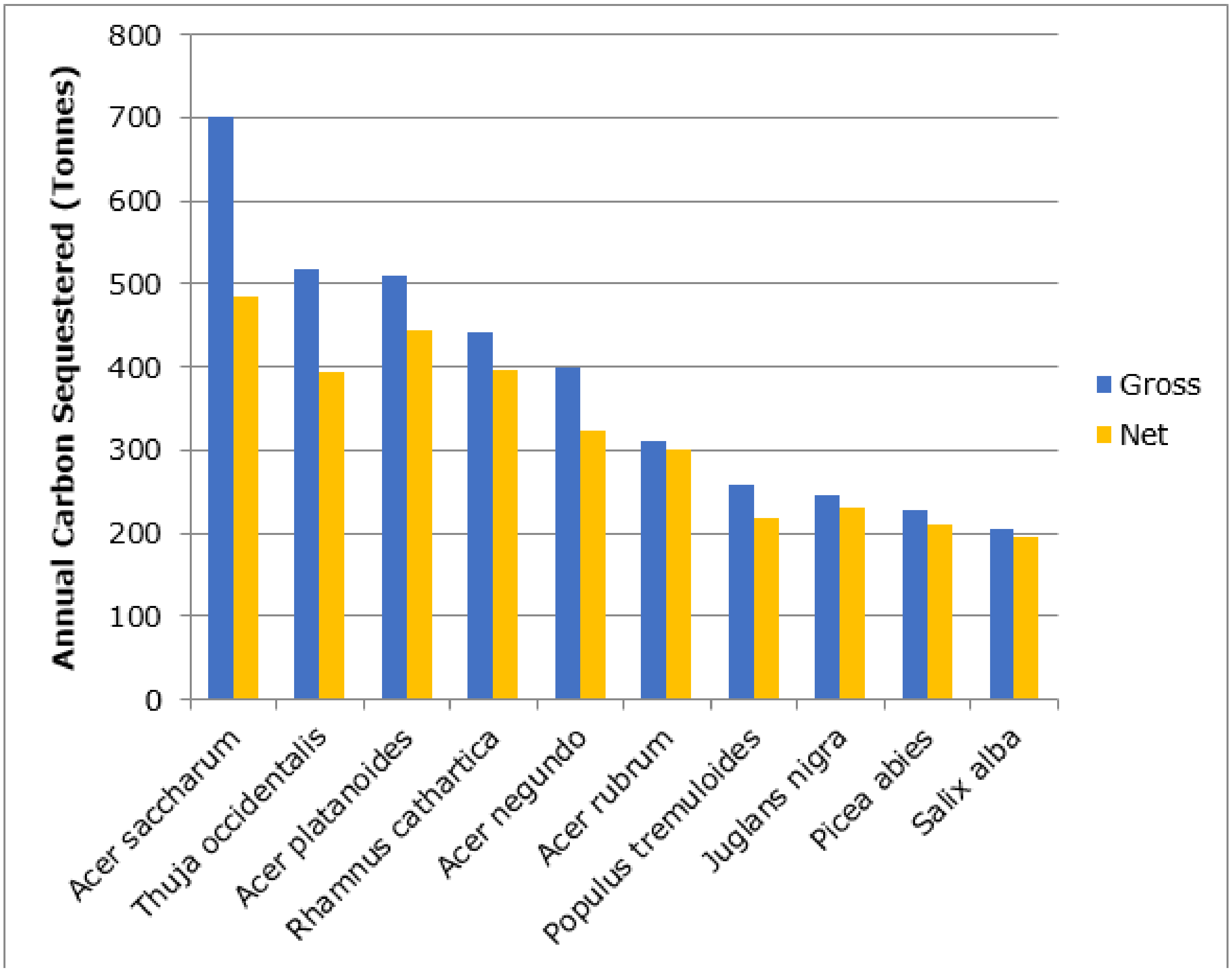


Figure 57: Annual carbon sequestration rates of top 10 species by amount of carbon sequestered in 2019 (Source: 2019 i-Tree Eco data)

The greatest annual loss of carbon is attributed to black, green, and white ash, which have a combined net annual carbon sequestration rate of -791.6 tonnes. This is equivalent to the annual emission of 2,902.7 tonnes of carbon dioxide.

The trees in the Vacant land use are responsible for about 53 per cent of the net annual carbon sequestration performed by Guelph's urban forest. This is disproportionately higher than the population of trees in that land use, which represents about 49.1 per cent of the city's trees and 42.6 per cent of the leaf area. Trees in the Residential land use are responsible for about 26.5 per cent of the net annual carbon sequestration performed by Guelph's urban forest (Figure 58).

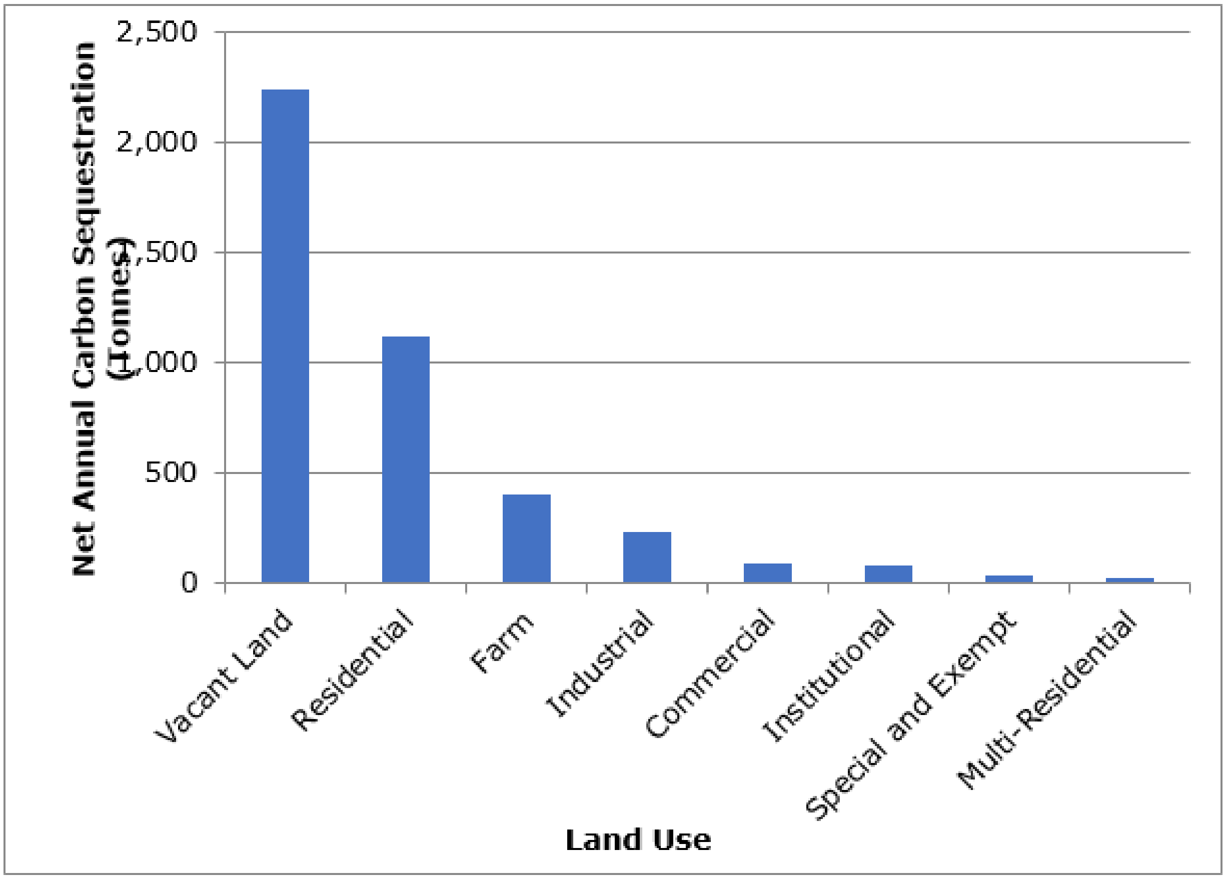


Figure 58: Net annual carbon sequestration performed by trees, by land use in 2019 (Source: 2019 i-Tree Eco data)

POLLUTION REMOVAL

As with atmospheric carbon, trees remove pollution from the air by direct absorption through the leaf stomata as well as by capturing particulate matter on and in plant tissue. In doing so, trees can mitigate air pollution to some extent. The removal of air pollution and particulate matter can have beneficial effects on human health, including reducing instances of respiratory conditions (Nowak et al. 2018). Because this benefit is linked to leaf area and function and because sources of pollution may be scattered across a city, the distribution of the effect may be uneven across the landscape. Areas with less trees and trees of smaller stature may experience relatively less pollution mitigation benefits than areas with larger trees and more urban forest cover.

In 2019, Guelph's trees are estimated to remove about 156.4 tonnes of pollution per year (Figure 59). The total annual value of pollution removal performed by Guelph's trees is estimated at $2,051,438.

Guelph's urban forest removed ozone (O_3) at higher levels than any other pollutant – approximately 121.6 tonnes, which has an associated annual value of about $850,600 (Figure 59).

The annual rate of removal of nitrogen dioxide (NO_2) is 12.3 tonnes per year and has an associated value of about $12,890. This reduction is equivalent to the annual nitrogen dioxide emissions of 1,950 automobiles.

The annual rate of sulphur dioxide removal is 17,186 tonnes, which has an associated annual value of about $6,500. This reduction is equivalent to the annual sulphur dioxide emissions from 204,000 automobiles.

The highest value associated with pollution removal relates to the removal of small particulate matter under 2.5 microns (PM 2.5). Guelph's urban forest removes about 4,861 tonnes of PM 2.5 each year, which carries an annual value of about $1.18 million.

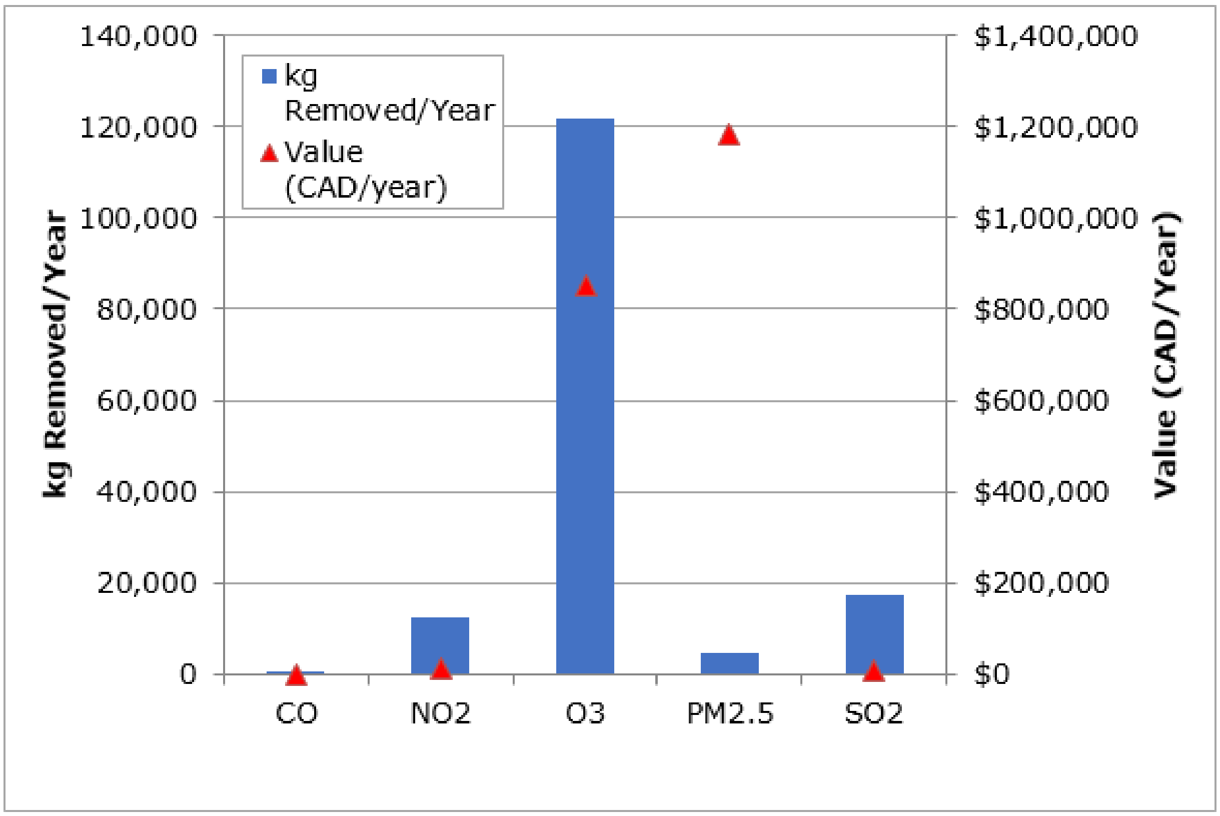


Figure 59: Annual pollution removal by Guelph's urban forest and equivalent value in 2019 (Source: 2019 i-Tree Eco data)

RESIDENTIAL ENERGY SAVINGS

When properly placed, the presence of trees on residential properties helps to lower home energy costs. In summer, trees that shade the residence contribute to lower cooling costs, and in winter, evergreen trees can help to block cold winds, thus lowering the cost of home heating. By lowering home energy demands, trees help to reduce carbon emissions that result from energy use as well. These benefits are enhanced as the size and leaf area of the trees increase.

In Guelph, trees currently reduce annual home energy consumption by approximately 141,941 million British thermal units (MBTUS) and 4,429 mega-watt hours (MWHs), which translates to a total annual savings of $1,882,502 (Table 23).[56]

As a result of these energy savings, Guelph's trees reduce carbon emissions related to home energy use by 3,450 tonnes each year, a service that has an associated annual value of about $396,300 (Table 25).[57]

Table 25: Annual building energy savings for residential properties, resulting from trees in 2019 (Source: 2019 i-Tree Eco data)

Unit	Heating	Cooling	Total Energy Savings (Heating & Cooling)	Total Savings (Heating & Cooling)
MBTUs	141,941.278	N/A	141,941.278	$1,483,915
MWHs	1,198.090	3,230.654	4,428.743	$398,587
Carbon avoided (tonnes)	3,230.771	219.31	3,450.079	$396,311

HYDROLOGY EFFECTS

Trees intercept rainfall on their leaves and branches which helps to regulate the flow of stormwater on the landscape. This ecological service is particularly important in areas with high levels of impervious surfaces, which do not allow water to infiltrate into the ground. In these areas, rain falling on impervious surfaces flows into municipal stormwater infrastructure. This is an important issue in light of climate change and the occurrence of unpredictable extreme weather events, which can deliver large amounts of precipitation in short periods of time. These events can overwhelm so-called grey infrastructure systems, which may not be designed to accommodate such high inputs of precipitation.

Guelph's trees prevent approximately 399,938 cubic metres of runoff annually, which has an equivalent annual value of about $929,742 (Table 24).[58] Due to the large amount of leaf area in the Vacant land use, it prevents the largest amount of runoff – more than 170,000 m³ per year, with an equivalent annual value of more than $395,800. This accounts for 42.6 per cent of the avoided runoff performed by

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[56] Home energy savings are calculated based on home energy costs in 2019. Electricity/hydro cost was set at $0.09/kwh (the average value of off-peak, mid-peak, and peak rates as of October 30, 2019). Natural gas rate for heating was set at $1.04/therm, using the default i-Tree Eco value.

[57] Energy prices used in 2019 results: $0.09/kWh (electricity), $0.23/therm (heating), $114.87/tonne of carbon.

[58] Avoided runoff value is based on the price of $2.325/m³ (CAD), using the i-Tree Eco default value. Runoff values are based on the reported data from the Waterloo weather monitoring station, the nearest to the study area, and are based on 75.8 cm of total annual precipitation.

Guelph's urban forest and aligns with the large tree population and leaf area present in the Vacant land use.

Trees in the Residential land use also contribute a great deal to the avoided runoff service provided by Guelph's urban forest. Trees in the Residential land use prevent about 116,850 m^3 of runoff each year, which has an equivalent annual value of about $271,600. This accounts for 29.2 per cent of avoided runoff performed by Guelph's urban forest (Table 26).

Table 26: Annual avoided runoff and associated value by land use in 2019 (Source: 2019 i-Tree Eco data)

Land Use	Number of Trees	Leaf Area (ha)	Avoided Runoff (m^3/year)	Avoided Runoff Value (CAD/year)
Commercial	101,183	650.2	18,052.43	$41,966.73
Farm	337,858	1,053.63	29,253.61	$68,006.26
Industrial	113,342	721.25	20,025.28	$46,553.04
Institutional	230,111	1,154.77	32,061.6	$74,534.04
Multi-Residential	3,904	89.26	2,478.34	$5,761.44
Residential	607,979	4,208.88	116,857.89	$271,661.12
Special & Exempt	119,297	393.37	10,921.71	$25,389.86
Vacant	1,459,706	6,133.26	170,287.64	$395,869.99
Total	**2,973,380**	**14,404.61**	**399,938.5**	**$929,742.47**

In Guelph, eastern white cedar prevents more runoff than any other species, with about 66,402 m^3 per year of avoided runoff. This is 16.6 per cent of the avoided runoff performed by Guelph's urban forest and has an equivalent annual value of about $154,366. Norway maple and sugar maple also contribute significantly to the avoided runoff service provided by Guelph's urban forest. Norway maple accounts for 36,311 m^3 of avoided runoff per year, which has an equivalent annual value of $84,412. Sugar maple accounts for 35,422 m^3 of avoided runoff per year, which has an equivalent annual value of $82,347.

REFERENCES

Bergh, J., Freeman, M., Sigurdsson, B., Kellomäki, S., Laitinen, K., Niinistö, S., Peltola, H., and S. Linder. 2003. Modelling the short-term effects of climate change on the productivity of selected tree species in Nordic countries. Forest Ecology and Management 183: 327-340.

Hejda, M., Pyšek, P., and V. Jarošík. 2009. Impact of invasive plants on the species richness, diversity, and composition of invaded communities. Journal of Ecology 97: 393-403.

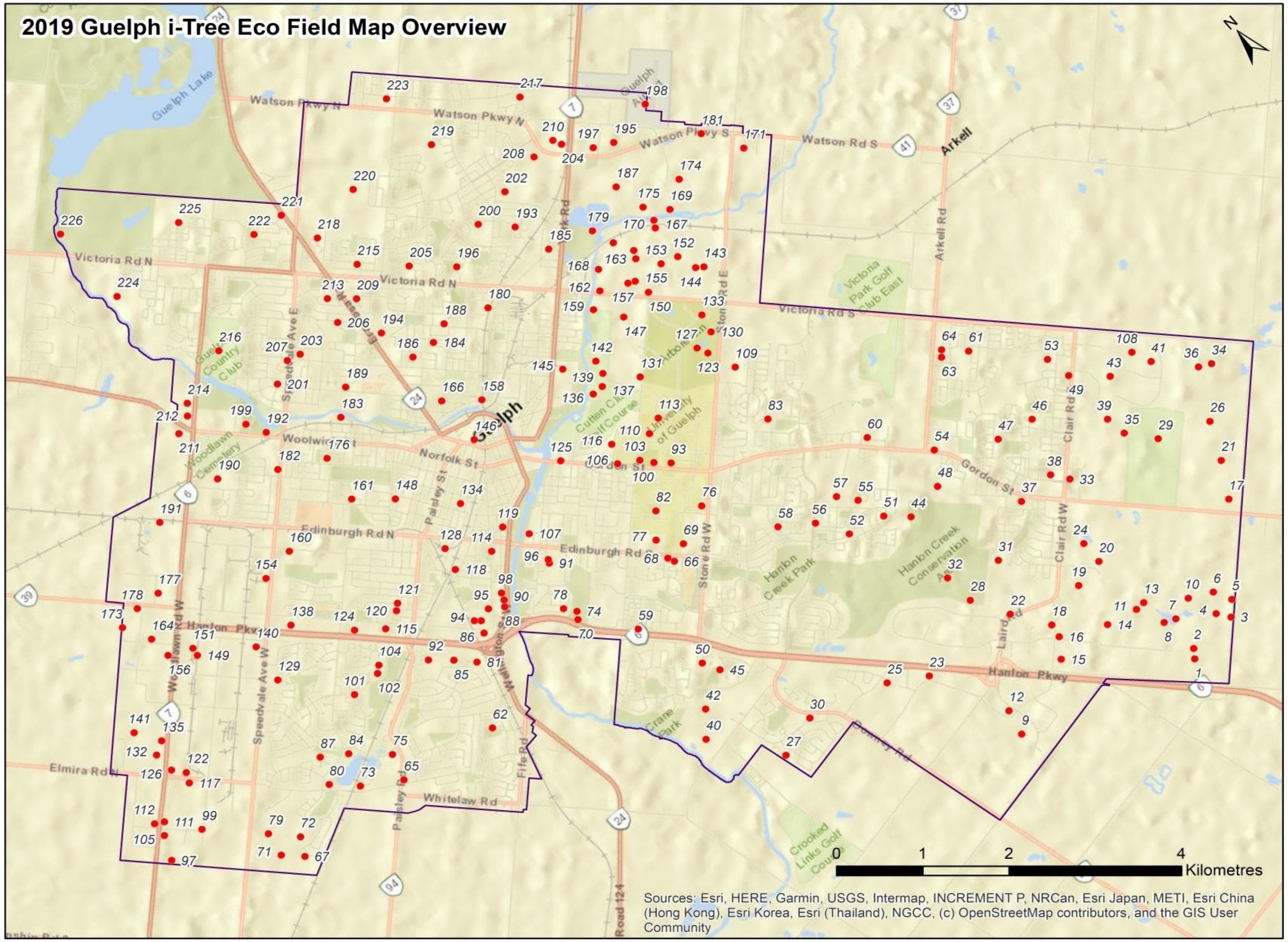
Natural Resources Canada (NRCAN). Asian longhorned beetle. Available online at: Asian longhorned beetle [Accessed November 12, 2019]

Nowak, D. J., Hirabayashi, S., Doyle, M., McGovern, M. and J. Pasher. 2018. Air pollution removal by urban forests in Canada and its effect on air quality and human health. Urban Forestry & Urban Greening 29: 40-48.

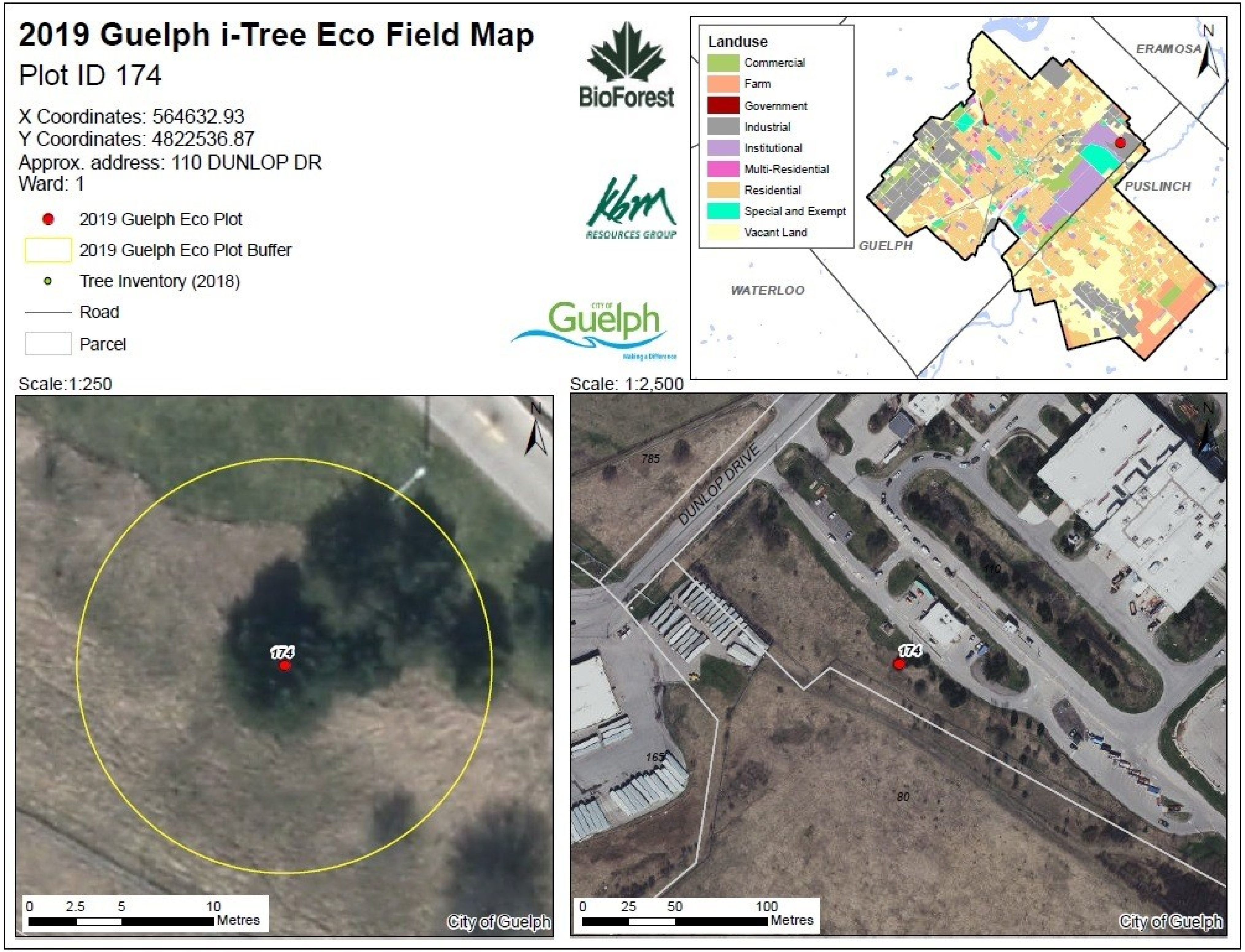
Williams, A.P., Allen, C.D., Macalady, A.K., Griffin, D., Woodhouse, C.A., Meko, D.M., Swetnam, T.W., Rauscher, S.A., Seager, R., Grissino-Mayer, H.D., Dean, J.S., Cook, E.R., Gangodagamage, C., Cai, M., and N.G. McDowell. 2013. Temperature as a potent driver of regional forest drought stress and tree mortality. Nature Climate Change 3: 292-297.

Wolfe, B.E., Rodgers, V.L., Stinson, K.A., and A. Pringle. 2008. The invasive plant *Alliaria petiolata* (garlic mustard) inhibits ectomycorrhizal fungi in its introduced range. Journal of Ecology 96: 777-783.

SUPPLEMENT 1: OVERVIEW MAP OF I-TREE ECO PLOTS



SUPPLEMENT 2: I-TREE ECO PLOT MAP



COMPLETE LIST OF TREE SPECIES

Species	Common Name	Per cent Population	Per cent Leaf Area	Importance Value[59]
Abies alba	White fir	0.00	0.10	0.10
Abies balsamea	Balsam fir	2.70	0.80	3.40
Acer ginnala	Amur maple	0.00	0.00	0.00
Acer negundo	Manitoba maple	2.70	5.90	8.60
Acer nigrum	Black maple	0.10	0.30	0.40
Acer palmatum	Japanese maple	0.00	0.10	0.10
Acer platanoides	Norway maple	3.00	9.10	12.10
Acer pseudoplatanus	Sycamore maple	0.00	0.10	0.20
Acer rubrum	Red maple	0.70	3.80	4.50
Acer saccharinum	Silver maple	0.50	2.00	2.50
Acer saccharum	Sugar maple	3.60	8.90	12.50
Acer x freemanii	Freeman maple	0.20	0.30	0.40
Aesculus hippocastanum	Horsechestnut	0.00	0.00	0.10
Alnus glutinosa	Black alder	0.20	0.00	0.20

[59] Importance value is calculated as the sum of the per cent population and per cent leaf area represented by each species. Importance values communicate the relative dominance of each species in the urban forest.

Species	Common Name	Per cent Population	Per cent Leaf Area	Importance Value[59]
Amelanchier	Serviceberry	0.10	0.00	0.10
Amelanchier arborea	Downy serviceberry	1.40	0.10	1.60
Berberis vulgaris	Common barberry	0.00	0.00	0.00
Betula alleghaniensis	Yellow birch	0.00	0.10	0.20
Betula papyrifera	White birch	0.30	2.20	2.60
Betula pendula	European birch	0.10	0.50	0.60
Carya cordiformis	Bitternut hickory	0.00	0.00	0.00
Cercis canadensis	Eastern redbud	0.00	0.00	0.10
Cornus alternifolia	Alternate leaf dogwood	0.20	0.10	0.30
Cornus racemosa	Grey dogwood	0.10	0.00	0.10
Crataegus spp.	Hawthorn	0.80	0.30	1.10
Crataegus mollis	Downy hawthorn	0.00	0.10	0.10
Crataegus punctata	Dotted hawthorn	0.50	0.20	0.70
Elaeagnus angustifolia	Russian olive	0.00	0.00	0.10

Species	Common Name	Per cent Population	Per cent Leaf Area	Importance Value[59]
Euonymus alatus	Winged euonymus	0.00	0.00	0.10
Fagus grandifolia	American beech	0.00	0.00	0.00
Fagus sylvatica 'Purpurea'	Copper beech	0.10	0.30	0.30
Frangula alnus	Glossy buckthorn	1.30	0.20	1.60
Fraxinus spp.	Ash	0.00	0.00	0.00
Fraxinus americana	White ash	2.10	1.20	3.30
Fraxinus excelsior	European ash	0.10	0.00	0.10
Fraxinus nigra	Black ash	0.80	0.10	0.80
Fraxinus pennsylvanica	Green/red ash	10.10	2.10	12.20
Gleditsia triacanthos	Honey locust	0.10	0.30	0.40
Gymnocladus dioicus	Kentucky coffee tree	0.10	0.10	0.20
Hibiscus syriacus	Rose of Sharon	0.10	0.00	0.10
Ilex verticillata	Winterberry	0.00	0.00	0.00
Juglans nigra	Black walnut	1.40	6.10	7.60

Species	Common Name	Per cent Population	Per cent Leaf Area	Importance Value[59]
Juniperus spp.	Juniper	0.10	0.20	0.20
Juniperus chinensis	Chinese juniper	0.10	0.00	0.20
Juniperus virginiana	Eastern red cedar	0.00	0.10	0.10
Larix laricina	Tamarack	0.20	0.10	0.40
Ligustrum vulgare	Common privet	0.20	0.00	0.20
Lonicera spp.	Honeysuckle	0.20	0.00	0.20
Lonicera tatarica	Tatarian honeysuckle	0.10	0.00	0.10
Lonicera xylosteum	Fly honeysuckle	0.10	0.00	0.10
Malus spp.	Apple	0.00	0.00	0.10
Malus domestica	Common apple	0.40	0.30	0.70
Malus tschonoskii	Flowering crabapple	0.10	0.20	0.20
Morus alba	White mulberry	0.10	0.00	0.10
Morus rubra	Red mulberry	0.10	0.00	0.10
Ostrya virginiana	Ironwood	1.10	1.30	2.40
Phellodendron amurense	Amur cork tree	0.00	0.10	0.10

Species	Common Name	Per cent Population	Per cent Leaf Area	Importance Value[59]
Physocarpus opulifolius	Common ninebark	0.20	0.00	0.20
Picea spp.	Spruce	0.00	0.00	0.00
Picea abies	Norway spruce	1.40	3.80	5.30
Picea glauca	White spruce	0.90	2.50	3.50
Picea mariana	Black spruce	0.10	0.10	0.20
Picea pungens	Blue spruce	0.40	2.00	2.50
Pinus mugo	Dwarf mountain pine	0.00	0.00	0.10
Pinus nigra	Austrian pine	0.10	0.70	0.80
Pinus resinosa	Red pine	1.50	0.50	2.00
Pinus strobus	Eastern white pine	3.70	4.10	7.80
Pinus sylvestris	Scots pine	0.10	0.30	0.50
Populus balsamifera	Balsam poplar	0.90	0.30	1.10
Populus deltoides	Eastern cottonwood	0.30	0.30	0.60
Populus grandidentata	Largetooth aspen	0.20	0.40	0.60
Populus nigra v. italica	Black poplar	0.90	0.10	1.00

Species	Common Name	Per cent Population	Per cent Leaf Area	Importance Value[59]
Populus tremuloides	Trembling aspen	3.00	2.70	5.70
Populus x canadensis	Carolina poplar	0.20	0.20	0.30
Prunus spp.	Cherry	0.00	0.00	0.00
Prunus avium	Sweet cherry	0.10	0.00	0.20
Prunus serotina	Black cherry	0.80	1.20	2.00
Prunus virginiana	Chokecherry	0.20	0.00	0.20
Pyrus spp.	Pear	0.00	0.00	0.00
Pyrus calleryana	Callery pear	0.00	0.00	0.10
Pyrus communis	Common pear	0.50	0.20	0.70
Quercus bicolor	Swamp white oak	0.00	0.80	0.80
Quercus macrocarpa	Burr oak	0.00	0.20	0.20
Quercus robur	English oak	0.10	0.10	0.20
Quercus robur 'Fastigiata'	Upright English oak	0.30	0.00	0.30
Quercus rubra	Red oak	0.20	0.50	0.70
Rhamnus cathartica	Common buckthorn	19.30	4.10	23.40

Species	Common Name	Per cent Population	Per cent Leaf Area	Importance Value[59]
Rhus hirta	Staghorn sumac	0.20	0.00	0.30
Robinia pseudoacacia	Black locust	0.00	0.20	0.20
Rosa spp.	Rose	0.10	0.00	0.10
Salix spp.	Willow	0.40	0.90	1.40
Salix alba	White willow	0.20	0.90	1.10
Salix matsudana	Chinese willow	0.00	0.00	0.10
Salix x sepulcralis	Weeping golden willow	0.00	0.70	0.70
Sorbus americana	American mountain ash	0.10	0.00	0.10
Sorbus aucuparia	Rowan tree	0.10	0.00	0.10
Syringa spp.	Lilac	0.20	0.10	0.20
Syringa reticulata	Japanese tree lilac	0.20	0.00	0.20
Syringa vulgaris	Common lilac	2.00	0.10	2.10
Taxus baccata	English yew	0.00	0.20	0.20
Thuja occidentalis	Eastern white cedar	20.80	16.60	37.40
Tilia americana	Basswood	1.60	2.30	3.90
Tilia cordata	Littleleaf linden	0.50	2.50	3.00

Species	Common Name	Per cent Population	Per cent Leaf Area	Importance Value[59]
Tsuga canadensis	Eastern hemlock	0.20	0.80	1.00
Ulmus americana	American elm	0.70	0.90	1.70
Ulmus pumila	Siberian elm	0.10	0.20	0.30
Viburnum lantana	Wayfaring tree	0.30	0.00	0.40

LEAF AREA AND BIOMASS ESTIMATES FOR ALL SHRUB SPECIES, BY LAND USE

COMMERCIAL

Species	Common Name	Leaf Area (ha)	Leaf Biomass (tonne)
Acer negundo	Manitoba maple	<0.1	<0.1
Cornus alternifolia	Alternate leaf dogwood	2	1.4
Crataegus spp.	Hawthorn	<0.1	<0.1
Euonymus alatus	Winged euonymus	11.1	8.3
Euonymus fortunei	Winter creeper	0.3	0.3
Fraxinus americana	White ash	0.1	0.1
Fraxinus nigra	Black ash	0.1	0.1
Fraxinus pennsylvanica	Green/red ash	0.8	0.5
Juglans nigra	Black walnut	2.9	2.3
Lonicera spp.	Honeysuckle	0.7	0.3
Ostrya virginiana	Ironwood	<0.1	<0.1
Physocarpus opulifolius	Common ninebark	9.1	6.8
Populus tremuloides	Trembling aspen	0.3	0.2
Prunus spp.	Cherry	0.1	0.1
Prunus avium	Sweet cherry	0.5	0.4
Prunus serotina	Black cherry	0.4	0.3
Prunus spinosa	Blackthorn	0.1	0.1

Species	Common Name	Leaf Area (ha)	Leaf Biomass (tonne)
Rhamnus cathartica	Common buckthorn	1.8	0.8
Ribes triste	Northern redcurrant	0.1	0.1
Rosa spp.	Rose	0.9	0.7
Sorbus americana	American mountain ash	0.1	0.1
Spiraea japonica	Japanese spirea	3.1	2.3
Syringa vulgaris	Common lilac	0.5	0.4
Tilia spp.	Linden	0.1	0.1
Total – Commercial	**N/A**	**35.2**	**25.6**

FARM

Species	Common Name	Leaf Area (ha)	Leaf Biomass (tonne)
Acer saccharum	Sugar maple	0.2	0.1
Amelanchier spp.	Serviceberry	0.6	0.5
Cornus racemosa	Grey dogwood	0.9	0.4
Cornus sericea	Red osier dogwood	4.3	2.5
Crataegus spp.	Hawthorn	0.6	0.2
Fraxinus americana	White ash	1.6	0.9
Fraxinus nigra	Black ash	<0.1	<0.1
Fraxinus pennsylvanica	Green/red ash	2.1	1.4
Ilex verticillata	Winterberry	4.1	5.4
Juglans nigra	Black walnut	1	0.8
Lonicera x notha	Honeysuckle	11.7	5.8
Lonicera spp.	Honeysuckle	23.1	11.4
Lonicera tatarica	Tatarian honeysuckle	7.2	3.6
Ostrya virginiana	Ironwood	1.2	0.8
Populus balsamifera	Balsam poplar	1.3	0.9
Populus tremuloides	Trembling aspen	0.7	0.6
Prunus serotina	Black cherry	0.3	0.2
Prunus virginiana	Chokecherry	0.3	0.2
Pyrus spp.	Pear	1.3	1
Rhamnus cathartica	Common buckthorn	72.2	32.1
Frangula alnus	Glossy buckthorn	19.8	14.8
Ribes spp.	Currant	<0.1	<0.1
Robinia pseudoacacia	Black locust	0.1	<0.1
Rubus spp.	Raspberry	0.5	0.2

Rubus idaeus	Red raspberry	2.7	1
Salix spp.	Willow	0.7	0.5
Sambucus canadensis	American black elderberry	0.1	0.1
Syringa vulgaris	Common lilac	0.9	0.8
Tilia americana	Basswood	0.1	<0.1
Ulmus americana	American elm	<0.1	<0.1
Ulmus spp.	Elm	<0.1	<0.1
Viburnum lantana	Wayfaring tree	9.4	7
Viburnum lentago	Nannyberry	1	0.8
Total – Farm	**N/A**	**169.9**	**93.9**

INDUSTRIAL

Species	Common Name	Leaf Area (ha)	Leaf Biomass (tonne)
Acer x freemanii	Freeman maple	1	0.6
Acer negundo	Manitoba maple	0.4	0.3
Alnus glutinosa	Black alder	0.4	0.3
Cornus sericea	Red osier dogwood	6.8	3.9
Fraxinus pennsylvanica	Green/red ash	0.1	0.1
Juniperus spp.	Juniper	4	11.1
Juglans nigra	Black walnut	1.1	0.9
Populus tremuloides	Trembling aspen	<0.1	<0.1
Rhamnus cathartica	Common buckthorn	15.8	7
Ribes spp.	Currant	7.1	5.3
Rosa spp.	Rose	1.3	0.9
Rubus spp.	Raspberry	0.2	0.1
Ulmus pumila	Siberian elm	<0.1	<0.1
Total – Industrial	**N/A**	**38.1**	**30.5**

INSTITUTIONAL

Species	Common Name	Leaf Area (ha)	Leaf Biomass (tonne)
Acer platanoides	Norway maple	2.8	1.5
Acer rubrum	Red maple	0.3	0.2
Acer saccharum	Sugar maple	0.3	0.2
Cercis spp.	Redbud	0.1	0.1
Cornus spp.	Dogwood	0.8	0.5
Cornus alternifolia	Alternate leaf dogwood	8.1	5.4
Cotinus coggygria	European smoketree	5.3	4

Cornus racemosa	Grey dogwood	0.6	0.3
Cornus sericea	Red osier dogwood	2.9	1.7
Cupressus funebris	Chinese weeping cypress	9.2	14.5
Fraxinus americana	White ash	5.2	3
Fraxinus pennsylvanica	Green/red ash	7	4.6
Hamamelis virginiana	Witch-hazel	0.4	0.3
Juglans nigra	Black walnut	1.1	0.9
Ligustrum vulgare	Common privet	1.9	1.7
Lonicera spp.	Honeysuckle	9.3	4.6
Magnolia spp.	Magnolia	2.6	1.7
Pinus strobus	Eastern white pine	0.2	0.1
Populus tremuloides	Trembling aspen	0.3	0.2
Prunus virginiana	Chokecherry	4.4	3.4
Quercus bicolor	Swamp white oak	<0.1	<0.1
Rhamnus cathartica	Common buckthorn	30.6	13.6
Frangula alnus	Glossy buckthorn	1.2	0.9
Rhus hirta	Staghorn sumac	9.3	8.9
Spiraea japonica	Japanese spirea	0.4	0.3
Syringa spp.	Lilac	1.4	1.4
Taxus canadensis	Canada yew	4.9	7.6
Thuja occidentalis	Eastern white cedar	38.3	73.6
Tilia americana	Basswood	0.3	0.1
Toxicodendron radicans	Poison ivy	0.2	0.2
Viburnum spp.	Viburnum	3.5	2.7
Total – Institutional	**N/A**	**152.9**	**157.8**

MULTI-RESIDENTIAL

Species	Common Name	Leaf Area (ha)	Leaf Biomass (tonne)
Acer negundo	Manitoba maple	0.1	0.1
Acer platanoides	Norway maple	0.1	0.1
Amelanchier arborea	Downy serviceberry	0.2	0.1
Euonymus alatus	Winged euonymus	0.8	0.6
Euonymus fortunei	Winter creeper	0.2	0.2

Fraxinus americana	White ash	<0.1	<0.1
Juniperus spp.	Juniper	0.7	1.8
Juglans nigra	Black walnut	<0.1	<0.1
Ligustrum spp.	Privet	1.5	1.4
Physocarpus opulifolius	Common ninebark	0.3	0.2
Picea glauca	White spruce	0.5	0.8
Rhamnus cathartica	Common buckthorn	0.2	0.1
Spiraea japonica	Japanese spirea	0.2	0.2
Syringa reticulata	Japanese tree lilac	0.4	0.4
Syringa vulgaris	Common lilac	<0.1	<0.1
Taxus spp.	Yew	0.2	0.3
Taxus canadensis	Canada yew	1	1.6
Thuja occidentalis	Eastern white cedar	<0.1	<0.1
Ulmus americana	American elm	<0.1	<0.1
Ulmus pumila	Siberian elm	<0.1	<0.1
Viburnum lantana	Wayfaring tree	0.1	0.1
Total – Multi-residential	**N/A**	**6.5**	**7.9**

RESIDENTIAL

Species	Common Name	Leaf Area (ha)	Leaf Biomass (tonne)
Acer griseum	Paperbark maple	0.3	0.2
Acer negundo	Manitoba maple	1.3	1.2
Acer platanoides	Norway maple	2.3	1.3
Aesculus hippocastanum	Horsechestnut	1.6	1.1
Amelanchier spp.	Serviceberry	0.7	0.5
Berberis spp.	Barberry	0.2	0.2
Berberis thunbergii	Japanese barberry	2	1.5
Buxus sempervirens	Common box	4.2	3.2
Buxus spp.	Box tree	1	0.7
Cercis canadensis	Eastern redbud	5.1	3.3
Celtis occidentalis	Common hackberry	1.7	0.9
Chaenomeles japonica	Maule’s quince	3.1	2.3
Cotoneaster buxifolius	Boxwood cotoneaster	0.2	0.2
Cornus florida	Flowering dogwood	0.1	0.1

Cornus sericea	Grey dogwood	0.8	0.5
Euonymus alatus	Winged euonymus	26.1	19.6
Euonymus europaeus	European spindle tree	7.9	5.9
Euonymus fortunei	Winter creeper	5.5	4.1
Euonymus spp.	Euonymus	5	3.8
Forsythia x intermedia	Showy forsythia	17.2	12.9
Forsythia spp.	Forsythia	4.2	3.2
Forsythia viridissima	Green-stem forsythia	14.2	10.6
Fraxinus americana	White ash	6.2	3.5
Fraxinus excelsior	European ash	0.3	0.3
Fraxinus pennsylvanica	Green/red ash	0.9	0.6
Gleditsia triacanthos	Honey locust	0.2	0.2
Hibiscus syriacus	Rose of Sharon	18.5	8.9
Hydrangea paniculata	Panicled hydrangea	1.3	1
Hydrangea spp.	Hydrangea	9	6.7
Ilex spp.	Holly	1.3	1.8
Juniperus spp.	Juniper	22.3	62.1
Juglans nigra	Black walnut	4.3	3.5
Ligustrum spp.	Privet	0.6	0.6
Ligustrum vulgare	Common privet	0.3	0.3
Lonicera spp.	Honeysuckle	15.6	7.7
Lonicera tatarica	Tatarian honeysuckle	0.5	0.2
Lonicera xylosteum	Fly honeysuckle	6.1	3
Malus tschonoskii	Flowering crab apple	4.7	4.1
Morus rubra	Red mulberry	2.7	2.6
Philadelphus coronarius	Sweet mock-orange	2.9	2.2
Physocarpus opulifolius	Common ninebark	7.8	5.8
Picea glauca	White spruce	42.9	68.9
Pinus mugo	Dwarf mountain pine	0.1	0.1
Picea pungens	Blue spruce	9.2	15.6
Potentilla fruiticosa	Shrubby cinquefoil	3	2.2
Prunus x cistena	Purple leaf sand cherry	2	1.5
Prunus domestica	Common plum	0.1	0.1
Prunus virginiana	Chokecherry	1.2	0.9
Pyrus spp.	Pear	0.5	0.4

Rhamnus cathartica	Common buckthorn	96.9	43.1
Frangula alnus	Glossy buckthorn	10	7.5
Rhus hirta	Staghorn sumac	2.2	2.1
Ribes spp.	Currant	2	1.5
Rosa spp.	Rose	4.1	3.1
Rubus spp.	Raspberry	11.2	4.2
Salix spp.	Willow	1.8	1.1
Sambucus nigra	Black elder	12	9
Sorbaria sorbifolia	False spiraea	0.6	0.4
Spiraea chamaedryfolia	Germander meadowsweet	23.6	17.7
Spiraea japonica	Japanese spirea	7.1	5.3
Spiraea spp.	Spiraea	0.9	0.7
Spiraea x vanhouttei	Vanhoutte spirea	8.9	6.7
Syringa spp.	Lilac	4.6	4.5
Syringa vulgaris	Common lilac	15.9	15.4
Taxus spp.	Yew	11.4	17.9
Taxus canadensis	Canada yew	10.8	16.9
Taxus cuspidata	Japanese yew	54	84.6
Thuja occidentalis	Eastern white cedar	77.9	149.9
Tilia americana	Basswood	1.3	0.4
Tilia cordata	Littleleaf linden	0.1	0.1
Ulmus pumila	Siberian elm	0.7	0.5
Viburnum spp.	Viburnum	1.3	1
Weigela florida	Oldfashioned weigela	3.2	2.4
Total – Residential	**N/A**	**632.3**	**677.7**

SPECIAL & EXEMPT

Species	Common Name	Leaf Area (ha)	Leaf Biomass (tonne)
Acer negundo	Manitoba maple	0.6	0.6
Acer palmatum	Japanese maple	2.2	1.3
Acer platanoides	Norway maple	<0.1	<0.1
Amelanchier spp.	Serviceberry	<0.1	<0.1
Betula nigra	River birch	0.1	0.1
Cornus alternifolia	Alternate leaf dogwood	0.3	0.2
Cornus florida	Flowering dogwood	<0.1	<0.1

Cornus racemosa	Grey dogwood	0.3	0.2
Cornus sericea	Red osier dogwood	1.4	0.8
Fagus sylvatica	European beech	0.1	<0.1
Fraxinus americana	White ash	0.3	0.1
Fraxinus pennsylvanica	Green/red ash	<0.1	<0.1
Juniperus spp.	Juniper	0.4	1.1
Juglans nigra	Black walnut	1.8	1.4
Ligustrum vulgare	Common privet	0.1	0.1
Lonicera spp.	Honeysuckle	0.8	0.4
Lonicera tatarica	Tatarian honeysuckle	0.5	0.2
Pinus strobus	Eastern white pine	0.3	0.2
Populus nigra v. italica	Black poplar	15.2	11
Prunus serotina	Black cherry	<0.1	<0.1
Prunus virginiana	Chokecherry	0.3	0.2
Quercus macrocarpa	Bur oak	<0.1	<0.1
Rhamnus cathartica	Common buckthorn	8.5	3.8
Frangula alnus	Glossy buckthorn	0.1	<0.1
Rosa spp.	Rose	0.3	0.2
Salix spp.	Willow	9.9	6.1
Spiraea japonica	Japanese spirea	0.5	0.4
Syringa vulgaris	Common lilac	3.7	3.6
Taxus spp.	Yew	0.4	0.7
Taxus canadensis	Canada yew	0.1	0.2
Thuja occidentalis	Eastern white cedar	0.1	0.3
Tilia americana	Basswood	<0.1	<0.1
Viburnum opulus	Guelder-rose	<0.1	<0.1
Total – Special & Exempt	**N/A**	**48.5**	**33.3**

VACANT

Species	Common Name	Leaf Area (ha)	Leaf Biomass (tonne)
Acer negundo	Manitoba maple	0.5	0.4
Acer platanoides	Norway maple	0.1	0.1
Acer rubrum	Red maple	<0.1	<0.1
Acer saccharinum	Silver maple	0.1	0.1
Acer saccharum	Sugar maple	22	13.3
Catalpa speciosa	Northern catalpa	<0.1	<0.1

Cornus racemosa	Grey dogwood	6.6	3.2
Cornus sericea	Red osier dogwood	46.7	26.7
Euonymus fortunei	Winter creeper	1.3	1
Forsythia x intermedia	Showy forsythia	0.4	0.3
Frangula alnus	Glossy buckthorn	19.8	14.8
Fraxinus americana	White ash	3.4	1.9
Fraxinus pennsylvanica	Green/red ash	26.2	17.1
Ligustrum spp.	Privet	1.5	1.4
Lonicera spp.	Honeysuckle	37	18.2
Physocarpus opulifolius	Common ninebark	2.4	1.8
Populus balsamifera	Balsam poplar	0.8	0.6
Populus nigra v. italica	Black poplar	23.2	16.7
Populus tremuloides	Trembling aspen	2.2	1.7
Prunus serotina	Black cherry	0.1	0.1
Prunus virginiana	Chokecherry	1	0.8
Rhamnus cathartica	Common buckthorn	131.1	58.3
Frangula alnus	Glossy buckthorn	6.8	5.1
Rhus hirta	Staghorn sumac	0.4	0.4
Ribes rubrum	Redcurrant	1.5	1.1
Ribes triste	Northern redcurrant	0.1	<0.1
Rosa spp.	Rose	0.4	0.3
Rubus idaeus	Red raspberry	0.6	0.2
Salix spp.	Willow	56.3	34.7
Syringa vulgaris	Common lilac	2.7	2.6
Taxus canadensis	Canada yew	5.5	8.6
Thuja occidentalis	Eastern white cedar	14.6	28.1
Tilia spp.	Linden	4.5	2.1
Ulmus americana	American elm	0.3	0.2
Viburnum spp.	Viburnum	0.5	0.4
Total – Vacant Land	**N/A**	**420.5**	**262.2**

STUDY AREA

Study Area	Leaf Area (ha)	Leaf Biomass (tonne)
Total – Study Area	**1,504.1**	**1,289**

SUMMARY OF BENEFITS FOR ALL TREES BY LAND USE

COMMERCIAL

Species	Common Name	Trees	Carbon storage (tonnes)	Carbon storage (CAD)	Gross carbon sequestration (tonnes/year)	Gross carbon sequestration (CAD/year)	Avoided runoff (m³/year)	Avoided runoff (CAD/year)	Pollution removal (tonnes/year)	Pollution removal (CAD/year)	Structural Value (CAD)
Acer negundo	Manitoba maple	5764	1139.22	130862.1	40.49	4651.17	1989.82	4625.75	0.64	8885.09	5798473
Acer platanoides	Norway maple	1281	12.38	1421.63	2.14	246.26	47.31	109.98	0.02	211.24	78384.84
Acer saccharum	Sugar maple	28818	1548.74	177903.2	88.42	10156.28	4468.76	10388.59	1.43	19954.26	12275448
Amelanchier arborea	Downy serviceberry	640	4.49	515.27	0	0	0	0	0	0	0
Crataegus	Hawthorn	640	5.34	613.25	0.58	66.5	17.02	39.58	0.01	76.02	31699.75
Fraxinus americana	White ash	640	279.19	32071.06	0	0	0	0	0	0	0
Fraxinus nigra	Black ash	3202	81.55	9367.64	2.25	258.51	107.89	250.82	0.03	481.76	111429.4
Fraxinus pennsylvanica	Green/red ash	4483	126.19	14494.9	8.22	944.08	583.16	1355.69	0.19	2603.99	1116173
Gleditsia triacanthos	Honey locust	1281	23.51	2700.07	3.4	390.57	83.76	194.72	0.03	374.02	130568.7
Juniperus spp.	Juniper	640	58.01	6663.37	2.97	341.09	300.57	698.75	0.1	1342.14	795050.3
Juglans nigra	Black walnut	7685	261.91	30085.2	26.34	3026.03	2665.62	6196.81	0.85	11902.76	1867171
Ostrya virginiana	Ironwood	8325	251.48	28887.93	15.97	1834.45	1448.32	3366.92	0.46	6467.13	1617993
Picea glauca	White spruce	6404	233.11	26777.62	17.69	2031.76	1598.66	3716.43	0.51	7138.47	1833550
Picea pungens	Blue spruce	640	9.31	1069.17	1.24	142.28	78.5	182.49	0.03	350.52	51380.37
Pinus strobus	Eastern white pine	2562	155.94	17912.38	5.47	628.19	842.29	1958.09	0.27	3761.08	1886112
Pinus sylvestris	Scots pine	640	26.43	3035.87	1.71	196.21	218	506.78	0.07	973.41	339716.2
Prunus spp.	Cherry	640	2.09	239.9	0.8	91.55	25.9	60.22	0.01	115.67	29118.14
Prunus avium	Sweet cherry	640	1.54	177.12	0.67	77.53	10.72	24.93	0	47.88	28217.58
Prunus serotina	Black cherry	1281	388.31	44605	19.38	2226.47	403.29	937.54	0.13	1800.81	2799342
Rhamnus cathartica	Common buckthorn	14729	95.86	11011.96	9.77	1122.75	545.78	1268.77	0.18	2437.05	835032.5

Species	Common Name	Trees	Carbon storage (tonnes)	Carbon storage (CAD)	Gross carbon sequestration (tonnes/year)	Gross carbon sequestration (CAD/year)	Avoided runoff (m³/year)	Avoided runoff (CAD/year)	Pollution removal (tonnes/year)	Pollution removal (CAD/year)	Structural Value (CAD)
Syringa reticulata	Japanese tree lilac	2562	13.55	1556.85	3.55	407.71	62.65	145.64	0.02	279.74	181721.2
Thuja occidentalis	Eastern white cedar	4483	274.39	31519.48	9.06	1041.01	1220.3	2836.84	0.39	5448.97	6375693
Tilia americana	Basswood	1281	167.43	19233.14	5.28	606.77	408.09	948.7	0.13	1822.25	2125005
Ulmus pumila	Siberian elm	1921	515.34	59197.47	15.22	1747.76	926.01	2152.7	0.3	4134.89	2551211
Total – Commercial	**N/A**	**101183**	**5675.3**	**651921.6**	**280.62**	**32234.95**	**18052.43**	**41966.73**	**5.79**	**80609.15**	**42858490**

FARM

Species	Common Name	Trees	Carbon storage (tonnes)	Carbon storage (CAD)	Gross carbon sequestration (tonnes/year)	Gross carbon sequestration (CAD/year)	Avoided runoff (m³/year)	Avoided runoff (CAD/year)	Pollution removal (tonnes/year)	Pollution removal (CAD/year)	Structural Value (CAD)
Acer negundo	Manitoba maple	22740	2413.58	277247.9	81.23	9330.85	4723.65	10981.14	1.51	21092.44	5351801
Acer nigrum	Black maple	541	0.69	79.15	0.18	21.02	20.39	47.39	0.01	91.03	8520.9
Acer rubrum	Red maple	7580	1176.44	135137.3	51.92	5964.55	3162.12	7351.02	1.01	14119.74	2549211
Acer saccharinum	Silver maple	3249	1202.14	138090.1	24.02	2759.02	809.63	1882.16	0.26	3615.23	992439.1
Acer saccharum	Sugar maple	3790	6551.54	752575.5	134.77	15480.8	3929.8	9135.67	1.26	17547.67	15795471
Amelanchier	Serviceberry	541	1.06	122.21	0.25	28.95	5.51	12.81	0	24.61	8841.71
Betula alleghaniensis	Yellow birch	541	17.27	1983.44	1.39	159.75	40.91	95.1	0.01	182.67	17025.06
Betula papyrifera	White birch	1083	31.06	3568.3	2.83	325.54	64.53	150.01	0.02	288.14	31417.87
Cornus racemosa	Grey dogwood	541	0.49	55.8	0.21	23.61	6.44	14.97	0	28.75	6529.76
Crataegus spp.	Hawthorn	541	12.5	1435.47	0.89	101.73	184.16	428.13	0.06	822.35	11598.3
Fagus grandifolia	American beech	541	4.13	473.85	0.7	80.55	30.49	70.88	0.01	136.15	9475.19
Fraxinus excelsior	European ash	1624	7.32	840.92	0.77	88.31	14.54	33.8	0	64.93	14943.73

Species	Common Name	Trees	Carbon storage (tonnes)	Carbon storage (CAD)	Gross carbon sequestration (tonnes/year)	Gross carbon sequestration (CAD/year)	Avoided runoff (m^3/year)	Avoided runoff (CAD/year)	Pollution removal (tonnes/year)	Pollution removal (CAD/year)	Structural Value (CAD)
Fraxinus nigra	Black ash	5414	245.94	28250.9	0	0	0	0	0	0	0
Fraxinus pennsylvanica	Green/red ash	94752	2974.92	341729.6	33.95	3899.31	1918.12	4459.07	0.62	8564.92	999336.4
Ilex verticillata	Winterberry	1083	3.82	438.82	0.49	55.72	35.51	82.54	0.01	158.55	15774.59
Juglans nigra	Black walnut	541	1.39	159.58	0.33	37.34	62.02	144.18	0.02	276.94	9069.11
Lonicera spp.	Honeysuckle	541	2.23	255.65	0.33	37.43	25.51	59.3	0.01	113.9	15774.59
Lonicera tatarica	Tatarian honeysuckle	2166	6.71	771.16	0.95	108.69	34.7	80.66	0.01	154.93	29261.86
Malus domestica	Common apple	2166	408.36	46908.46	11.34	1302.17	256.87	597.16	0.08	1147.01	613910.8
Ostrya virginiana	Ironwood	10287	352.71	40516.1	21.12	2426.04	1159.73	2696.04	0.37	5178.52	725003.6
Pinus strobus	Eastern white pine	13536	417.42	47949.24	23.18	2662.57	2982.96	6934.52	0.96	13319.74	1830781
Pinus sylvestris	Scots pine	541	0.83	95.9	0.2	22.6	26.35	61.25	0.01	117.65	7174.07
Populus x canadensis	Carolina poplar	4873	734.26	84343.9	24.2	2779.68	622.29	1446.65	0.2	2778.71	954903.3
Populus tremuloides	Trembling aspen	541	137.21	15761.33	5.97	686.12	217.18	504.88	0.07	969.76	314216.2
Prunus serotina	Black cherry	541	3.6	413.51	1.02	117.2	8.35	19.41	0	37.29	7805.75
Pyrus spp.	Pear	541	27.12	3115.25	0	0	0	0	0	0	0
Pyrus communis	Common pear	10829	532.51	61169.07	33.35	3831.01	824.11	1915.81	0.26	3679.86	1295005
Rhamnus cathartica	Common buckthorn	89338	575.3	66084.71	62.37	7164.04	2012.66	4678.85	0.65	8987.08	1562084
Frangula alnus	Glossy buckthorn	23282	73.84	8481.75	10.66	1224.24	469.06	1090.42	0.15	2094.47	315637.8
Robinia pseudoacacia	Black locust	1083	274.62	31545.22	11.42	1311.35	663.49	1542.43	0.21	2962.67	610174.2
Salix spp.	Willow	1083	0.68	78.41	0.3	34.05	9.79	22.75	0	43.69	10828.79
Thuja occidentalis	Eastern white cedar	1083	29.76	3418.92	0.86	98.81	14.09	32.75	0	62.9	166996.7
Tilia americana	Basswood	14619	598.92	68797.61	32.41	3722.42	2440.18	5672.72	0.78	10896.09	3228471
Tsuga canadensis	Eastern hemlock	3790	1625.15	186681.1	24.16	2775.41	2336.76	5432.29	0.75	10434.28	4682540

Species	Common Name	Trees	Carbon storage (tonnes)	Carbon storage (CAD)	Gross carbon sequestration (tonnes/year)	Gross carbon sequestration (CAD/year)	Avoided runoff (m³/year)	Avoided runoff (CAD/year)	Pollution removal (tonnes/year)	Pollution removal (CAD/year)	Structural Value (CAD)
Ulmus americana	American elm	1624	28.64	3289.42	0.33	38.47	56.19	130.62	0.02	250.9	7812.29
Viburnum lantana	Wayfaring tree	10287	16.78	1927.65	3.43	394.55	85.55	198.88	0.03	382	137869.9
Total – Farm	**N/A**	**337858**	**20490.93**	**2353793**	**601.5**	**69093.89**	**29253.61**	**68006.26**	**9.38**	**130625.6**	**42337706**

INDUSTRIAL

Species	Common Name	Trees	Carbon storage (tonnes)	Carbon storage (CAD)	Gross carbon sequestration (tonnes/year)	Gross carbon sequestration (CAD/year)	Avoided runoff (m³/year)	Avoided runoff (CAD/year)	Pollution removal (tonnes/year)	Pollution removal (CAD/year)	Structural Value (CAD)
Acer negundo	Manitoba maple	7021	71.67	8232.73	4.93	565.89	254.68	592.05	0.08	1137.2	144775.2
Acer saccharum	Sugar maple	2006	21.54	2474.52	5.13	588.82	200.74	466.67	0.06	896.37	149513.5
Alnus glutinosa	Black alder	6018	26.45	3037.79	5.28	606.11	89.9	208.98	0.03	401.41	68581.87
Amelanchier	Serviceberry	1003	1.72	197.42	0.48	54.59	10.2	23.72	0	45.55	17803.7
Elaeagnus angustifolia	Russian olive	1003	7.38	847.73	1.64	188.42	95.88	222.9	0.03	428.15	12918.97
Fraxinus americana	White ash	8024	194.29	22318.17	0.25	28.72	14	32.54	0	62.51	2136.44
Fraxinus pennsylvanica	Green/red ash	4012	35.81	4113.47	2.65	304.47	137.79	320.33	0.04	615.28	55948.27
Juglans nigra	Black walnut	10030	1532.24	176007.9	68.21	7835.27	6557.76	15244.92	2.1	29282.24	10117218
Juniperus virginiana	Eastern red cedar	1003	51.47	5912.52	1.67	191.84	206.22	479.41	0.07	920.84	133208.4
Larix laricina	Tamarack	2006	9.45	1085.18	1.18	135.95	139.75	324.87	0.04	624.01	36162.62
Picea glauca	White spruce	11033	1149.72	132068.6	48.16	5532.12	5847.67	13594.15	1.88	26111.47	13432408
Pinus nigra	Austrian pine	1003	88.31	10144.13	4.42	507.44	387.48	900.78	0.12	1730.21	2214072
Picea pungens	Blue spruce	1003	253.31	29097.26	9.9	1136.73	871.29	2025.5	0.28	3890.56	879469.4
Prunus avium	Sweet cherry	1003	0.7	80.18	0.24	27.74	16.17	37.6	0.01	72.22	11785.55
Prunus serotina	Black cherry	1003	1.01	116.25	0.3	34.62	5.3	12.33	0	23.68	14460.29

Species	Common Name	Trees	Carbon storage (tonnes)	Carbon storage (CAD)	Gross carbon sequestration (tonnes/year)	Gross carbon sequestration (CAD/year)	Avoided runoff (m³/year)	Avoided runoff (CAD/year)	Pollution removal (tonnes/year)	Pollution removal (CAD/year)	Structural Value (CAD)
Quercus rubra	Red oak	1003	53.31	6124.08	5.7	655.21	450.85	1048.09	0.14	2013.16	479862.2
Rhamnus cathartica	Common buckthorn	33100	281.25	32307.22	33.89	3893.41	1055.11	2452.82	0.34	4711.35	1202831
Salix spp.	Willow	9027	1694.32	194626.3	54.06	6210.31	2444.96	5683.83	0.78	10917.43	7835070
Thuja occidentalis	Eastern white cedar	13039	218.73	25125.28	13.65	1568.24	1239.53	2881.55	0.4	5534.84	1176816
Total – Industrial	**N/A**	**113342**	**5692.67**	**653916.8**	**261.74**	**30065.9**	**20025.28**	**46553.04**	**6.42**	**89418.48**	**37985042**

INSTITUTIONAL

Species	Common Name	Trees	Carbon storage (tonnes)	Carbon storage (CAD)	Gross carbon sequestration (tonnes/year)	Gross carbon sequestration (CAD/year)	Avoided runoff (m³/year)	Avoided runoff (CAD/year)	Pollution removal (tonnes/year)	Pollution removal (CAD/year)	Structural Value (CAD)
Acer negundo	Manitoba maple	754	48.56	5577.93	2.92	335.7	223.17	518.81	0.07	996.52	83418.77
Acer platanoides	Norway maple	2263	855.84	98310.64	23.04	2646.67	1253.71	2914.52	0.4	5598.18	7949031
Acer pseudoplatanus	Sycamore maple	754	159.59	18332.64	5.5	632.02	514.04	1194.98	0.16	2295.31	1261054
Acer rubrum	Red maple	3772	132.62	15234.45	10.24	1176.77	972.88	2261.66	0.31	4344.18	951655
Acer saccharum	Sugar maple	15089	2865.22	329127.9	86.1	9890.24	4468.35	10387.64	1.43	19952.44	5467732
Carya cordiformis	Bitternut hickory	754	0.36	41	0.1	11.64	0.52	1.2	0	2.31	37579.25
Cornus alternifolia	Alternate leaf dogwood	4527	8.56	983.71	1.72	197.88	270.25	628.24	0.09	1206.72	305556.9
Fagus sylvatica 'Purpurea'	Copper beech	1509	64.03	7355.55	7.61	874.67	1006.52	2339.87	0.32	4494.4	415208.3
Fraxinus americana	White ash	24897	514.23	59069.17	27.01	3102.57	1465.24	3406.26	0.47	6542.69	2230870
Fraxinus nigra	Black ash	2263	196.61	22585.16	0.22	25.36	11.13	25.88	0	49.71	41023.84

Species	Common Name	Trees	Carbon storage (tonnes)	Carbon storage (CAD)	Gross carbon sequestration (tonnes/year)	Gross carbon sequestration (CAD/year)	Avoided runoff (m³/year)	Avoided runoff (CAD/year)	Pollution removal (tonnes/year)	Pollution removal (CAD/year)	Structural Value (CAD)
Fraxinus pennsylvanica	Green/red ash	36969	1307.75	150221.1	24.25	2785.91	1460.32	3394.84	0.47	6520.76	1800203
Gleditsia triacanthos	Honey locust	754	431.87	49609.27	8.44	969.99	201.9	469.36	0.06	901.54	2683532
Gymnocladus dioicus	Kentucky coffee tree	1509	59.31	6812.81	5.25	603.57	559.05	1299.64	0.18	2496.33	652173.6
Juglans nigra	Black walnut	1509	584.86	67183.13	13.64	1567.28	1180.55	2744.44	0.38	5271.49	1126587
Picea abies	Norway spruce	2263	2197.11	252381.6	40.56	4659.29	3008.21	6993.23	0.96	13432.51	24361174
Pinus mugo	Dwarf mountain pine	754	12.48	1433.87	0.98	112.58	195.24	453.88	0.06	871.81	96130.71
Pinus nigra	Austrian pine	754	869.05	99827.75	9.78	1123.17	1891.74	4397.76	0.61	8447.17	11295933
Picea pungens	Blue spruce	1509	928.9	106702.4	21.2	2435.07	1954.16	4542.86	0.63	8725.88	11456763
Pinus strobus	Eastern white pine	754	1.56	179.45	0.28	32.41	12.6	29.3	0	56.28	53048.07
Populus balsamifera	Balsam poplar	2263	2.72	312.88	0.46	52.78	17.75	41.25	0.01	79.24	54887.07
Populus deltoides	Eastern cottonwood	1509	52.66	6049.38	0	0	0	0	0	0	0
Populus grandidentata	Large tooth aspen	4527	855.63	98286.42	37.11	4263.24	1797.7	4179.15	0.58	8027.25	6378127
Populus tremuloides	Trembling aspen	11317	1199.34	137768.3	53.38	6131.25	2367.47	5503.7	0.76	10571.43	9746583
Prunus serotina	Black cherry	1509	80.87	9289.09	8.35	959.3	724.91	1685.22	0.23	3236.95	520510.1
Pyrus calleryana	Callery pear	754	20.6	2366.29	2.85	327.3	153.75	357.42	0.05	686.53	104256.8
Quercus macrocarpa	Bur oak	754	138.91	15956.3	8.93	1025.87	705.97	1641.19	0.23	3152.37	1696465
Quercus robur	English oak	754	49.39	5673.26	5.03	577.66	322.86	750.57	0.1	1441.68	518887.3
Quercus rubra	Red oak	754	46.01	5284.86	2.92	335.18	178.53	415.04	0.06	797.19	324302.3
Rhamnus cathartica	Common buckthorn	62620	309.77	35583.8	33.79	3881.44	2078.97	4833	0.67	9283.17	3224253
Frangula alnus	Glossy buckthorn	9808	16.55	1900.99	3.46	397	137.99	320.78	0.04	616.15	426154.4

Species	Common Name	Trees	Carbon storage (tonnes)	Carbon storage (CAD)	Gross carbon sequestration (tonnes/year)	Gross carbon sequestration (CAD/year)	Avoided runoff (m³/year)	Avoided runoff (CAD/year)	Pollution removal (tonnes/year)	Pollution removal (CAD/year)	Structural Value (CAD)
Rhus hirta	Staghorn sumac	3772	13.53	1553.85	0	0	0	0	0	0	0
Salix spp.	Willow	1509	34.83	4001.12	2.21	254.21	24.82	57.69	0.01	110.81	6794.27
Syringa spp.	Lilac	4527	77.62	8915.72	5.71	655.55	303.62	705.82	0.1	1355.73	467400.6
Thuja occidentalis	Eastern white cedar	18107	282.01	32394.7	17.45	2004.25	1345.04	3126.84	0.43	6005.99	4566160
Tilia americana	Basswood	1509	466.29	53563.14	10.96	1259.36	1081.59	2514.39	0.35	4829.61	2965266
Ulmus americana	American elm	754	7.93	911.47	0.68	78.07	171.03	397.6	0.05	763.7	10704.48
Total – Institutional	**N/A**	**230111**	**14893.19**	**1710781**	**482.16**	**55385.26**	**32061.6**	**74534.04**	**10.28**	**143164**	**103279424.5**

MULTI-RESIDENTIAL

Species	Common Name	Trees	Carbon storage (tonnes)	Carbon storage (CAD)	Gross carbon sequestration (tonnes/year)	Gross carbon sequestration (CAD/year)	Avoided runoff (m³/year)	Avoided runoff (CAD/year)	Pollution removal (tonnes/year)	Pollution removal (CAD/year)	Structural Value (CAD)
Abies alba	White fir	223	31.09	3571.02	0.95	109.4	218.82	508.7	0.07	977.11	235306.1
Acer ginnala	Amur maple	112	30.71	3527.18	0.89	102.69	73.38	170.58	0.02	327.65	211221.3
Acer platanoides	Norway maple	781	402.78	46267.42	9.79	1124.75	966.45	2246.71	0.31	4315.45	2564365
Acer saccharinum	Silver maple	112	78.37	9002	2.01	230.32	217.64	505.95	0.07	971.83	528452.2
Acer saccharum	Sugar maple	112	17.76	2040.44	0.71	81.62	94.46	219.6	0.03	421.8	77744.17
Betula papyrifera	White birch	223	29.79	3422.22	1.51	173.88	93.97	218.44	0.03	419.58	120398.9
Gleditsia triacanthos	Honey locust	223	54.99	6316.14	2.69	308.72	94.84	220.48	0.03	423.49	394327.9
Hibiscus syriacus	Rose of Sharon	112	0.25	28.3	0.05	6	1.99	4.64	0	8.91	4241.38
Juniperus chinensis	Chinese juniper	112	1.46	167.68	0.17	19.25	8.05	18.71	0	35.93	9225.12
Malus tschonoskii	Flowering crab apple	112	39.59	4548.18	1	114.67	105.42	245.07	0.03	470.72	184596.5
Picea glauca	White spruce	112	9.31	1068.93	0.6	69.48	78.2	181.8	0.03	349.2	82105.24

Species	Common Name	Trees	Carbon storage (tonnes)	Carbon storage (CAD)	Gross carbon sequestration (tonnes/year)	Gross carbon sequestration (CAD/year)	Avoided runoff (m³/year)	Avoided runoff (CAD/year)	Pollution removal (tonnes/year)	Pollution removal (CAD/year)	Structural Value (CAD)
Pinus nigra	Austrian pine	223	29.51	3389.28	1.25	143.6	182.78	424.91	0.06	816.17	455911.2
Picea pungens	Blue spruce	223	11.58	1329.94	0.96	109.82	76.95	178.89	0.02	343.61	91587.32
Pinus strobus	Eastern white pine	112	0.51	58.82	0.11	12.18	7.66	17.82	0	34.23	6274.96
Pinus sylvestris	Scots pine	223	19.78	2271.86	1.01	116.11	132.67	308.42	0.04	592.4	297255
Rhamnus cathartica	Common buckthorn	112	0.14	16.48	0.03	3.86	1.86	4.31	0	8.29	4728.9
Sorbus aucuparia	European mountain ash	223	11.55	1326.24	0.96	110.14	38.75	90.09	0.01	173.04	64047.54
Syringa vulgaris	Common lilac	223	8	918.55	0.77	87.89	33.87	78.73	0.01	151.23	57522
Thuja occidentalis	Eastern white cedar	223	4.99	573.27	0.38	43.96	32.97	76.65	0.01	147.23	63328.68
Tilia cordata	Littleleaf linden	112	1	114.46	0.19	21.87	17.61	40.94	0.01	78.63	7190.42
Total – Multi-residential	**N/A**	**3904**	**783.13**	**89958.41**	**26.03**	**2990.19**	**2478.34**	**5761.44**	**0.79**	**11066.5**	**5459830**

RESIDENTIAL

Species	Common Name	Trees	Carbon storage (tonnes)	Carbon storage (CAD)	Gross carbon sequestration (tonnes/year)	Gross carbon sequestration (CAD/year)	Avoided runoff (m³/year)	Avoided runoff (CAD/year)	Pollution removal (tonnes/year)	Pollution removal (CAD/year)	Structural Value (CAD)
Abies balsamea	Balsam fir	6940	386.99	44453.34	12.35	1418.36	727.87	1692.09	0.23	3250.15	1809220
Acer x freemanii	Freeman maple	2776	289.91	33302.03	12.04	1383.11	336.24	781.66	0.11	1501.4	1713591
Acer negundo	Manitoba maple	13881	2119.22	243434.9	82.02	9421.47	5820.63	13531.29	1.87	25990.73	8607594
Acer palmatum	Japanese maple	1388	122.19	14035.85	5.6	642.82	403.11	937.12	0.13	1800.01	711680
Acer platanoides	Norway maple	72180	11259.31	1293357	408.93	46973.6	29093.09	67633.1	9.33	129908.8	79480214
Acer saccharinum	Silver maple	2776	2189.75	251536.1	57.63	6619.67	6167.15	14336.85	1.98	27538.04	15568935

Species	Common Name	Trees	Carbon storage (tonnes)	Carbon storage (CAD)	Gross carbon sequestration (tonnes/year)	Gross carbon sequestration (CAD/year)	Avoided runoff (m³/year)	Avoided runoff (CAD/year)	Pollution removal (tonnes/year)	Pollution removal (CAD/year)	Structural Value (CAD)
Acer saccharum	Sugar maple	2776	853.47	98038.34	18.31	2103.41	1337.37	3108.99	0.43	5971.71	2714985
Aesculus hippocastanum	Horsechestnut	1388	19.92	2288.51	2.13	244.6	147.01	341.76	0.05	656.44	72765.94
Amelanchier	Serviceberry	1388	6.37	731.48	0.89	101.86	17.97	41.76	0.01	80.22	73915.25
Amelanchier arborea	Downy serviceberry	5552	24.79	2847.71	5.95	683.55	160.42	372.94	0.05	716.34	293864.6
Betula papyrifera	White birch	6940	3643.95	418580.8	163.48	18779.43	8798.84	20454.77	2.82	39289.27	19281397
Betula pendula	European birch	2776	184.64	21209.5	8.85	1017.07	2160.88	5023.44	0.69	9648.95	176855.8
Cercis canadensis	Eastern redbud	1388	21.49	2469.1	3.45	396.28	83.94	195.14	0.03	374.83	106303.5
Cornus racemosa	Grey dogwood	2776	8.01	919.62	1.34	154.19	93.76	217.97	0.03	418.67	147663.9
Euonymus alatus	Winged euonymus	1388	2.94	337.64	0.74	84.65	36.24	84.24	0.01	161.81	37610.19
Fraxinus	Ash	1388	16.14	1853.48	0	0	0	0	0	0	0
Fraxinus americana	White ash	11105	1469.65	168819.1	38.29	4398.15	2639.72	6136.59	0.85	11787.09	5422348
Fraxinus pennsylvanica	Green/red ash	5552	335.89	38583.88	1.14	130.76	38.96	90.56	0.01	173.96	95777.51
Gleditsia triacanthos	Honey locust	1388	689.62	79216.85	28.53	3277.69	777.05	1806.41	0.25	3469.74	5128951
Hibiscus syriacus	Rose of Sharon	1388	0.84	96.86	0.37	42.88	45.87	106.65	0.01	204.84	60661.6
Juniperus chinensis	Chinese juniper	4164	19.15	2199.41	2.04	234.75	98.76	229.59	0.03	440.99	152864
Juglans nigra	Black walnut	9717	810.67	93122.18	42.53	4885	5212.51	12117.6	1.67	23275.33	5127372
Ligustrum vulgare	Common privet	5552	37.51	4308.6	2.46	282.6	32.07	74.56	0.01	143.22	155293.7
Lonicera xylosteum	Fly honeysuckle	2776	16.11	1850.43	1.76	201.7	24.78	57.61	0.01	110.66	121323.2
Malus domestica	Common apple	1388	202.21	23228.13	13.44	1543.9	819.85	1905.93	0.26	3660.88	1397223
Malus tschonoskii	Flowering crab apple	1388	366.04	42046.5	10.4	1194.53	498.72	1159.38	0.16	2226.92	1791838
Morus alba	White mulberry	2776	42.17	4844.45	7.43	853.63	91.92	213.69	0.03	410.46	203106.4

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Morus rubra	Red mulberry	1388	95.21	10937.26	8.89	1021.07	66.99	155.74	0.02	299.14	718518.9
Physocarpus opulifolius	Common ninebark	5552	7.36	845.24	1.18	135.68	27.28	63.42	0.01	121.82	126782.7
Picea abies	Norway spruce	4164	408.84	46963.08	21.92	2518.52	3683.66	8563.46	1.18	16448.58	3618739
Picea glauca	White spruce	9717	313.07	35962.64	22.77	2616.03	2616.62	6082.89	0.84	11683.93	2316718
Pinus glabra	Spruce pine	4164	46.88	5385.38	5.71	655.38	535.03	1243.79	0.17	2389.05	353418.3
Picea mariana	Black spruce	2776	41.41	4756.74	3.28	376.84	392.19	911.73	0.13	1751.25	129437.7
Picea pungens	Blue spruce	9717	1003.33	115252.9	51.17	5877.89	5067.6	11780.71	1.63	22628.24	9857703
Pinus strobus	Eastern white pine	12493	584.02	67085.92	31.92	3666.69	3528.93	8203.74	1.13	15757.64	3556275
Pinus sylvestris	Scots pine	1388	2.15	246.59	0.64	73.24	16.82	39.09	0.01	75.09	55176.17
Prunus avium	Sweet cherry	2776	17.5	2009.86	1.85	212.15	18.09	42.05	0.01	80.77	48929.81
Prunus serotina	Black cherry	16657	1921.18	220686	113.5	13037.58	3401.2	7906.82	1.09	15187.31	10065959
Pyrus communis	Common pear	1388	54.36	6244.23	6.44	739.68	68.43	159.07	0.02	305.54	388265.2
Quercus bicolor	Swamp white oak	1388	1582.14	181740.7	49.58	5695.75	3103.74	7215.3	1	13859.05	11042319
Quercus robur	English oak	1388	11.61	1333.41	2.69	308.54	46.27	107.57	0.01	206.62	100351.7
Quercus robur 'Fastigiata'	Upright English oak	8328	2390.58	274606	56.17	6452.51	157.01	365	0.05	701.09	10578098
Quercus rubra	Red oak	1388	150.51	17288.69	12.29	1412.11	1137.48	2644.32	0.36	5079.17	1371889
Rhamnus cathartica	Common buckthorn	77732	654.41	75172.47	64.02	7354.37	2152.15	5003.14	0.69	9609.96	4013126
Frangula alnus	Glossy buckthorn	2776	2.94	337.97	0.77	88.71	123.5	287.09	0.04	551.44	40441.06
Rhus hirta	Staghorn sumac	2776	53.58	6154.47	7.83	899.88	171.08	397.7	0.05	763.9	241700.3
Rosa spp.	Rose	2776	31.18	3581.14	5.62	645.89	74.46	173.09	0.02	332.47	127644.1
Salix spp.	Willow	1388	910.88	104633.3	29.03	3334.14	1186.29	2757.78	0.38	5297.1	3785569
Salix matsudana	Chinese willow	1388	30.9	3549.15	4.68	537.07	191.27	444.64	0.06	854.06	114817.8
Sorbus americana	American mountain ash	2776	11.73	1347.6	1.52	174.52	18.54	43.1	0.01	82.79	124927.2

Species	Common Name	Trees	Carbon storage (tonnes)	Carbon storage (CAD)	Gross carbon sequestration (tonnes/year)	Gross carbon sequestration (CAD/year)	Avoided runoff (m³/year)	Avoided runoff (CAD/year)	Pollution removal (tonnes/year)	Pollution removal (CAD/year)	Structural Value (CAD)
Sorbus aucuparia	European mountain ash	1388	64.12	7365.46	2.78	319.04	157.18	365.4	0.05	701.86	269786.4
Syringa reticulata	Japanese tree lilac	2776	28.2	3239.61	4.91	564.05	118.16	274.69	0.04	527.62	237023.2
Syringa vulgaris	Common lilac	30538	763.81	87738.64	13.11	1505.69	251.93	585.66	0.08	1124.93	2373732
Taxus baccata	English yew	1388	75.03	8619.1	2.23	256.49	614.72	1429.04	0.2	2744.89	774058.1
Taxodium distichum	Bald cypress	1388	7.72	886.54	1.57	180.89	71.78	166.87	0.02	320.52	70583.86
Thuja occidentalis	Eastern white cedar	194331	2493.18	286392.1	134.35	15432.32	10126.96	23542.28	3.25	45219.71	19254277
Tilia americana	Basswood	6940	343.08	39410.02	18.05	2073.87	1482.98	3447.5	0.48	6621.91	3935907
Tilia cordata	Littleleaf linden	12493	2958.36	339826.9	96.38	11071.37	8521.03	19808.95	2.73	38048.77	31482919
Ulmus americana	American elm	5552	714.09	82027.55	24.77	2845	2063.82	4797.79	0.66	9215.52	4557207
Total	**N/A**	**607979**	**42912.32**	**4929338**	**1733.72**	**199152.6**	**116857.9**	**271661.1**	**37.47**	**521803.2**	**2.76E+08**

SPECIAL & EXEMPT

Species	Common Name	Trees	Carbon storage (tonnes)	Carbon storage (CAD)	Gross carbon sequestration (tonnes/year)	Gross carbon sequestration (CAD/year)	Avoided runoff (m³/year)	Avoided runoff (CAD/year)	Pollution removal (tonnes/year)	Pollution removal (CAD/year)	Structural Value (CAD)
Acer negundo	Manitoba maple	308	105.25	12090.21	3.85	442.79	244.15	567.58	0.08	1090.19	554287.6
Acer platanoides	Norway maple	7398	723.09	83061.04	36.3	4169.39	2655.32	6172.87	0.85	11856.77	5283195
Acer saccharum	Sugar maple	308	25.99	2985.83	2.11	242.92	48.06	111.72	0.02	214.59	187938.8
Amelanchier	Serviceberry	1233	12.04	1383.22	0.3	34.79	3.51	8.16	0	15.67	34676.42
Betula alleghaniensis	Yellow birch	925	278.04	31938.72	9.52	1093.75	540.34	1256.13	0.17	2412.76	598341
Berberis vulgaris	Common barberry	617	2.68	308.3	0.44	50.09	19.41	45.11	0.01	86.66	8981.03

Species	Common Name	Trees	Carbon storage (tonnes)	Carbon storage (CAD)	Gross carbon sequestration (tonnes/year)	Gross carbon sequestration (CAD/year)	Avoided runoff (m³/year)	Avoided runoff (CAD/year)	Pollution removal (tonnes/year)	Pollution removal (CAD/year)	Structural Value (CAD)
Cornus alternifolia	Alternate leaf dogwood	617	2.92	335.67	0.46	52.29	31.57	73.4	0.01	140.98	10930.92
Fraxinus americana	White ash	7090	466.62	53601.07	2.16	247.59	214.83	499.41	0.07	959.26	226982.6
Fraxinus pennsylvanica	Green/red ash	3083	102.37	11759.77	3.41	392.28	210.25	488.76	0.07	938.81	191844.7
Juglans nigra	Black walnut	3391	571.84	65687.29	27.41	3149.03	3464.23	8053.35	1.11	15468.78	5362358
Lonicera spp.	Honeysuckle	925	19.79	2273.03	0.69	79.63	10.95	25.45	0	48.89	35794.21
Lonicera tatarica	Tatarian honeysuckle	308	0.54	61.68	0.14	15.55	0.66	1.53	0	2.94	4131.27
Malus spp.	Apple	617	29.24	3359.16	2.47	283.34	137.49	319.63	0.04	613.94	221309.1
Phellodendron amurense	Amur cork tree	925	53.54	6150.25	5.21	598.64	313.28	728.3	0.1	1398.9	537757.7
Picea abies	Norway spruce	308	67.61	7766.36	2.44	280.08	167.22	388.74	0.05	746.69	700186.6
Pinus nigra	Austrian pine	308	88.37	10151.08	2.87	329.59	274.61	638.38	0.09	1226.19	1666057
Pinus sylvestris	Scots pine	308	0.4	45.87	0.11	13	7.64	17.76	0	34.1	3961.92
Populus balsamifera	Balsam poplar	2774	1.54	177.22	1.02	117.37	32.44	75.42	0.01	144.86	100916.8
Populus nigra v. italica	Black poplar	20037	13.32	1530.33	7.27	835.67	266.77	620.17	0.09	1191.22	745469.8
Populus tremuloides	Trembling aspen	5857	128.12	14717.53	11.68	1341.77	259.91	604.21	0.08	1160.56	279966.4
Prunus virginiana	Chokecherry	4007	4.97	570.34	1.01	116.28	49.14	114.23	0.02	219.42	41775.47
Quercus rubra	Red oak	308	23.02	2644.7	1.91	219.17	162.74	378.32	0.05	726.67	212842.5
Rhamnus cathartica	Common buckthorn	22195	184.9	21239.56	17.85	2050.98	528.02	1227.5	0.17	2357.76	962782.7
Frangula alnus	Glossy buckthorn	1233	3.71	425.89	0.68	77.56	27.08	62.96	0.01	120.93	17423.2
Syringa vulgaris	Common lilac	25277	97.37	11185.32	12.88	1479.54	148.37	344.93	0.05	662.53	1506428
Thuja occidentalis	Eastern white cedar	5857	53.95	6196.89	3.64	418.3	165.35	384.39	0.05	738.33	217633.5
Tilia americana	Basswood	1541	30.09	3456.73	3.06	351.74	372.55	866.07	0.12	1663.53	82850.19
Ulmus americana	American elm	1541	113.23	13006.58	6.03	692.72	565.83	1315.39	0.18	2526.58	995372.6

Species	Common Name	Trees	Carbon storage (tonnes)	Carbon storage (CAD)	Gross carbon sequestration (tonnes/year)	Gross carbon sequestration (CAD/year)	Avoided runoff (m³/year)	Avoided runoff (CAD/year)	Pollution removal (tonnes/year)	Pollution removal (CAD/year)	Structural Value (CAD)
Total – Special & Exempt	**N/A**	**119297**	**3204.58**	**368109.6**	**166.94**	**19175.85**	**10921.71**	**25389.86**	**3.5**	**48768.51**	**20792196**

VACANT

Species	Common Name	Trees	Carbon storage (tonnes)	Carbon storage (CAD)	Gross carbon sequestration (tonnes/year)	Gross carbon sequestration (CAD/year)	Avoided runoff (m³/year)	Avoided runoff (CAD/year)	Pollution removal (tonnes/year)	Pollution removal (CAD/year)	Structural Value (CAD)
Abies balsamea	Balsam fir	72716	1187.22	136376.4	76.77	8818.31	2321	5395.66	0.74	10363.91	1488570
Acer x freemanii	Freeman maple	2693	43.46	4992.2	6.35	729.66	706.68	1642.83	0.23	3155.52	198114.7
Acer negundo	Manitoba maple	30972	9651.1	1108622	184.28	21168.54	10222.74	23764.94	3.28	45647.38	17587550
Acer nigrum	Black maple	1347	241.34	27723.14	14.36	1649.61	1375.23	3197.01	0.44	6140.78	1905162
Acer platanoides	Norway maple	5386	584.53	67144.46	28.69	3295.16	2295.17	5335.62	0.74	10248.59	4005393
Acer rubrum	Red maple	10773	8498.54	976227.2	248.03	28491.28	10974.84	25513.36	3.52	49005.73	17785438
Acer saccharinum	Silver maple	8080	93.92	10788.85	11.91	1368.59	775.35	1802.47	0.25	3462.16	177588.3
Acer saccharum	Sugar maple	55210	14568.39	1673471	364.16	41830.66	20875.01	48528.41	6.69	93212.75	29083274
Amelanchier arborea	Downy serviceberry	36358	341.8	39262.41	32.52	3735.73	415.67	966.32	0.13	1856.1	735542.8
Betula papyrifera	White birch	1347	0.79	90.45	0.24	27.43	15.27	35.5	0	68.19	51840.42
Cornus alternifolia	Alternate leaf dogwood	1347	54.46	6255.96	3.42	392.61	179.45	417.17	0.06	801.29	57234.3
Crataegus spp.	Hawthorn	21545	1515.72	174110.5	55.78	6407.12	986.48	2293.29	0.32	4404.93	2281743
Crataegus mollis	Downy hawthorn	1347	125.15	14375.63	5.48	629.73	206.42	479.88	0.07	921.74	203062.3
Crataegus punctata	Dotted hawthorn	13466	500.79	57525.74	25.8	2963.76	898.19	2088.03	0.29	4010.66	642923.3
Fraxinus americana	White ash	10773	307.45	35317.19	22.03	2530.3	430.18	1000.05	0.14	1920.88	1366243

Species	Common Name	Trees	Carbon storage (tonnes)	Carbon storage (CAD)	Gross carbon sequestration (tonnes/year)	Gross carbon sequestration (CAD/year)	Avoided runoff (m³/year)	Avoided runoff (CAD/year)	Pollution removal (tonnes/year)	Pollution removal (CAD/year)	Structural Value (CAD)
Fraxinus nigra	Black ash	12119	15.03	1726.3	3.31	380.03	140.07	325.63	0.04	625.46	156009.4
Fraxinus pennsylvanica	Green/red ash	150818	4484.47	515130.7	130.32	14969.58	3974.83	9240.35	1.27	17748.75	4156284
Juniperus	Juniper	1347	83.07	9542.39	0.71	82.12	397.73	924.61	0.13	1775.97	94123.91
Juglans nigra	Black walnut	9426	2555.27	293524	67.47	7749.86	5422.49	12605.73	1.74	24212.92	15364321
Larix laricina	Tamarack	5386	195.44	22450.35	11.54	1325.56	352.46	819.37	0.11	1573.84	1813753
Lonicera spp.	Honeysuckle	4040	39.71	4562.05	3.56	409.42	106.48	247.55	0.03	475.48	74792.8
Malus domestica	Common apple	8080	654.83	75219.85	7.23	830.19	224.41	521.68	0.07	1002.03	396550.6
Morus rubra	Red mulberry	1347	36.54	4197.24	4.88	560.81	94.3	219.21	0.03	421.06	130065.3
Ostrya virginiana	Ironwood	13466	257.99	29635.45	20.23	2324.21	2593.36	6028.83	0.83	11580.1	707939.5
Picea spp.	Spruce	1347	81.52	9364.32	0	0	0	0	0	0	0
Picea abies	Norway spruce	36358	4616	530239.7	163.86	18822.65	8505.92	19773.84	2.73	37981.34	24221131
Pinus resinosa	Red pine	44438	4202.33	482722	116.04	13329.06	1925.32	4475.82	0.62	8597.09	10394946
Pinus strobus	Eastern white pine	79449	3324.74	381912.4	124.76	14331.32	9023.63	20977.35	2.89	40293.02	14470060
Pinus sylvestris	Scots pine	1347	116.81	13417.54	6.04	693.34	832.14	1934.49	0.27	3715.74	522030.2
Populus balsamifera	Balsam poplar	21545	991.58	113903	25.48	2927.34	959.79	2231.23	0.31	4285.72	740649.8
Populus deltoides	Eastern cottonwood	8080	896.9	103027.1	24.43	2805.88	1285.17	2987.66	0.41	5738.66	909696.9
Populus nigra v. italica	Black poplar	5386	6.15	706.78	3.05	350.12	124.5	289.43	0.04	555.94	203337.8
Populus tremuloides	Trembling aspen	71369	3117.64	358123.6	186	21365.81	7794.41	18119.76	2.5	34804.21	7642547
Prunus serotina	Black cherry	2693	728.79	83716.43	13.93	1600.19	300.4	698.35	0.1	1341.39	720703.3
Prunus virginiana	Chokecherry	1347	2.68	307.49	0.53	61.37	8.04	18.69	0	35.9	17344.1
Pyrus communis	Common pear	1347	483.09	55492.25	0	0	0	0	0	0	0
Quercus rubra	Red oak	1347	3.86	443.27	1.47	168.94	66.53	154.66	0.02	297.08	26450.43
Rhamnus cathartica	Common buckthorn	274705	3136.24	360260	219.76	25243.41	7892.48	18347.75	2.53	35242.13	5753433

Species	Common Name	Trees	Carbon storage (tonnes)	Carbon storage (CAD)	Gross carbon sequestration (tonnes/year)	Gross carbon sequestration (CAD/year)	Avoided runoff (m³/year)	Avoided runoff (CAD/year)	Pollution removal (tonnes/year)	Pollution removal (CAD/year)	Structural Value (CAD)
Frangula alnus	Glossy buckthorn	2693	11.42	1312.08	1.08	124.22	128.62	299.01	0.04	574.34	19616.17
Salix alba	White willow	5386	13980.59	1605951	205.62	23619.41	3527.63	8200.73	1.13	15751.86	16132245
Salix x sepulcralis	Weeping golden willow	1347	5685.61	653106	66.38	7625.48	2770.41	6440.41	0.89	12370.66	16479715
Syringa vulgaris	Common lilac	2693	2.32	266.89	0.66	75.79	33.36	77.55	0.01	148.96	160162
Thuja occidentalis	Eastern white cedar	381085	14048.65	1613768	336.75	38682.9	52258.15	121485.2	16.76	233347.3	68341485
Tilia americana	Basswood	21545	1318.48	151454.2	53.65	6162.29	3539.88	8229.2	1.14	15806.54	4099074
Tilia cordata	Littleleaf linden	1347	122.62	14085.59	8.48	973.79	1512.69	3516.56	0.49	6754.57	1607868
Tsuga canadensis	Eastern hemlock	1347	200.14	22989.9	5.8	665.9	964.25	2241.59	0.31	4305.62	633628.3
Ulmus americana	American elm	12119	127.53	14649.7	9.73	1117.44	850.5	1977.17	0.27	3797.73	335712.5
Total	**N/A**	**1459706**	**103242.7**	**11859491**	**2902.56**	**333417**	**170287.6**	**395870**	**54.61**	**760382**	**273895355.9**

STUDY AREA

Study Area	Trees	Carbon storage (tonnes)	Carbon storage (CAD)	Gross carbon sequestration (tonnes/year)	Gross carbon sequestration (CAD/year)	Avoided runoff (m³/year)	Avoided runoff (CAD/year)	Pollution removal (tonnes/year)	Pollution removal (CAD/year)	Structural Value (CAD)
Total – Study Area	**2973380**	**196894.8**	**22617309**	**6455.26**	**741515.6**	**399938.5**	**929742.5**	**128.25**	**1785837**	**802793693.6**

Appendix K: i-Tree Street Tree Benefits Analysis

BACKGROUND & RATIONALE

Street trees represent an important component of a city's urban forest. Street trees enhance the aesthetics of neighbourhoods, provide valuable ecosystem services, and make up a significant portion of cities' urban forest cover. In some densely built neighbourhoods, street trees can represent most of the urban forest cover, and thus make valuable contributions to neighbourhood character and livability. Street trees also play an important role in increasing urban environmental equity in low income and underserviced communities. Street trees have been linked to reduced asthma rates in young children (Lovasi et al. 2008). Street trees also help to reduce runoff from asphalt during rain storms, thereby helping to reduce the burden of storm events on municipal infrastructure (Armson et al. 2013).

However, their location adjacent to roadways also predisposes street trees to a variety of stress factors that trees in woodlands and yards are unlikely to face. Street trees are often subject to salt deposits during the winter that can alter soil chemistry. Street trees may be planted in confined growing spaces with inadequate soil volume and poor soil quality. When planted along heavily trafficked streets, this soil can become compacted by repeated pedestrian trampling, which contributes to anaerobic soil conditions. Street trees can also be injured by snow removal or construction equipment, vehicles, and vandals. Street trees growing in areas with abundant impervious ground cover and reflective building surfaces can suffer heat stress during the summer months. Injuries and increased stress can predispose trees to insect and disease infestation, further endangering their longevity and sacrificing the benefits that are provided by mature trees.

Some innovations, such as modular pavement systems and pervious paving, seek to incorporate engineered solutions to urban infrastructure so that street trees can have adequate space for root growth and water infiltration. By enhancing soil volume, these solutions can help to prevent negative interactions between trees and grey infrastructure, such as pipes and sidewalks, which can arise from root growth. However, widespread application of these solutions may be impractical due to financial costs and the logistics of retrofitting existing infrastructure.

An analysis of the benefits provided by Guelph's street trees complements the assessment of the City's entire urban forest by highlighting the value provided by the street tree population. The value of a street tree resource is in many ways contingent on the health of the trees and the extent of leaf area they collectively represent. As the City is responsible for planting, maintaining, and removing street trees, an overview of the benefits provided by street trees is pertinent data that can provide insights into the outcomes of the City's investments in the resource and help to inform management decisions.

METHODOLOGY

BioForest acquired street tree inventory data from the City of Guelph's Department of Parks and Recreation in November, 2019. The data provided by the City included a total of 52,510 trees, which encompassed street and park trees. At the direction of City of Guelph staff, all park trees (a total of 8,100 trees) were removed from the database so that the analysis would focus solely on street trees. No attempts were made to ground truth the content of the databases, as the data was collected and provided by the City of Guelph, and no field audits of street tree data were scheduled as part of the Guelph Urban Forest Study project.

i-Tree Eco version 6 software was used to process the tree inventory data and produce the benefits analysis. The street tree inventory was edited in accordance with the parameters of the i-Tree Eco software. All data fields that fed directly into the i-Tree Eco analysis were retained: address, DBH, species, and condition. The tree ownership field was retained to add context to the analysis. All other data fields were removed from each ward's inventory.

The species and condition fields were further edited to make the entries compatible with i-Tree Eco. The entries in the species field were converted to i-Tree species codes. Subspecies, varieties, and cultivars were designated by the appropriate species codes and listed as unique entries. Any subspecies, varieties, or cultivars that were not included in the list of species codes were assigned the closest applicable species code. For example, *Acer rubrum* 'Autumn Spire', a cultivar of red maple, was assigned the species code for red maple because a specific i-Tree species code for this cultivar did not exist. Finally, the tree condition field was converted to condition percentage ranges that reflected the designation assigned to each tree in the city's inventory. For example, a condition rating of Poor was assigned a percentage of 52, which is expressed in the i-Tree Eco software as a canopy condition rating of 50-55 per cent.

The street tree database was further edited to remove records with erroneous DBH entries. Through this process one entry, which had a DBH of 9996, was removed.

Once edited the database was uploaded from Excel to Eco. After the process of editing the inventory, a total of 43,659 street trees were submitted for analysis. The project was submitted to the i-Tree server and results were retrieved and compiled using Microsoft Excel.

RESULTS & DISCUSSION

The Guelph street tree inventory classifies trees according to three ownership types: city, boundary, and private. City trees are those that are planted fully within the municipal boulevard; boundary trees are those that are planted along the boundary between the city boulevard and private property, where the trunk straddles the property line; and private trees are those that are planted fully on private property, yet which the City of Guelph manages, at least in part, and records in its inventory. Figure 60 illustrates the distribution of ownership type among street trees. Nearly one third of street trees in the City of Guelph's inventory (32 per cent) are identified as being planted on private property.

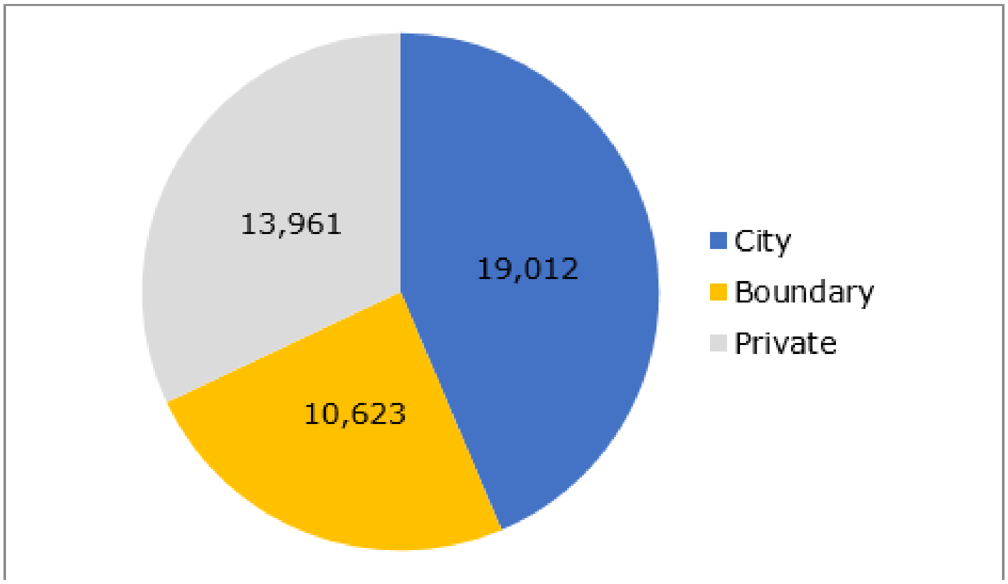


Figure 60: Distribution of tree ownership type among street trees in Guelph (Source: i-Tree Eco analysis of Guelph street tree inventory)

The structural value of Guelph's street trees (population 43,659) is approximately $105.6 million. Street trees make up about 1.5 per cent of Guelph's total tree population, but their structural value represents about 13 per cent of the total structural value of Guelph's trees.

Street trees store approximately 15,412 tonnes of carbon, with an associated value of $1,770,000. This represents 7.8 per cent of the total carbon stored by Guelph's trees.

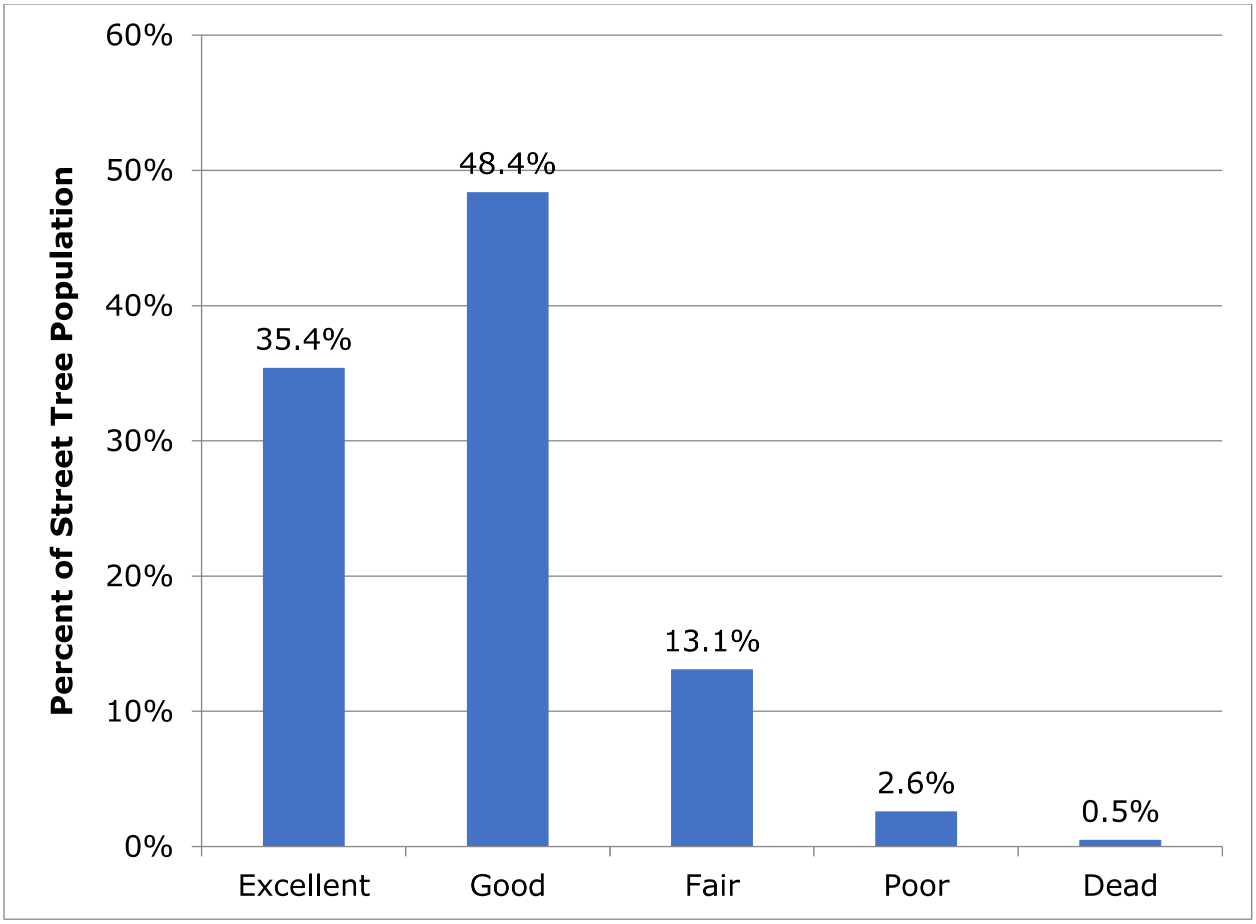
Street trees provide annual ecosystem services with an approximate net value of $199,750. These include annual carbon sequestration, pollution removal, and avoided runoff.

Annual carbon sequestration by street trees totals 287.9 tonnes, with an associated value of $33,066. This represents about 4.5 per cent of the annual carbon sequestration performed by all of Guelph's trees. Annual pollution removal by street trees totals 8.5 tonnes, with an associated value of about $105,820. This represents about 5.4 per cent of the total annual pollution removal performed by all of Guelph's trees. Annual avoided runoff by street trees totals 26,184 m^3, with an associated value of $60,870. This represents about 6.5 per cent of the total annual avoided runoff performed by all of Guelph's trees.

These results indicate that the benefits provided by Guelph's street trees are outsized compared to the portion of the total tree population they represent. This may be attributed in part to the relatively good condition and health of the street tree population, which the City is responsible for managing, as well as their relative size. The results also speak to the importance of investing in municipal green infrastructure, as the City of Guelph's management of its street trees has clearly resulted in substantial environmental benefits. The city's role in improving neighbourhoods and delivering the benefits to the city's residents that flow from street trees is significant.

STREET TREE CONDITION

The health of Guelph's street trees is relatively good, according to the condition ratings recorded in the city's tree inventory (Figure 61). About 84 per cent of Guelph's street trees are in excellent or good condition. Dead trees made up about 0.5 per cent of the street tree population in 2019. The species with the highest percentage of dead trees was white ash (*Fraxinus americana*), with 23.8 per cent. However, only 21 trees of this species still stand, so these dead trees do not represent a large share of the street tree population.



60%
50%
40%
30%
20%
10%
0%
Percent of Street Tree Population
35.4%
48.4%
13.1%
2.6%
0.5%
Excellent
Good
Fair
Poor
Dead

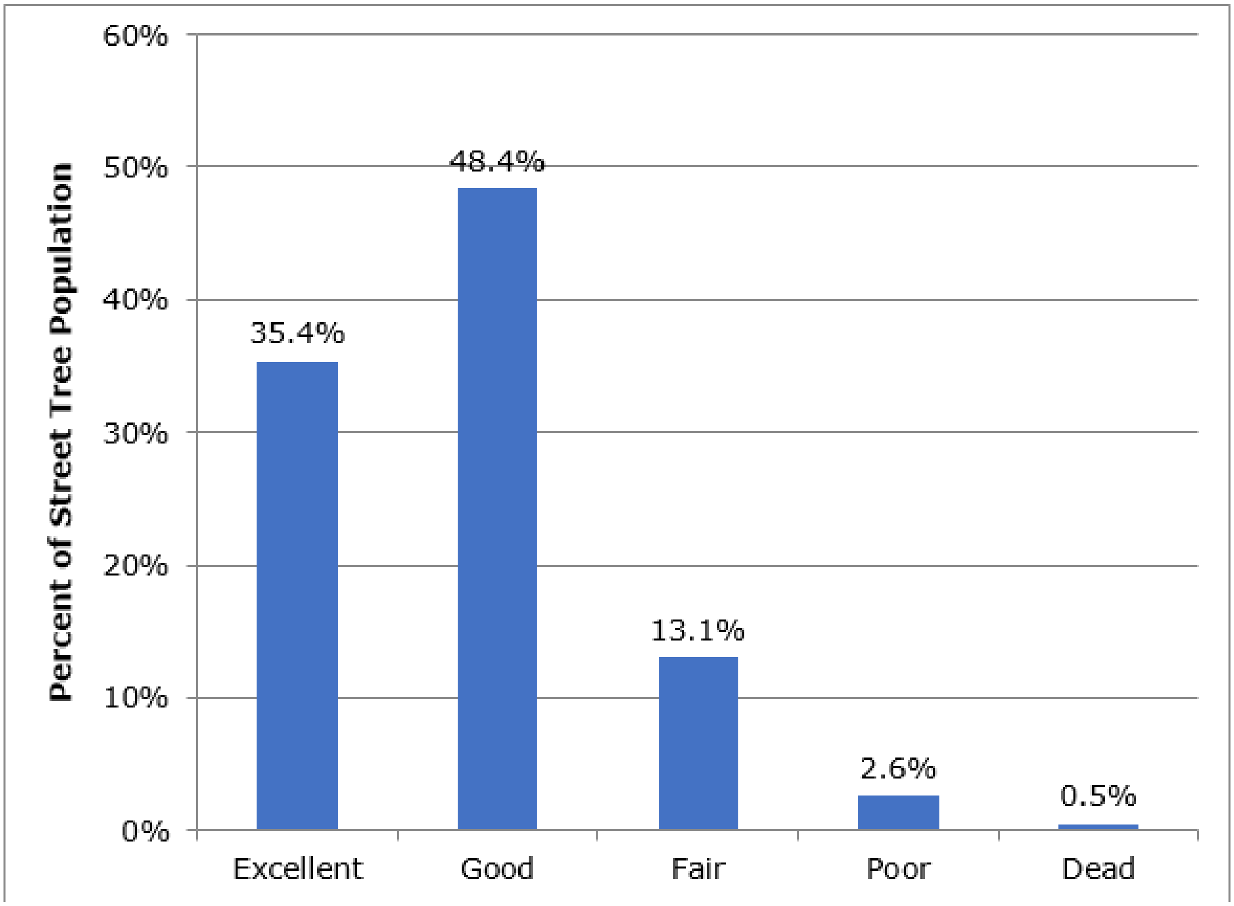


Figure 61: Street tree condition as per cent of population in 2019 (Source: i-Tree Eco analysis of Guelph street tree inventory)

The distribution of street tree diameter classes in the street tree population is variable among urban areas. Many municipalities have street tree populations with relatively few large-diameter trees and a greater abundance of small- to medium-diameter trees, while some have fairly even distribution among age classes (McPherson et al 2016). As of 2019, about 36.6 per cent of street trees measure 15.2 cm or less in diameter. About 38.3 per cent of street trees now measure more than 30.5 cm in diameter, which suggests that Guelph's street tree population has a fairly sizable component of mature street trees (Figure 62). This seems to align Guelph's street tree population with what McPherson and Rowntree (1983) and McPherson et al. (2016) consider a maturing street tree population, where the majority of trees were planted approximately 20-50 years ago and trees in the middle size classes (16-45 cm) outnumber those in the small size classes (under 16 cm). While these mature street trees deliver important ecosystem services to Guelph's residents, it will be important to continue to plant new street trees at a pace that will insure sufficient numbers of street trees are able to replace senescent and dying trees in the future.

STREET TREE POPULATION STRUCTURE

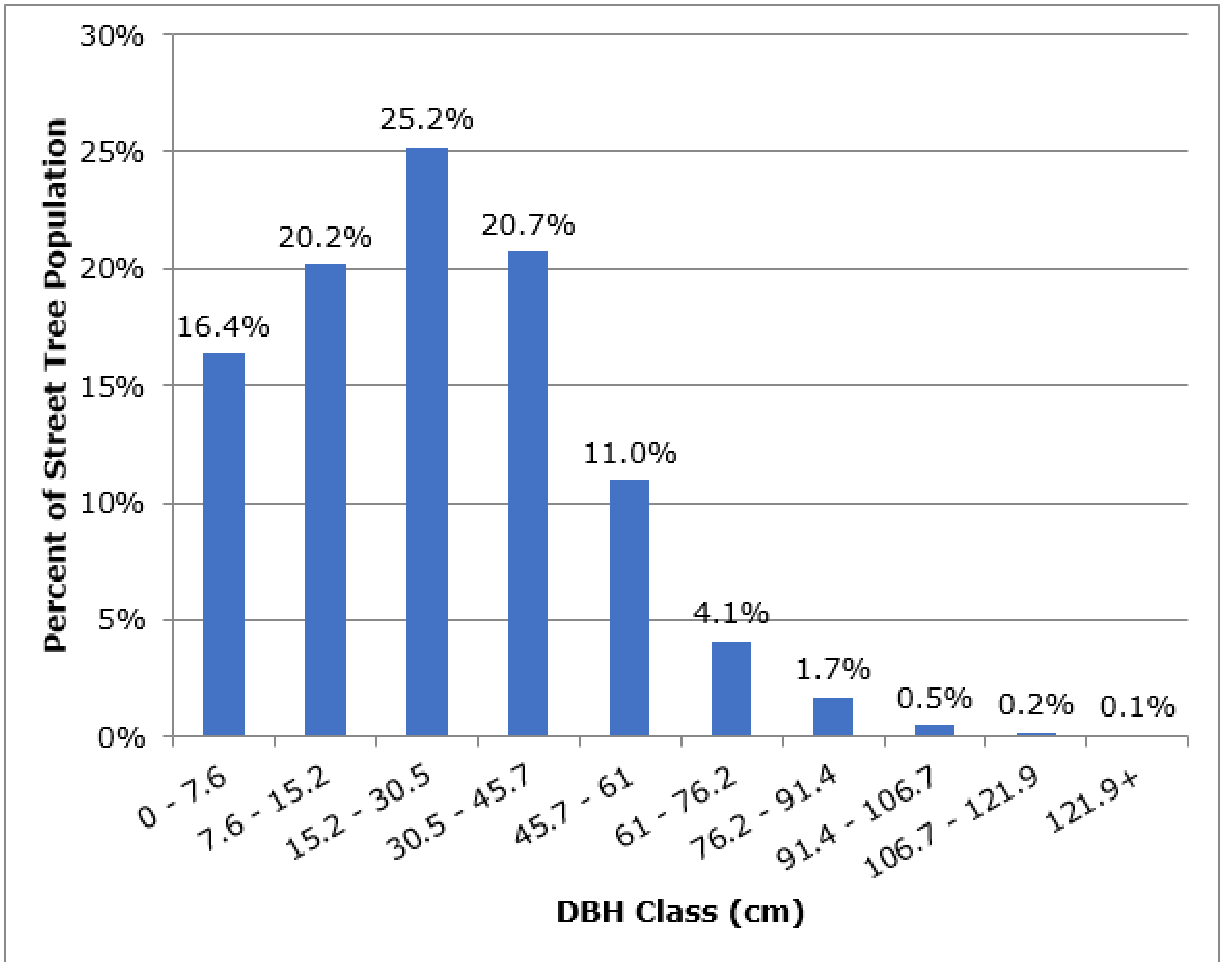


Figure 62: Distribution of Guelph's street tree population by DBH class (cm) in 2019 (Source: i-Tree Eco analysis of Guelph street tree inventory)

In terms of population, Norway maple (*Acer platanoides*) is the most abundant street tree, comprising about 18.5 per cent of the total street tree population (Figure 63). However, it should be noted that the top ten species of street tree by population also contains Crimson King Norway maple, which comprises an additional 3.8 per cent of the total street tree population. When totaled together, it may be said that Norway maple makes up 22.3 per cent of Guelph's street trees.

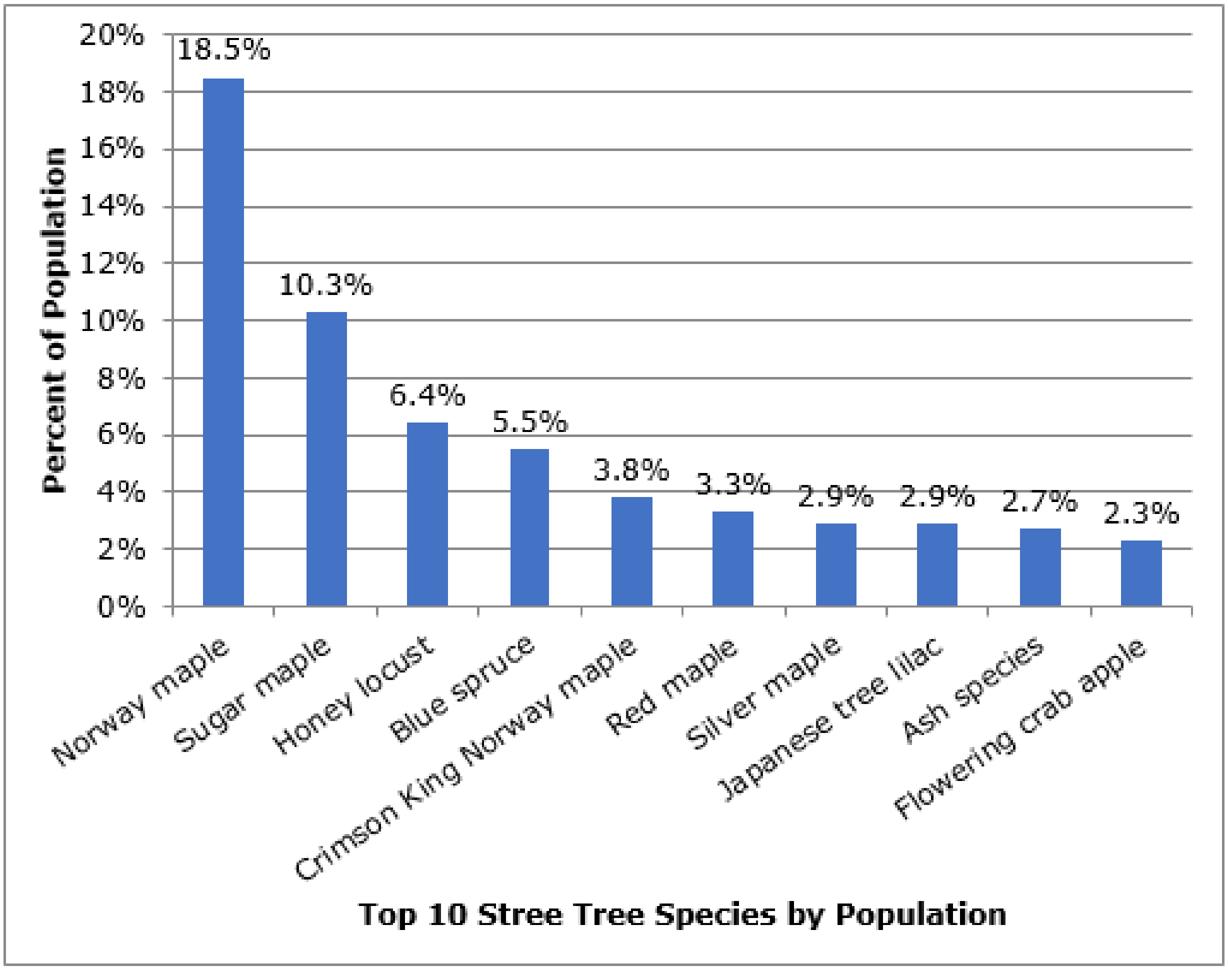


Figure 63: Top ten species of street tree by population in 2019 (Source: i-Tree Eco analysis of Guelph street tree inventory)

Sugar maple (*Acer saccharum*) is also abundant in the street tree population, comprising about 10.3 per cent of Guelph's street trees (Figure 63). In combination with Green Mountain sugar maple, which comprises 1.5 per cent of Guelph's street trees, sugar maple makes up a total of 11.8 per cent of the street tree population.

With the exception of Japanese tree lilac (*Syringa reticulata*) and crabapple (*Malus tschonoskii*), the top ten species of Guelph's street trees are capable of growing into medium- to large-stature trees. Therefore, they have the potential to deliver more significant benefits, provided the conditions exist to allow them to grow to their full biological potential. As large stature trees, their per-tree leaf area would be much greater than a smaller stature tree such as Japanese tree lilac, and hence each tree would deliver proportionately more benefits.

Norway maple is also dominant among street trees in terms of the leaf area it represents. Norway maple contributes about 35.5 per cent of the leaf area of all of Guelph's street trees. When combined with Crimson King Norway maple, which comprises 5.4 per cent of street tree leaf area, the species accounts for 40.9 per cent of the leaf area represented by Guelph's street trees. As with population, sugar maple is the second most abundant street tree in terms of leaf area (Figure 64).

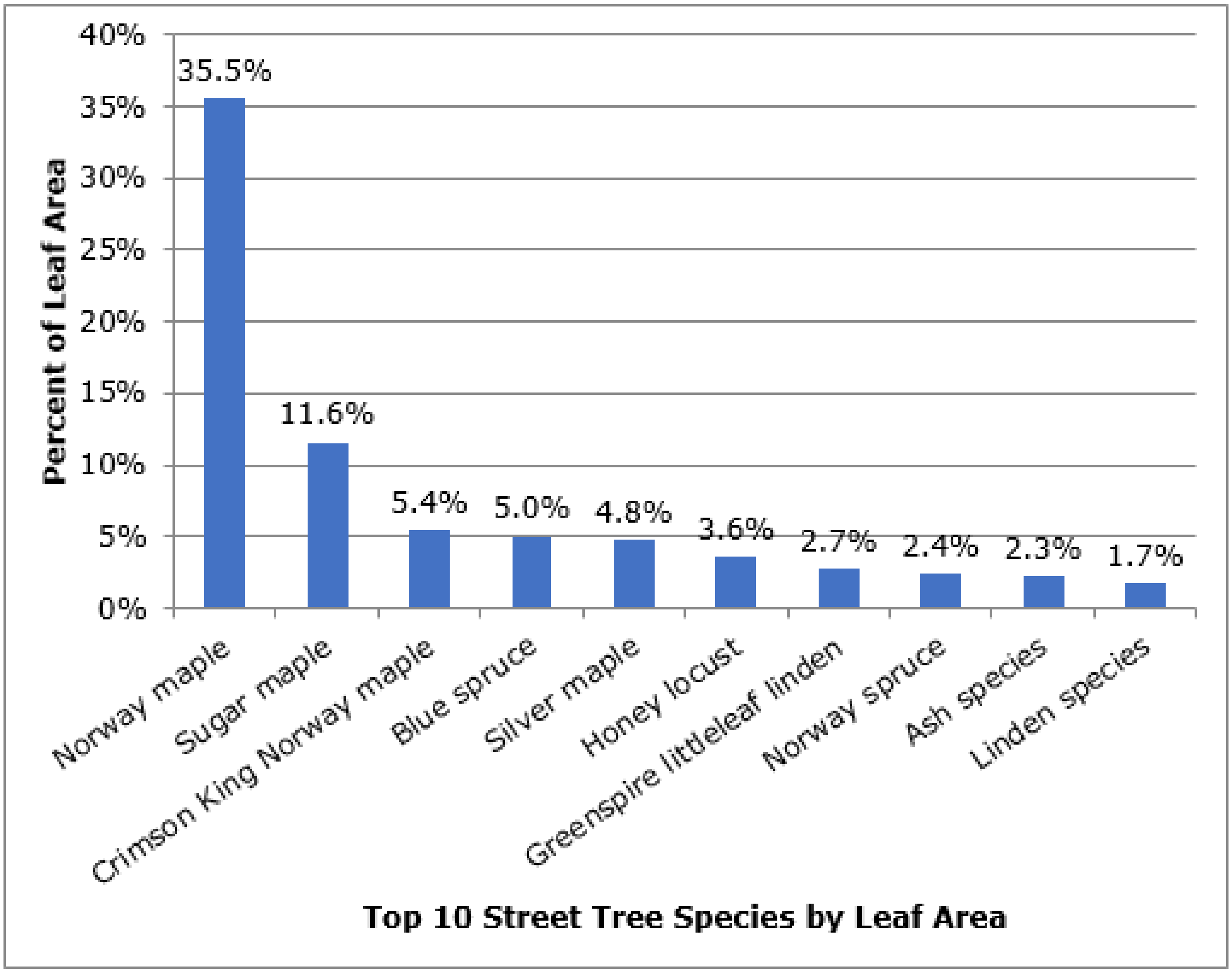


Figure 64: Top 10 species of street tree by leaf area in 2019 (Source: i-Tree Eco analysis of Guelph street tree inventory)

In light of its dominance among Guelph's street trees, it should also be noted that Norway maple is one of the preferred host species of Asian longhorned beetle (*Anoplophora glabripennis*), along with other species of maple, which are also abundant. As shown in the above two figures, half of the top ten street tree species in Guelph are maples, as are four of the top five species by leaf area. The vulnerability of such a large contingent of the street tree population to a devastating pest is a concern for the long-term resilience of the street tree resource. Planting Norway maple on streets has fallen out of favour, due to its invasive tendencies, so there is an opportunity to gradually reduce the Norway maple population over time. This will likely be a long term outcome, as mature Norway maples gradually decline and are replaced by a more diverse set of species.

ECOSYSTEM SERVICES PROVIDED BY STREET TREES

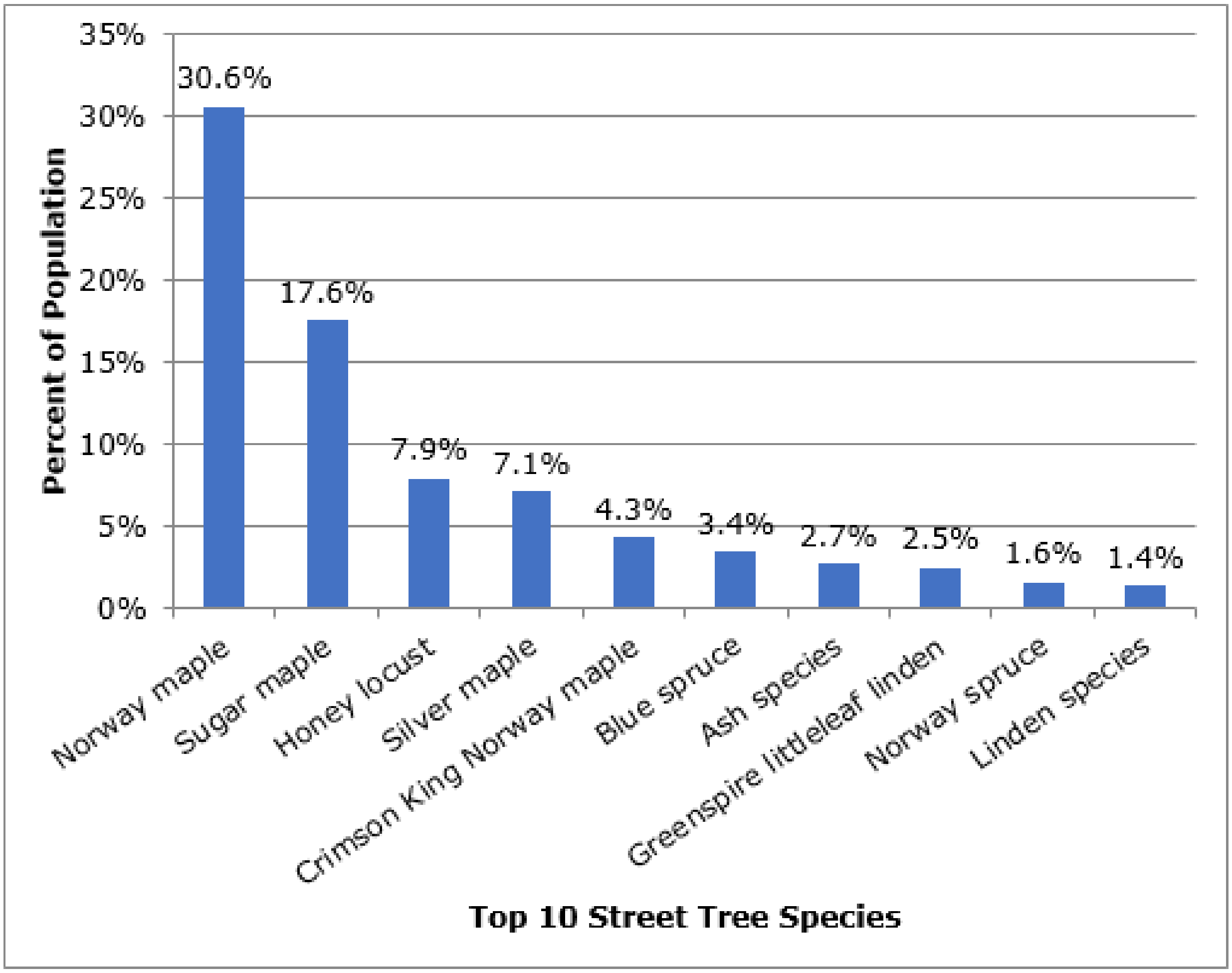


Figure 65: Top 10 street tree species by carbon storage in 2019 (Source: i-Tree Eco analysis of Guelph street tree inventory)

Norway maple dominates the street tree population in terms of carbon storage. Norway maple stores about 30.6 per cent of the carbon stored by Guelph's street trees. In combination with Crimson King Norway maple, the species stores a total of 34.9 per cent of the carbon stored by Guelph's street trees. Sugar maple stores the second largest amount of carbon among street trees, comprising 17.6 per cent of street tree carbon storage (Figure 65). Guelph's street trees store a total of 15,411.9 tonnes of carbon, which has an equivalent value of about $1,770,362.

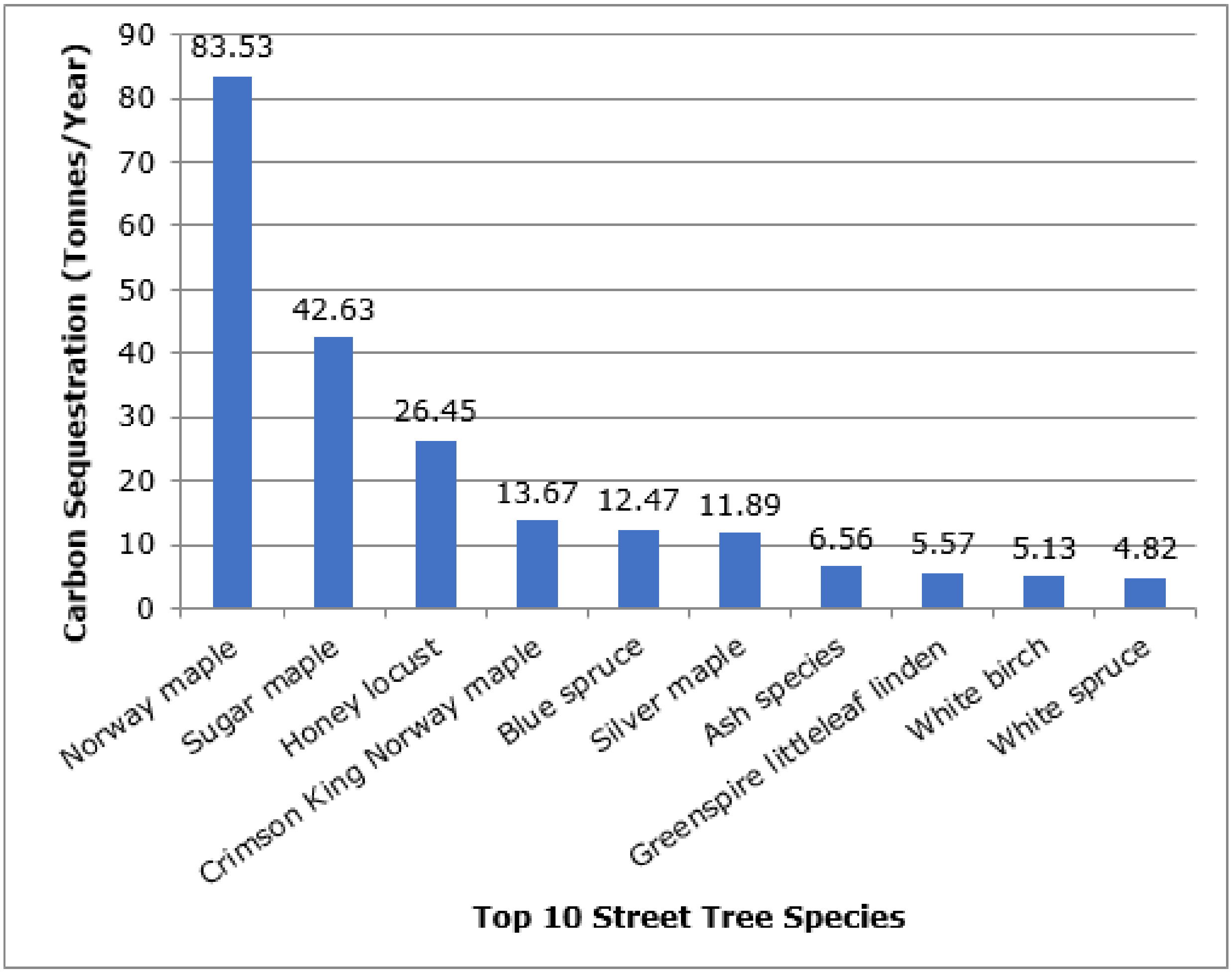


Figure 66: Annual carbon sequestration performed by Guelph's street trees (in tonnes per year) (Source: i-Tree Eco analysis of Guelph street tree inventory)

Guelph’s street trees also sequester approximately 287.86 tonnes of carbon annually, which has an equivalent value of $33,066. Norway maple is again the dominant species, in terms of annual amount of carbon sequestered, with 83.53 tonnes. When combined with Crimson King Norway maple, the total amount of carbon sequestered annually by this species is 97.2 tonnes (Figure 66). This combined amount is equivalent to 33.8 per cent of annual carbon sequestration performed by street trees. Sugar maple sequesters the second largest amount of carbon annually, at 42.63 tonnes, or 14.8 per cent of annual carbon sequestration by street trees.

From the results of the street tree analysis, it is clear that Norway maple plays a significant role in delivering the benefits provided by street trees. While its legacy with respect to ecological health in forest and ravine habitats is complicated, Norway maple’s contributions to the provision of ecosystem services by the urban forest are important.

Approximately 48.6 per cent of Guelph's street trees are native to North America, although this figure includes species whose native range it outside of Ontario. About 40 per cent of Guelph's street trees are native to Asia and Europe (Figure 67).

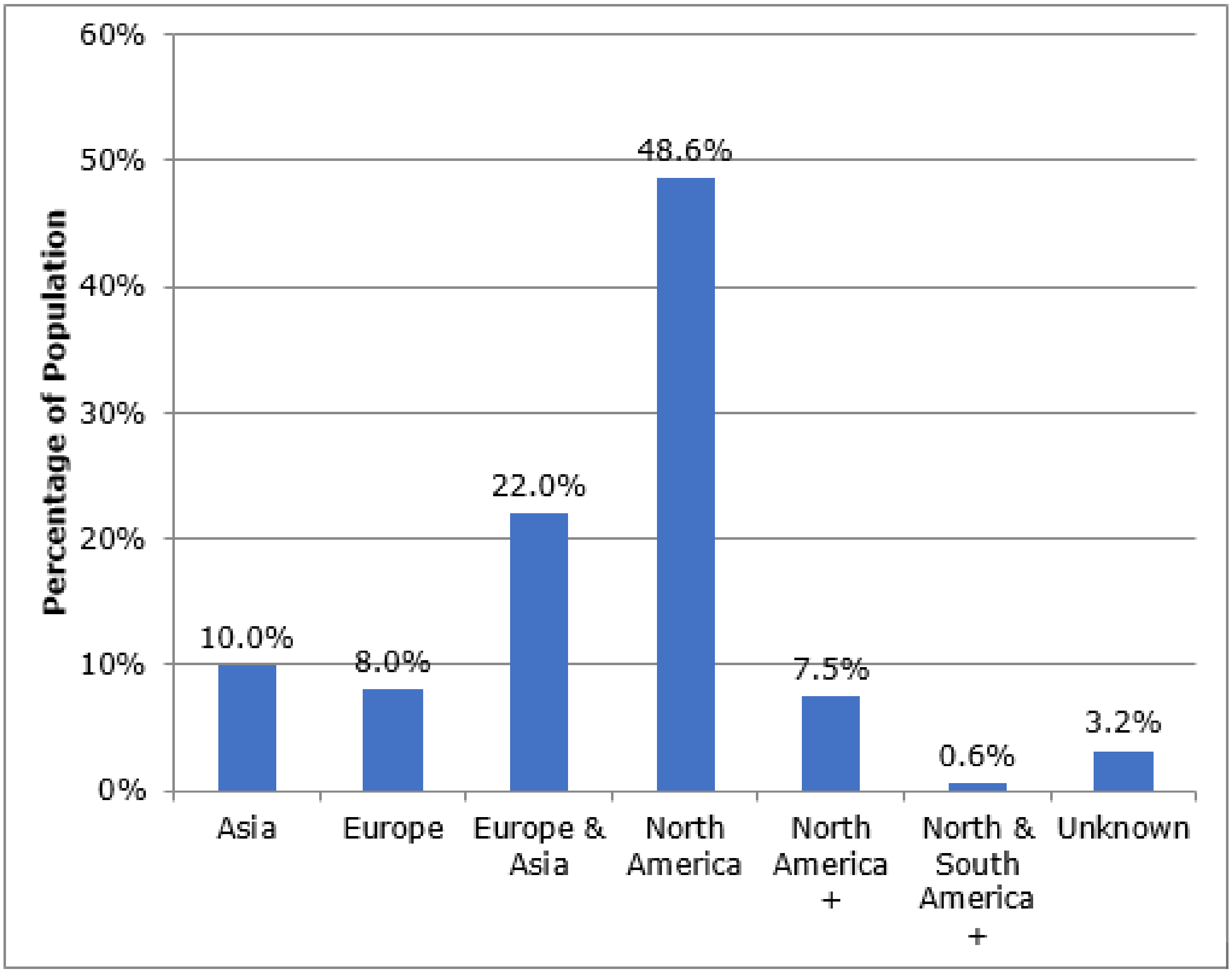


Figure 67: Native place of origin of Guelph's street tree population in 2019 (Source: i-Tree Eco analysis of Guelph street tree population)

PEST THREATS TO STREET TREES

The most significant pest threat to Guelph's street trees is Asian longhorned beetle (ALHB – *Anoplophora glabripennis*). This is primarily due to the dominance of maples in Guelph's street tree population, although other genera, such as birch and poplar are susceptible as well. About 49 per cent of Guelph's street trees (a total of 21,328 trees) are susceptible to infestation by ALHB. The structural value of these trees is about $64.3 million (Figure 68).

Only about 2.8 per cent of Guelph's street trees are susceptible to emerald ash borer (EAB – *Agrilus planipennis*) – a total of 1,229 trees. EAB likely reduced the ash population on Guelph's streets, although it is unknown how significant the reduction was. The remaining ash planted on Guelph's streets has a structural value of about $2.8 million.

About 13.2 per cent of Guelph's street trees are susceptible to gypsy moth (*Lymantria dispar dispar*) – a total of 5,772 trees that span a range of genera. The structural value of these trees is about $9.1 million. However, it should be noted that it is unlikely that gypsy moth infestation will result in tree loss, except under extremely severe and prolonged defoliation scenarios.

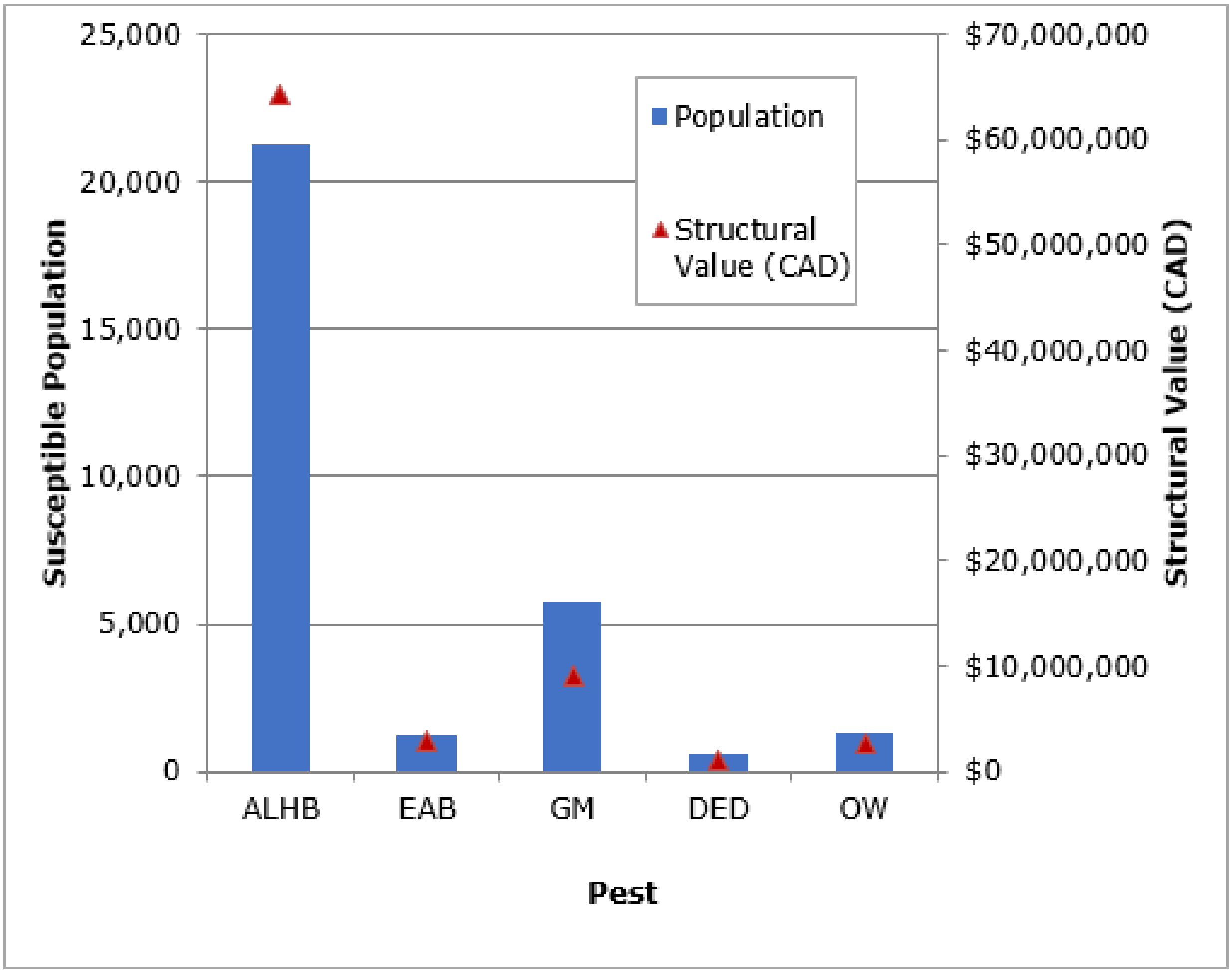


Figure 68: Susceptibility of Guelph's street trees to major pests in 2019 (Asian longhorned beetle – ALHB, emerald ash borer – EAB, gypsy moth – GM, Dutch elm disease – DED, oak wilt – OW (Source: i-Tree Eco analysis of Guelph street tree inventory)

CONCLUSIONS

Further investments in Guelph's street tree resource will be needed to continue the provision of important environmental services it currently provides to residents. Investments in Guelph's street trees have ensured that trees are largely in good condition and have allowed for the provision of benefits that are disproportionately large compared to the street tree population. It is also positive that Guelph has such a large component of mature trees in its street tree population.

However, the proportion of small diameter trees points to the need to increase street tree planting where possible in order to ensure that enough new recruits are available to take the place of older street trees as they are removed in the coming decades. This is also pertinent in light of the distribution of ownership captured by the street tree inventory. With nearly one third of Guelph’s street trees located on private property, municipal resources are effectively being used to manage trees that are typically the responsibility of a homeowner or business. While this situation has set a precedent, it would be prudent for the city to explore ways to divest management responsibility for trees on private property in the interest of redirecting funds and resources to managing and expanding the street tree population on city property.

REFERENCES

Armson, D., Stringer, P., and A.R. Ennos. 2013. The effect of street trees and amenity grass on urban surface water runoff in Manchester, UK. Urban Forestry & Urban Greening 12(3): 282-286.

Lovasi, G.S., Quinn, J.W., Neckerman, K.M., Perzanowski, M.S., and A. Rundle. 2008. Children living in areas with more street trees have lower prevalence of asthma. Journal of Epidemiology & Community Health 62: 647-649.

McPherson, E.G. and R.A. Rowntree. 1989. Using structural measures to compare twenty-two U.S. street tree populations. Landscape Journal 8(1): 13-23.

McPherson, E.G., van Doorn, N., and J. de Goede. 2016. Structure, function and value of street trees in California, USA. Urban Forestry & Urban Greening 17: 104-115.