CLIMATE CHANGE AND THE TREE CANOPY OF WATERLOO REGION

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Executive Summary

Climate change is a defining challenge of the 21st century, and Waterloo Region (WR) will increasingly experience its impacts. The tree canopy is no exception. Climate projection models for WR suggest an increase in temperature, extension of the growing season, reduced snowfall, water deficits in the summer, more ice storms, and an increase in extreme precipitation events with accompanying strong winds. These changes will put added stress on the trees that make up our tree canopy.

Currently, our tree canopy coverage is low and has limited species diversity. According to our GIS survey, only 14% of the area is covered by trees. Although coverage is within the range of neighbouring communities, it is well below the recommended 30% coverage for maintaining a healthy urban forest. Tree reports from Cambridge and Kitchener suggest that we also have limited diversity of tree species in the region. This report shows that this lack of diversity makes our tree canopy particularly vulnerable to stresses brought on by climate change, including pests and diseases that can migrate into the area due to changing conditions. Furthermore, we found that the geographic growing ranges for our local tree species have been, and will continue to shift northwards, making it more difficult for some existing trees to flourish in the Waterloo Region as climate conditions change. By the 2080's, under a low emission scenario, the WR will no longer be suitable for 7% of the species on our list, but under a high emission, that number jumps to 39%, with spruce and pine trees being particularly vulnerable to shifts in climate.

Research carried out for this report suggests that trees are important for building resilience of our community toward climate change. Trees can sequester carbon and thereby reduce the impact of our emissions. Trees also improve our air quality by removing pollutants, but careful selection of trees is essential to avoid tree species that can release harmful volatile compounds or produce high levels of pollen. Indeed, pollen production from trees and other plants are likely to increase with climate change. Furthermore, fruit trees can improve local food security. Trees also provide shade and can significantly reduce the urban heat island effect that can pose a health risk during extreme heat days. Finally, trees can help in managing stormwater during the extreme rainfall events that are also projected for the WR with climate change. Appended to this report is an extensive list of local tree species and available data on their projected growing ranges under different emission scenarios, rate of pollen production, production of harmful volatile compounds, growth characteristics, and susceptibilities to pests and diseases. This table can help decision-makers choose tree species that are suitable to the current and projected environment for Waterloo Region.

This report makes several key recommendations to manage and support the tree canopy of WR in the face of climate change. These are based on an analysis of the best practices of neighbouring urban forest management plans. We recommend that WR encourage collaboration between departments and municipal governments to support and grow our

tree canopy. To better understand the current status of tree species diversity, a comprehensive regional tree inventory is essential. With that, the WR can implement programs to improve the diversity of tree species. Structural pruning and prompt reforestation after disturbances would help to build resilience of our existing tree canopy. Landowners should be engaged and encouraged to plant trees on their properties to expand the tree canopy and reap the benefits of trees in our communities. Finally, this report recommends that the region develop a robust pest management strategy. We also make recommendations on stakeholder engagement and possible partnerships.

We believe that the information and recommendations contained in this report can help the Waterloo Region and institutions within the region build a more extensive tree canopy that is more resilient to the stresses that are projected to come with climate change. Such a tree canopy would provide our community with a healthier environment that can in turn help our community to be more resilient to climate change.

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List of Abbreviations

BVOC: Biogenic Volatile Organic Compounds

ECCC: Environment and Climate Change Canada

GHG: Greenhouse Gas

GIS: Geographical Information Systems

GRCA: Grand River Conservation Authority

IC3: Interdisciplinary Center on Climate Change

IPM: Integrated Pest Management

RCP: Representative Concentration Pathways

IPCC: Intergovernmental Panel on Climate Change

LEAF: Local Enhancement & Appreciation of Forests

LiDAR: Light Detection and Ranging

Kt: Kilotonnes

Mt: Megatonnes

SOLRIS: Southern Ontario Land Resource Information System

SNAP: Sustainable Neighbourhood Action Program

UFMP: Urban Forest Management Plans

USDA: United States Department of Agriculture

UTC: Urban Tree Canopy

TRCA: Toronto and Region Conservation Authority

WR: Waterloo Region

Climate Change and the Tree Canopy of Waterloo Region

1.0 Introduction

The objective of this report is to inform Waterloo Region (WR) stakeholders about how climate change will affect the urban tree canopy (UTC), and measures that can be taken to better manage and evaluate the tree canopy.

As global temperatures rise due to greenhouse gas emissions associated with human activity, it is increasingly having an effect on our climate. Even in Waterloo Region, average annual temperatures have risen (see Figure 3.1 in Appendix C), and we have experienced extreme precipitation events of the type that are likely to increase in frequency and severity with climate change (IC3, 2015). These, and other changes in our local climate, will have an impact on the life that depends on our climate for survival: including our trees. Trees provide so many valuable services to our communities, from physical and mental health benefits, cleaner air and water, relief from the urban heat island effect, and support for complex ecosystems. We cannot afford to ignore the effects of climate change on the tree canopy of Waterloo Region. This report aims to build our understanding of how our trees will be affected by climate change, how our trees affect our experience of climate change, and the tools we can use to build a stronger more climate resilient tree canopy.

The Region of Waterloo includes the cities of Kitchener, Waterloo, Cambridge, and the townships of Wellesley, Woolwich, Wilmot, and North Dumfries (see Figure 1.1 below). The management of the trees in the WR is shared among several stakeholders. The city and township governments own and manage trees on their properties. This includes trees along residential streets, in parks, and in urban forests. The Region of Waterloo protects significant public woodland features within its boundaries, including 16 regional forests. It also has jurisdiction over the trees planted along regional roads. The Grand River Conservation Authority also owns and maintains trees within the watersheds of Waterloo Region. Utilities maintain trees located near their aerial utility lines. Finally, institutions and private landowners control the trees on their properties (Urban Forest Innovations Inc. & Beacon Environmental Ltd., 2015).

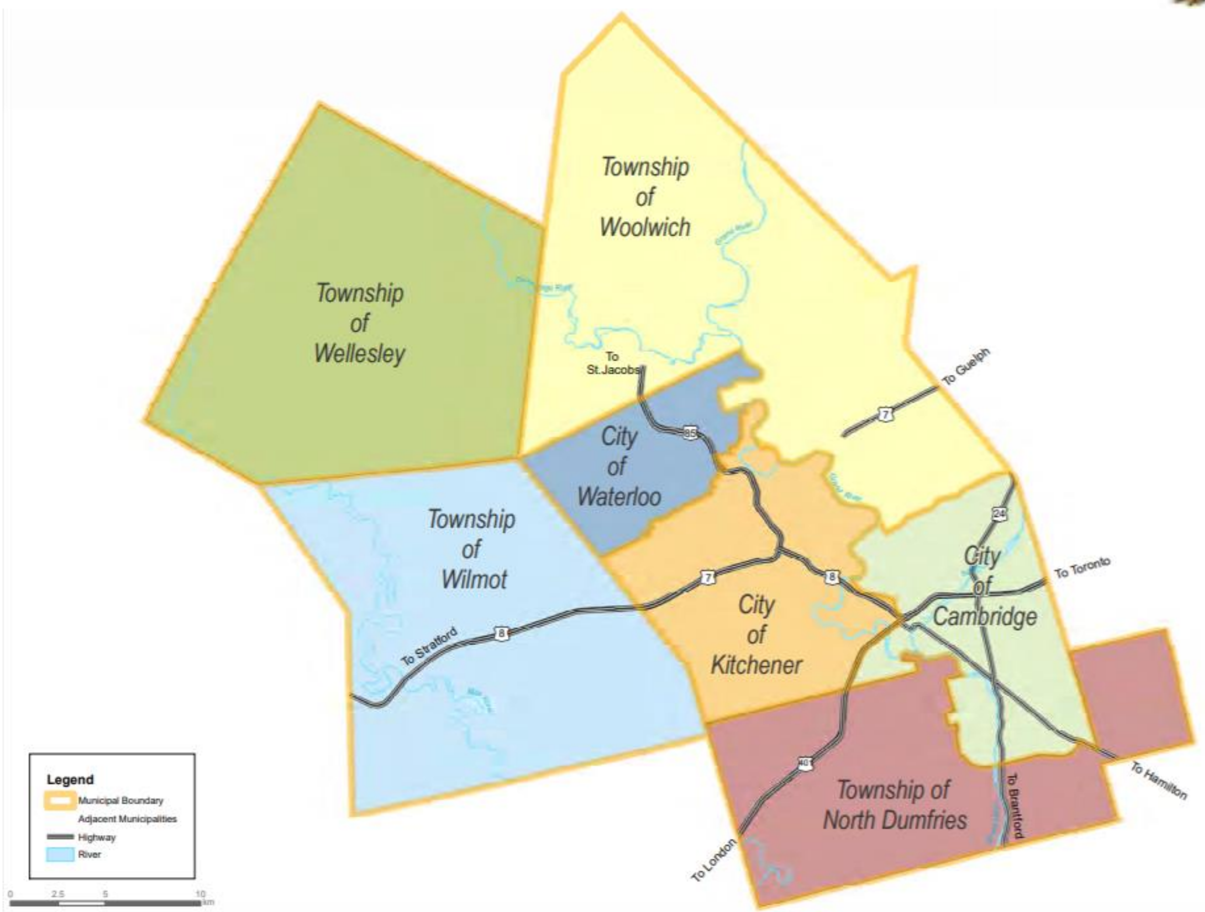

Figure 1.1. Map of the municipalities of Waterloo Region (Region of Waterloo, 2013).

Section 1 outlines the objectives of the report and provides important background information. Section 2 profiles the existing tree canopy management plans within the WR and describes the current status of the WR tree canopy. Section 3 provides details on the projected climate change impacts for the region, with emphasis on the climate variables that will impact local trees. Section 4 describes how climate change will impact the UTC and the various roles that trees can play in climate change mitigation, adaptation and resilience. Finally, Section 5 details seven key recommendations for how to manage the tree canopy with regards to climate change, as well as describing the roles that indicators and partners can play in supporting our trees.

Several appendices are included in this report to support and increase the information found in the body of the text. Appendix A outlines the methodologies used to generate GIS (geographic information systems) maps and calculate tree canopy coverage. Appendix B contains supporting data for the maps, while Appendix C contains climate projection graphs. A summary table of climate-related characteristics for local tree species is found in Appendix D. An i-Tree report is in Appendix E. Appendix F contains information on relevant tree pests and diseases. Finally, supplementary policies and guidelines are provided in Appendix G.

2.0 Baseline Tree Canopy

2.1 Introduction

This section describes what is known about the present tree canopy in WR and chronicling new data that has been collected about the tree canopy. The current status of WR tree canopy is displayed in Figure 2.4. Further research is required for all townships and within the City of Waterloo. Beyond the scope of literature, Section 2.3 aims to provide an assessment of the current forest conditions and develop a methodology for conducting urban tree canopy analysis using Geographic Information System (GIS) mapping technology.

2.2 Status of Urban Tree Canopy Analysis in Waterloo Region

In Waterloo Region the City of Cambridge and the City of Kitchener have both finalized city-wide urban forest management plans. This section will describe the plans which they have created to provide insight on current work taking place in Waterloo Region.

2.2.1 The City of Cambridge

The City of Cambridge report provides a detailed plan for the management of its urban forest which is valued at $85 million (Urban Forest Innovations Inc. & Beacon Environmental Ltd., 2015). The plan is divided into four implementation periods to enable the limited municipal staff capacity to manage this asset. By dividing up the initiatives, this plan seeks to address the knowledge gap on the urban forest, reduce risks to the tree stock, and improve the health of the urban tree canopy. While the report does consider climate change, it does not do so with the depth and breadth of this report.

The City of Cambridge report highlights the value and services provided by the urban tree canopy (Urban Forest Innovations Inc. & Beacon Environmental Ltd., 2015). This section provides information on the context of the plan, the ecosystem services provided by the urban tree canopy, and benefits that increase the sustainability of the community. The rationale for protecting the urban tree canopy in Cambridge is due to the high value of the trees. Through analysis, the City of Cambridge estimates the value of the trees to be approximately thirteen times greater than the management costs associated (Urban Forest Innovations Inc. & Beacon Environmental Ltd., 2015). To assess the urban forest canopy, the City of Cambridge report calculated the land area covered by tree canopy as a percentage. The report states that the tree canopy coverage is a limited metric because it does not provide information on the state of the trees in question (Urban Forest

Innovations Inc. & Beacon Environmental Ltd., 2015). While canopy cover is an acknowledged metric for assessing tree canopies, the management plan must include other metrics such as the community engagement, health of the trees, and diversity of tree species to ensure adequate planning.

The City of Cambridge report provides a detailed assessment of their urban tree canopy. Through the extensive collection of data through satellite images as well as ground-based measurements, Cambridge's report provides information regarding tree canopy coverage, the variation in coverage based on land use, and the state of the existing tree inventory (Urban Forest Innovations Inc. & Beacon Environmental Ltd., 2015).

The structure for the City of Cambridge report is based on establishing a 20-year plan from 2015-2034 to guide the management of the urban forest (Urban Forest Innovations Inc. & Beacon Environmental Ltd., 2015). Within this time frame, the goals are divided into four 5-year periods to connect with the short-term management activities. This is further broken down into annual operating plans to direct daily activities. Tying the day-to-day activities into a larger time frame aids in ensuring the actions correlate to the plan's overarching goals. The report focuses upon improving the urban forest to provide benefits for everyone in the community. Overall, the report provides an extensive breakdown of the initiatives it will implement to increase the benefit of the urban forest and how this can be carried out.

2.2.2 The City of Kitchener

The City of Kitchener has three detailed reports that outline the current status and future plans for the urban tree canopy (UTC). The Sustainable Urban Forest Report Card, and the Developing a Sustainable Urban Forest Program guidebook were both released in 2017 (City of Kitchener, 2017a; City of Kitchener, 2017b). More recently, a draft report was released: It's a trees life: Kitchener's Sustainable Urban Forest Strategy 2019-2039 (City of Kitchener, 2019). These reports do make some considerations of the effects of climate change on the tree canopy but not to the extent done here.

The Developing a Sustainable Urban Forest Program report raises awareness of the importance of mature trees and the social benefits of the urban tree canopy. The report suggests that a proactive management plan is required to establish pruning programs for healthy tree growth within the city (City of Kitchener, 2017b).

The 2017 Sustainable Urban Forest Report Card provides statistical data to describe the current UTC. It reviewed the level of community and industry cooperation and involvement to advance goals related to the urban tree canopy. Through the tree inventory collected by the City of Kitchener, a range of tree life stages are observed with a greater proportion of the population in the juvenile and semi-mature stages. The inventory concludes that 43% of street and park trees are from the Acer genus, overall suggesting low diversity of tree

species and tree life-stage. Lastly, the urban tree canopy coverage was estimated at 26%. These assessments were made before the Emerald Ash Borer had emerged as a serious threat to Ash trees in the Region. The 2017 Report Card rated the overall quality of Kitchener's urban tree canopy at low to fair with opportunities for improvement through creation of a urban forest management plan (City of Kitchener, 2017a).

The 2019, It's a trees life: Sustainable Urban Forest Strategy Report provides a planning strategy for developing and maintaining the UTC. This report provides recommendations for maintaining a healthy and resilient urban forest, and focuses on community engagement. Moving forward, the report recommends measures to increase Kitchener's urban forest rating from low/fair to good/optimal (City of Kitchener, 2019). Overall, 15 actions are identified under a 5 branch framework which includes stages to plan, engage, protect, maintain and plant trees. Through community engagement, the report details areas that require more attention within Kitchener, including the need for active management, protection of the UTC before and after urban development, and the turnover times when trees are removed and replaced (City of Kitchener, 2019).

2.3 Geographic Information System (GIS) Analysis

Geographic Information System (GIS) is the analysis of spatial information through visuals to increase understanding of the data and was used to analyze the current state of the tree canopy in the WR (Esri, n. d.). This analysis will provide a baseline for evaluating the success of future WR forestry programs and highlighting gaps in our current knowledge about the tree canopy. A compendium of GIS maps for Waterloo Region and neighbouring municipalities provides an analysis of the current tree canopy.

The primary purpose of GIS analysis was to assess the tree canopy coverage for Waterloo Region. The tree canopy coverage was determined by dividing the total area of trees above 2 meters tall by the total area under study (See Appendix A Tree Canopy Coverage Calculation for further information on the GIS process). The percentage of land with tree canopy coverage is a measure of the vitality of tree canopy because of the support they provide for the ecosystem (Mincey, Schmitt-Harsh, & Thurau, 2013; Urban Forest Innovations Inc. & Beacon Environmental Ltd., 2015). Understanding the presence of forest management policies provides additional insight on forest management practices in Ontario. The following maps detail the state of tree canopy coverage for the Region of Waterloo as well as comparing to the broader context of Southern Ontario.

2.3.1 Southern Ontario Land Resource Information System (SOLRIS) for Waterloo Region

In Ontario, the Ecological Land Classification is used to define different land uses (Government of Ontario, 2019a). This classification system defines areas based on the underlying bedrock, local climate conditions, abiotic factors in the environment, and the variety of vegetation present (Government of Ontario, 2019a). For WR, the SOLRIS data provided by the Ontario Ministry of Natural Resources (2002) classifies 65 percent of the land area as undifferentiated, with agriculture being the predominant land-use (See Figure 2.1 & 2.2). In comparison, this classification shows that the treed area (including forests, confierious, deciduous, mixed, plantation tree cultivation and hedgerows) covers 8% of the land, predominantly consisting of deciduous forests at approximately 6%. It should be noted, however, that there are trees in areas not classified as treed, but the density of trees in these areas are not sufficient to be recognized in this classification system (Ontario Ministry of Natural Resources and Forestry, 2015). In addition, the built-up areas comprise 12% of the land area for WR with sparse tree canopy coverage in these developed areas (See Figure 2.2). This system therefore provides a good coarse assessment of tree canopy coverage, but should be coupled with other analyses.

Figure 2.1 also provides insight into the urban heat island effect as the land use classification provides the extent of anthropogenic developments. The built-up areas comprise 12% of the land area for WR with sparse tree canopy coverage within their extent (See Figure 2.2). By understanding the ratio of tree canopy coverage to built-up area, this can indicate the potential for impervious surfaces to trap and release heat increasing the surrounding temperature. While it is a useful visual tool, this map may not depict all of the tree canopy due to how land is classified in the Ecological Land Classification system (Ministry of Natural Resources and Forestry, 2015; See Section 4.5).

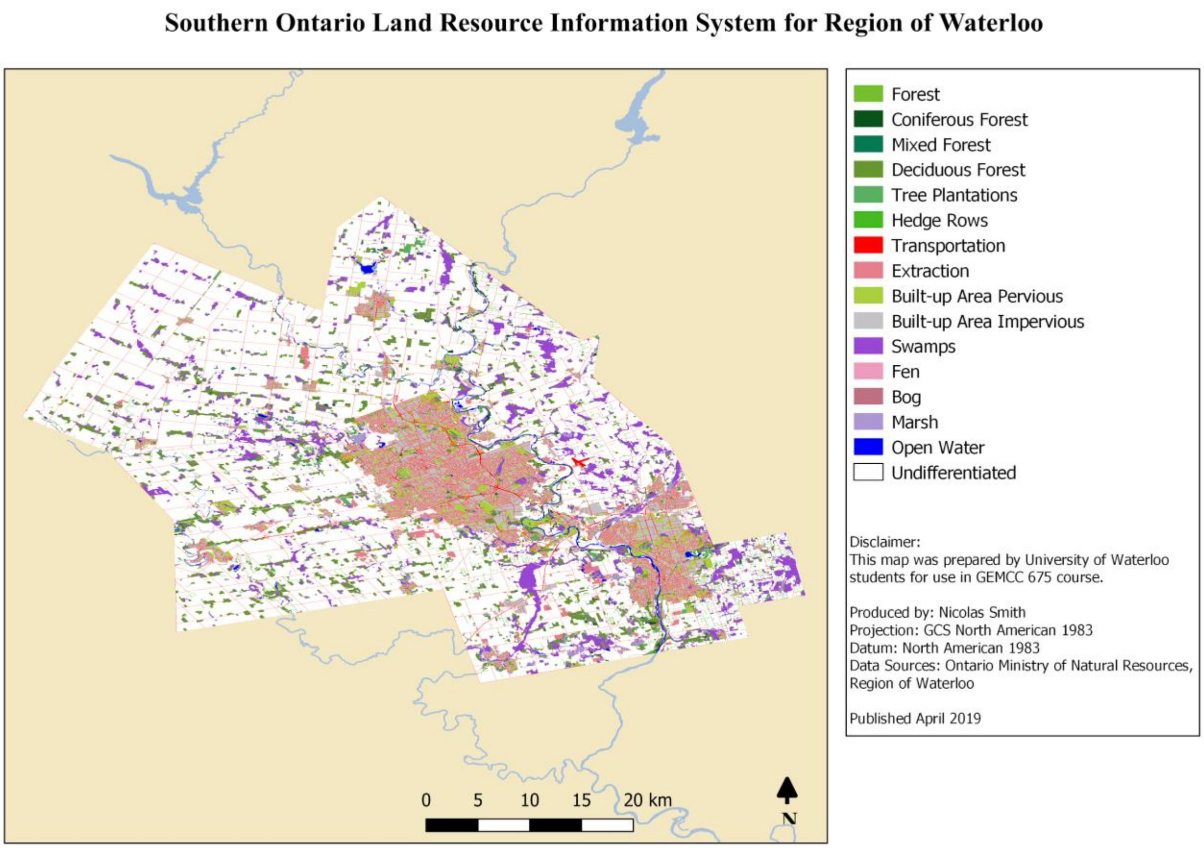

Figure 2.1. Map of Southern Ontario Land Resource Information System (SOLRIS) for Region of Waterloo (DMTI Spatial Inc., 2014c; Ontario Ministry of Natural Resources, 2002; Region of Waterloo, 2019).

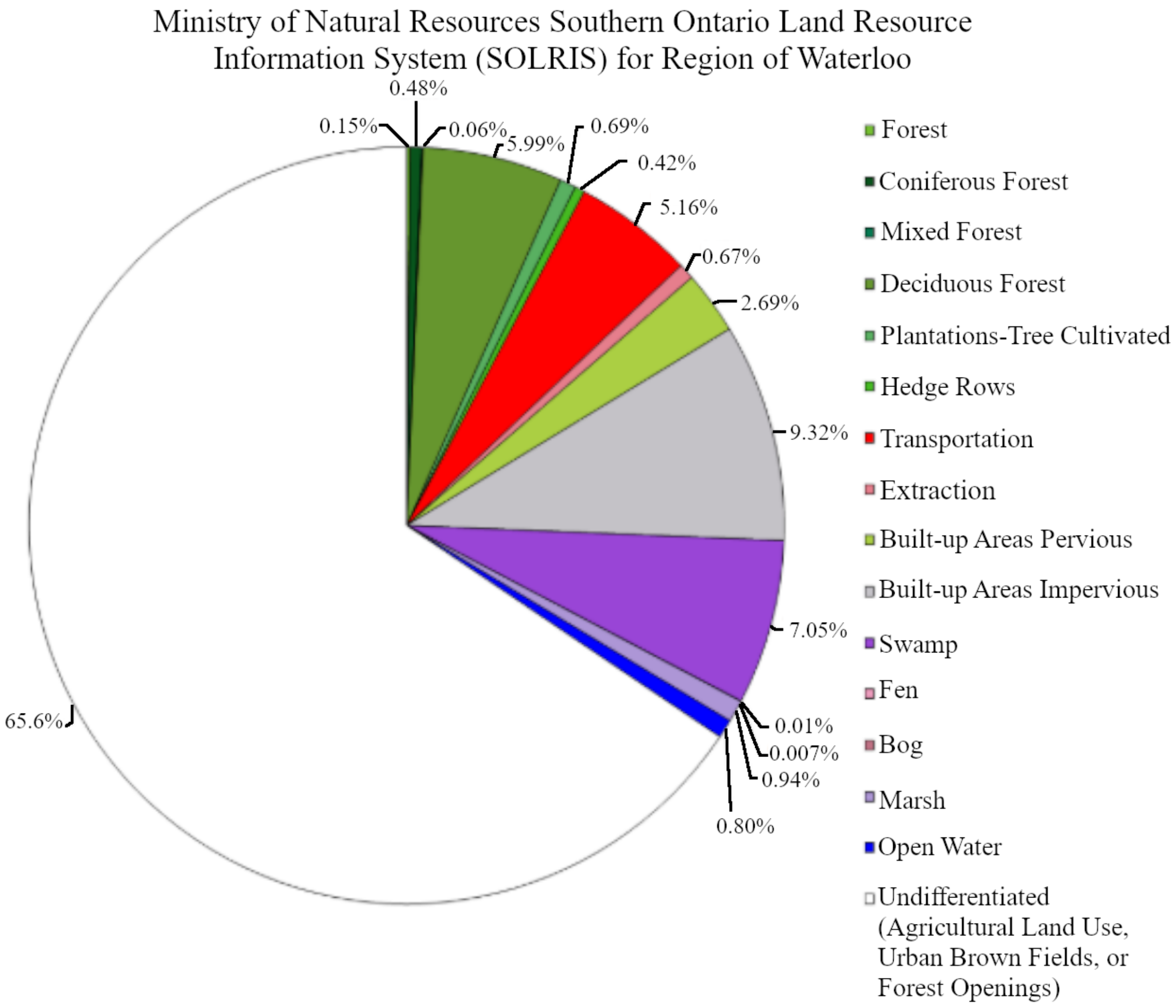

Figure 2.2. Pie graph depicting percentage of area coverage for various ecological land classifications under SOLRIS (Ontario Ministry of Natural Resources, 2002; Ontario Ministry of Natural Resources and Forestry, 2015).

2.3.2 Tree canopy coverage for small-scale (quaternary) watersheds in Waterloo Region

As tree canopy coverage decreases, so does the health and wildlife diversity of the ecosystem. The Environmental Commissioner of Ontario (2018) considers 30% tree coverage to be a minimum benchmark for healthy forests (See Appendix B Figure 2.11). Watersheds are the topographical water boundary controlling water outflow which creates a physical boundary to delineate the tree canopy coverage area (Government of Ontario,

2019b). The amount of wooded area with trees over 2 metres tall in an individual watershed is used to determine the amount of tree canopy coverage in this map (See Appendix A Tree Canopy Coverage Calculation). Waterloo Region contains six small-scale (quaternary-scale) watersheds with each of these watersheds containing canopy coverage of less than 20% with only one of the six at 34%. Therefore, the forests in WR are not optimal for supporting species richness as defined by the Environmental Commissioner of Ontario (2018) (See Figure 2.3). Neighbouring regional municipalities, including Guelph, Oakville, St Catherines, and Toronto have aspired to reach tree canopy coverage targets of 30-40% (City of Guelph, 2012; City of Toronto, 2016a). This lack of tree canopy coverage increases the rate of water runoff and limits the benefits of trees in urban settings (Szota et al., 2019).

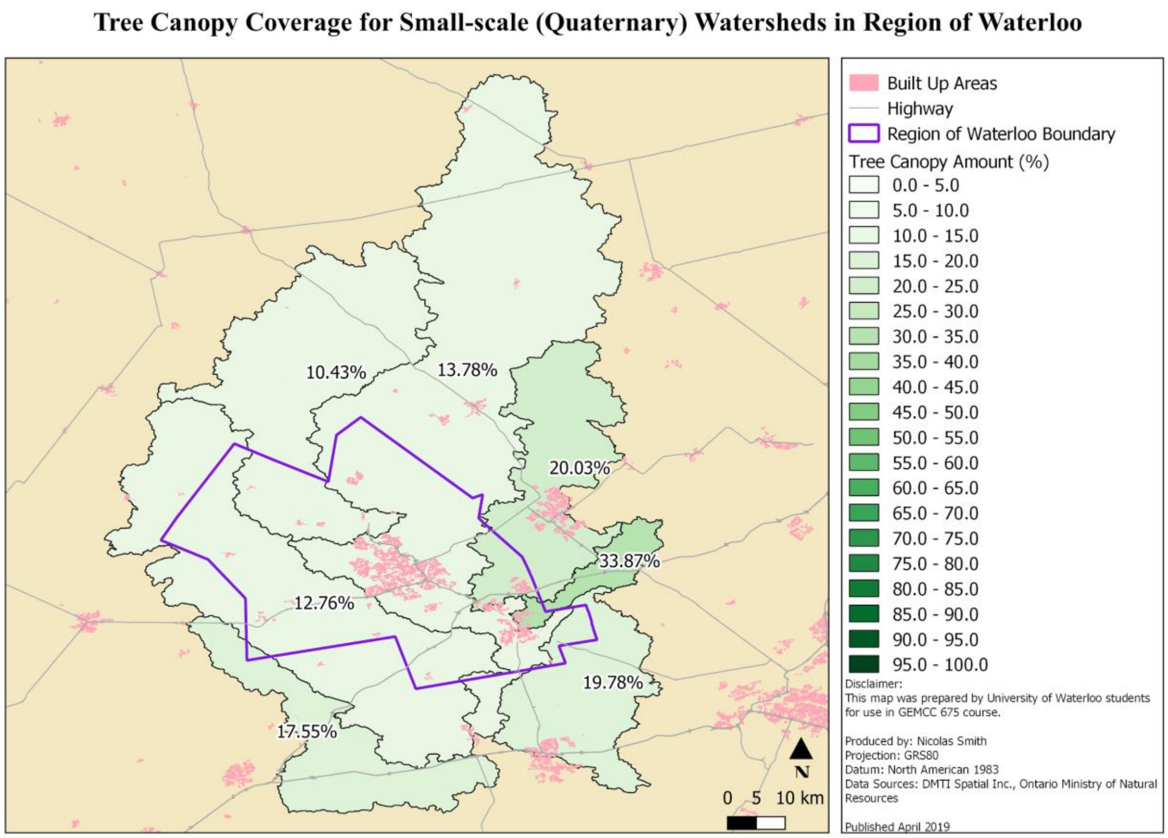

Figure 2.3. Map depicting tree canopy coverage for quaternary watersheds in the Region of Waterloo (DMTI Spatial Inc., 2014a; DMTI Spatial Inc., 2014b; DMTI Spatial Inc., 2014c; DMTI Spatial Inc., 2018a; Ontario Ministry of Natural Resources, 2006; Ontario Ministry of Natural Resources, 2010).

2.3.3 Waterloo Region tree canopy coverage area

Figure 2.4 and 2.5 show the tree canopy coverage by community and municipal area in Waterloo Region (See Appendix B Table 2.1 for tree canopy coverage values for WR communities and Table 2.2 for all of southern Ontario). Tree canopy coverage is affected by both the amount of trees present and the size of the area. North Dumfries township clearly has the greatest tree coverage in the Waterloo Region. This is a rural area with relatively low development and almost 1000 acres of the land is under the management of the rare Charitable Research Reserve (rare Charitable Research Reserve, 2019). In comparison, the urban areas are consist of impervious surfaces with a greater reduction in the tree canopy coverage. Understanding the variability in tree canopy coverage between rural and urban areas provide insight how tree management practices should be improved.

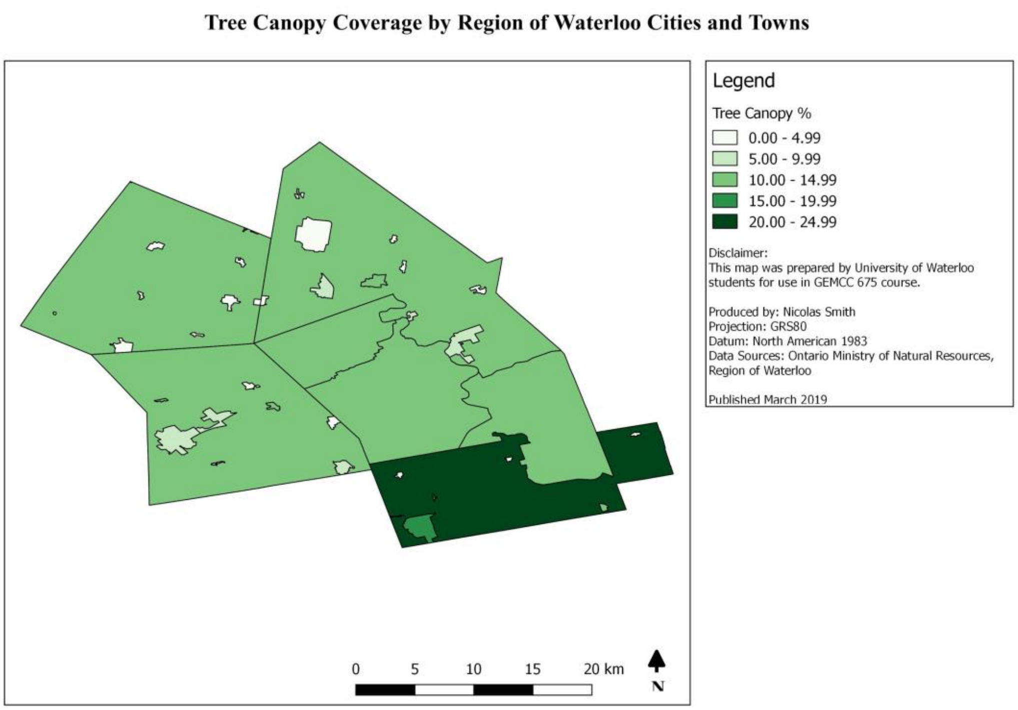

Figure 2.4. Map of tree canopy coverage by Region of Waterloo cities and towns (Ontario Ministry of Natural Resources, 2006; Region of Waterloo, 2019a).

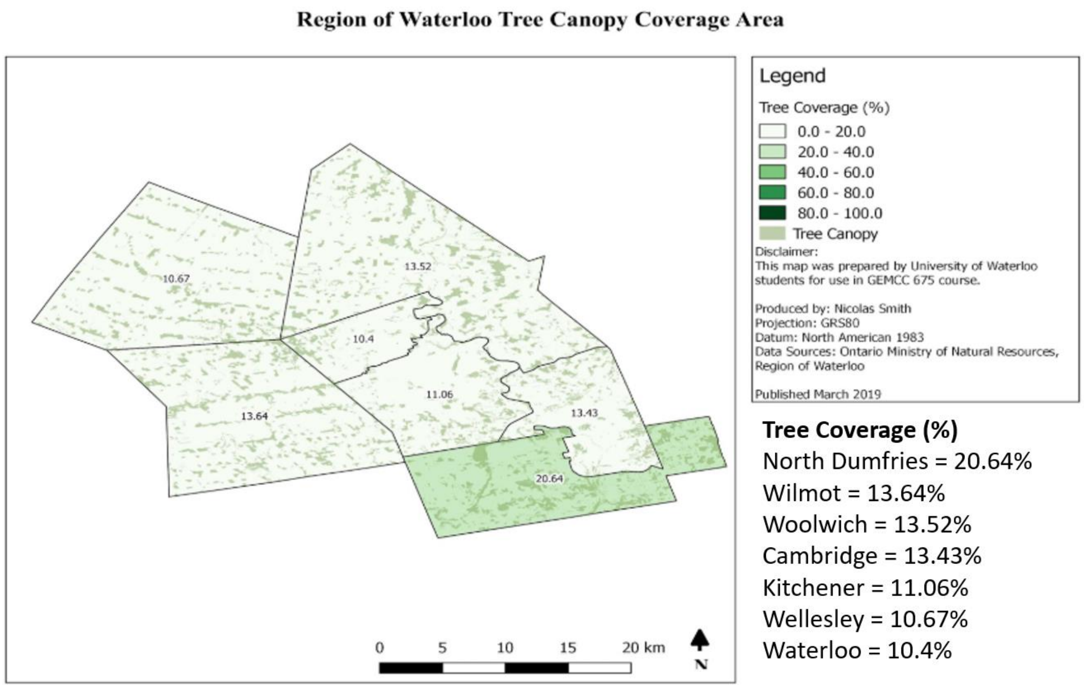

Figure 2.5. Region of Waterloo tree canopy coverage area map (Ontario Ministry of Natural Resources, 2006; Region of Waterloo, 2019c).

2.3.4 Tree canopy coverage for Waterloo Region and surrounding area

Figure 2.6 shows how WR compares to the surrounding municipalities in terms of total area of tree canopy coverage (See Appendix B Table 2.2 for all tree canopy coverage values for southern Ontario). Shown in pink on this map are built up urban areas with much of the surrounding area being agricultural land, a common land-use type for Southwestern Ontario. Comparison between municipalities provides an understanding of how tree canopy coverage can vary.

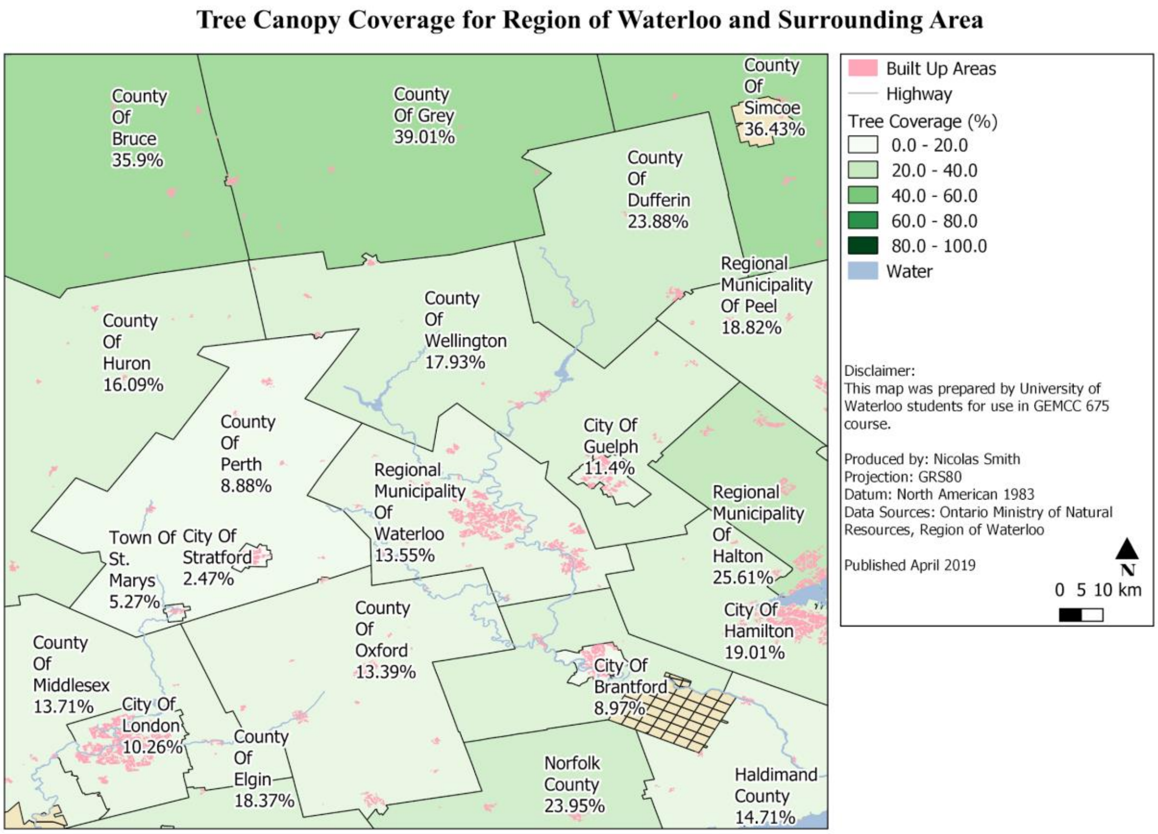

Figure 2.6. Map of the tree canopy coverage for the Region of Waterloo and surrounding area (DMTI Spatial Inc., 2014b; DMTI Spatial Inc., 2014c; DMTI Spatial Inc., 2018a; Ontario Ministry of Natural Resources, 2006; Ontario Ministry of Natural Resources, 2012a; Region of Waterloo, 2019c).

2.3.5 Wooded area of southern Ontario

Another means to assess the tree canopy coverage in southern Ontario was done through displaying the distribution of wooded areas with tree heights greater than 2 metres. This map provides a visual understanding of how tree canopy coverage is distributed (See Figure 2.7). Agricultural land and human settlements are clearly seen with the lack of trees greater than 2m. The most significant tree canopy coverage is located north of WR, in the Greenbelt surrounding the Greater Toronto Area, and in the Six Nations of the Grand River community (Environmental Commissioner of Ontario, 2018; See Figure 2.7).

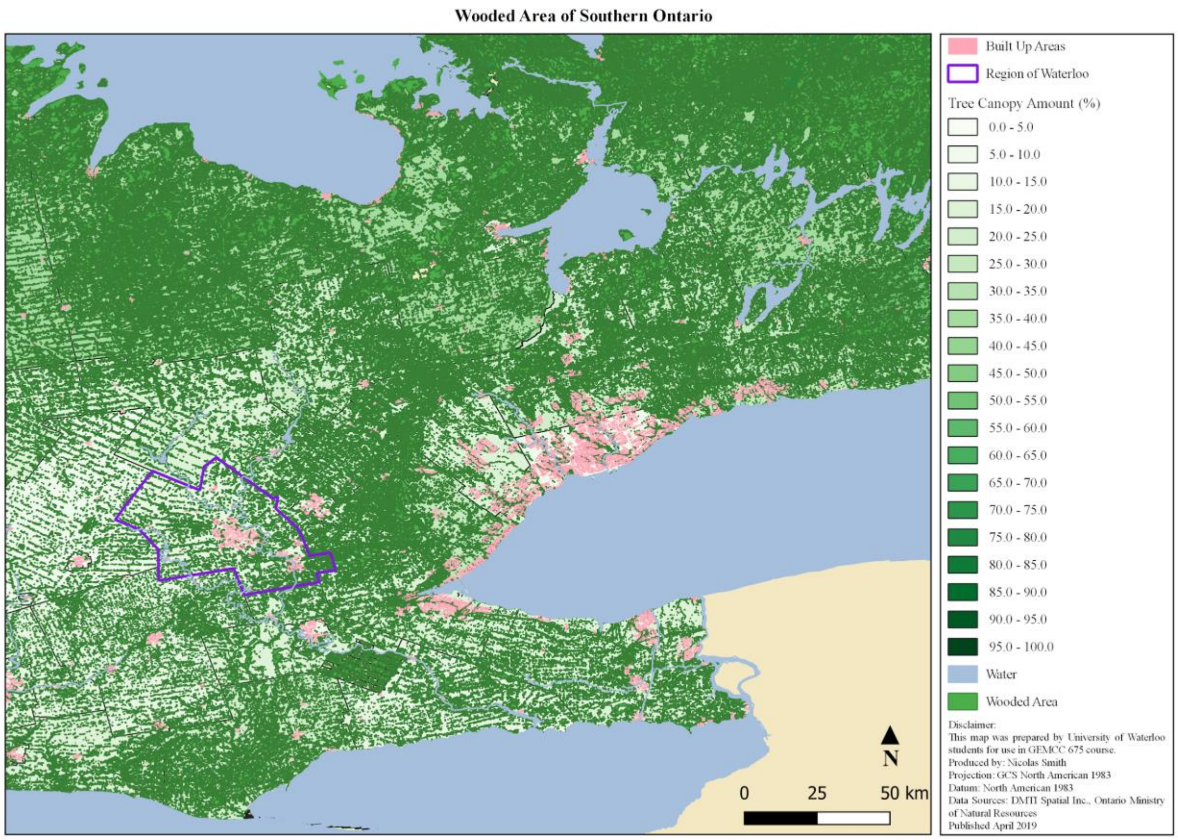

Figure 2.7. Map depicting the wooded area of southern Ontario (DMTI Spatial Inc., 2014c; DMTI Spatial Inc., 2018a; DMTI Spatial Inc., 2018b; Ontario Ministry of Natural Resources, 2006; Ontario Ministry of Natural Resources, 2012a; Ontario Ministry of Natural Resources, 2012b).

2.3.6 Built up area and tree canopy coverage in southern Ontario

The map in Figure 2.8, provides context to the percentage of land covered by the tree canopy and built up areas in southern Ontario (See Appendix B Table 2.2 for tree canopy coverage values). As seen in the previous map (Figure 2.7), agriculture and built up areas have greatly reduced the native forests to only a fraction of their former size. Continued development in southern Ontario continues to degrade what remains of the provinces natural history (Environmental Commissioner of Ontario, 2018).

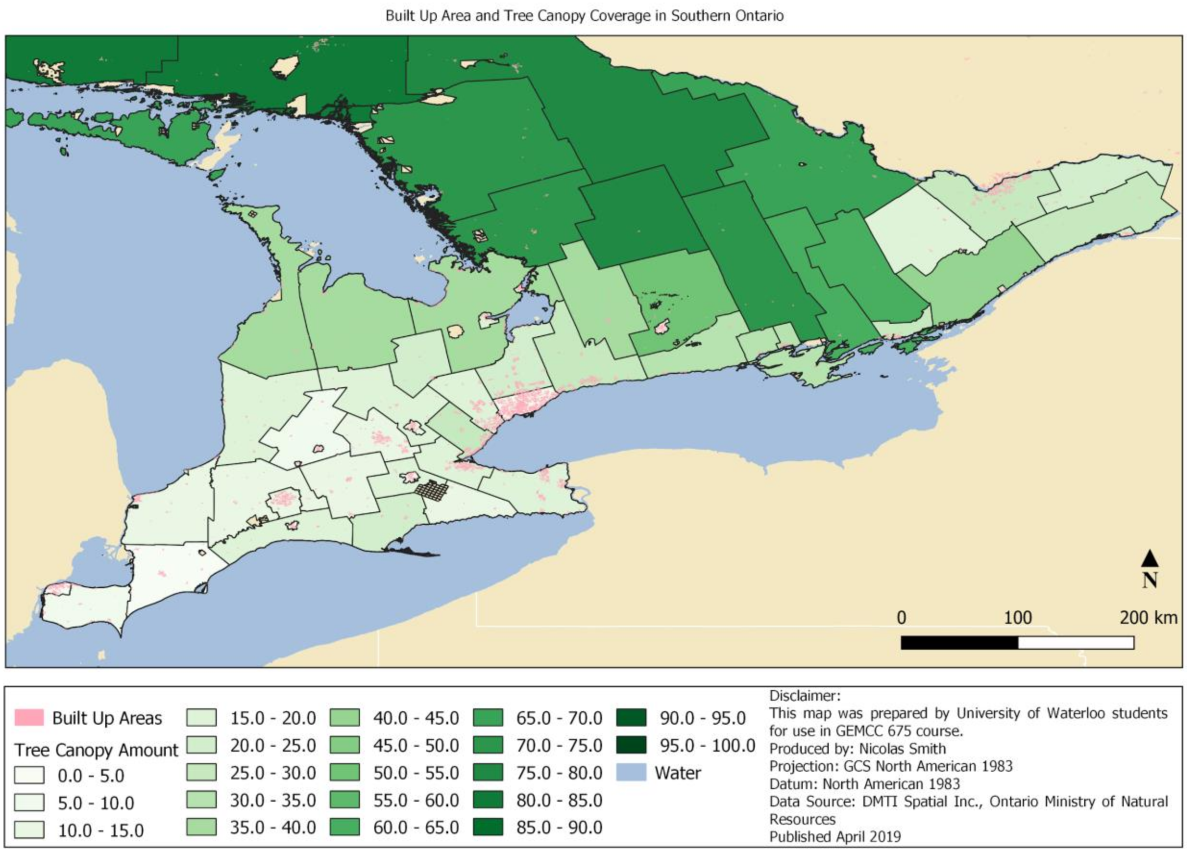

Figure 2.8. Map of the built-up area and tree canopy coverage in southern Ontario (DMTI Spatial Inc., 2014; DMTI Spatial Inc., 2018a; DMTI Spatial Inc., 2018b; Ontario Ministry of Natural Resources, 2006; Ontario Ministry of Natural Resources, 2012a; Ontario Ministry of Natural Resources, 2012b).

2.3.7 Tree canopy analysis progress by municipality

Different cities and municipalities within the WR have made investments in quantifying and managing their tree canopies. Figure 2.9 shows the municipalities of Kitchener and Cambridge have completed a tree canopy analysis, the City of Waterloo and Township of Woolwich are in the process of analyzing their tree canopies, and the remaining townships having not performed any tree canopy analysis to date.

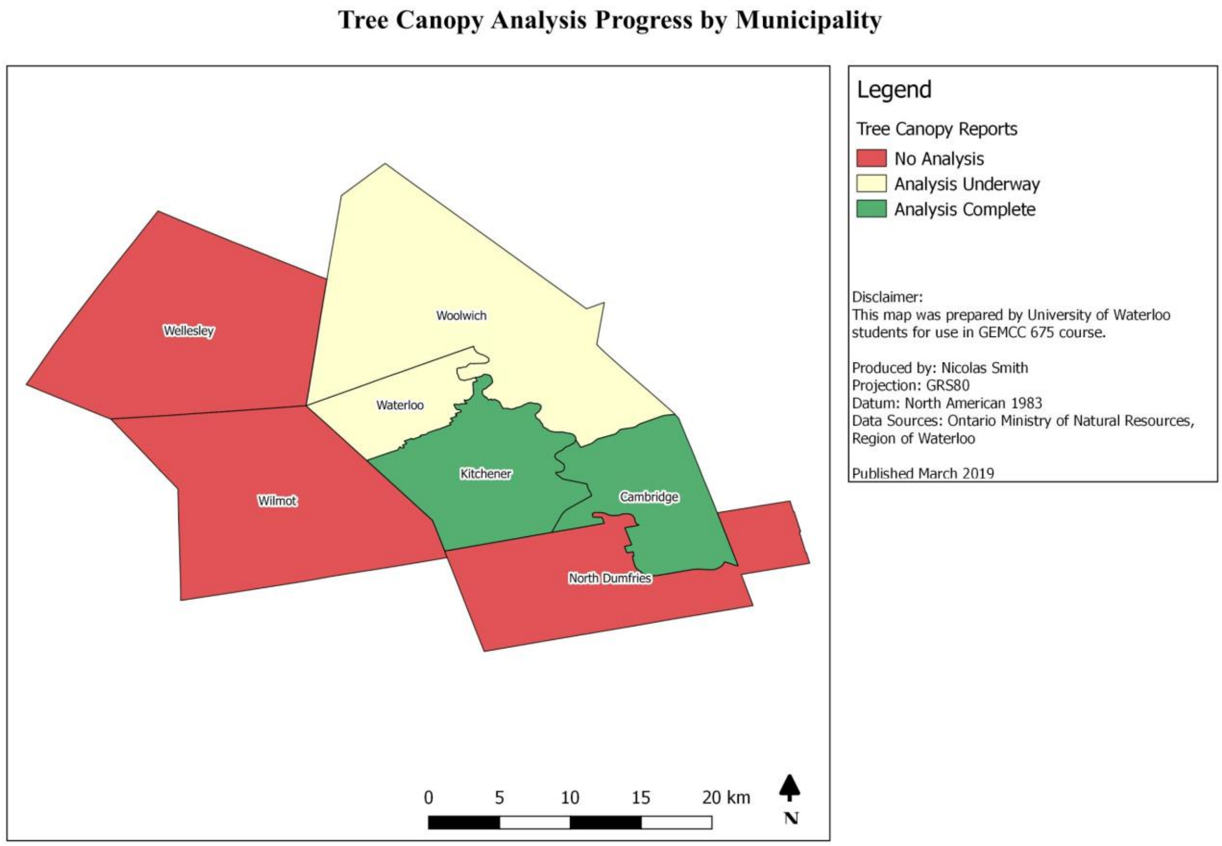

Figure 2.9. Map of tree canopy analysis by area in Region of Waterloo (City of Kitchener, 2017a; City of Kitchener 2019; Region of Waterloo, 2019b; Urban Forest Innovations Inc. & Beacon Environmental Ltd., 2015).

2.3.8 Limitations

For this project, there have been several limitations to the GIS analysis. These limitations included a lack of access to the cities and townships existing tree canopy analyses, the lack of current data for tree canopy characteristics, and poor resolution of the available data. With these limitations, the maps lacked the detail to provide accurate assessment of the urban tree canopy. In turn, this affected the quality of the maps created and the level of detail conveyed in the maps.

2.3.9 Recommendations

GIS analysis provides a fantastic means to assess the extent of tree canopies in southern Ontario. Some recommendations which can be done to increase the quality of the analysis include: accessing up-to-date map data to enable detailed analysis of the various land uses in the area; increasing the accuracy of the data used to make the maps higher resolution; establishing a shared online mapping resource such as ArcGIS Online between WR and the communities within it; and expanding the area of study to other issues which impact tree canopy coverage such as variation in coverage based on land usage (Wang, Wang, & Liu, 2018). LiDAR, which stands for Light Detection and Ranging, is a valuable resource as it uses light to map the 3-dimensional characteristics of the Earth to assess the diversity and age of the tree stock (Anderson, Reutebuch, & McGaughey, 2006; NOAA, 2018; Wang, Wang, & Liu, 2018). We recommend seeking current LiDAR maps of the tree canopy. Understanding the spatial distribution of tree species is vital to project how climate change will impact the urban canopy. Improving the quality of the GIS analysis can support decision makers with relevant and timely information to ensure beneficial decisions are made regarding forest management practices for Waterloo Region.

2.4 Conclusion

Current tree canopy coverage in southern Ontario has been shown to be at relatively low levels which are concern for providing adequate ecosystem services for the community. Understanding the current state of Waterloo Region's urban forests provides a baseline for taking initiatives to ensure better tree management. Being aware of the current state of the urban forests, through assessment of the tree management plans created by the cities of Kitchener and Cambridge, can be useful to inform the urban tree management plan for Waterloo Region. Use of GIS analysis provide a valuable assessment of the tree canopy and can used further to refine understanding of the benefit of WR tree stock.

3.0 Climate Change Projections for Waterloo Region

3.1 Introduction

To understand how the climate will be changing in Waterloo Region (WR), this report utilized climate projection models to generate and interpret data for 2011-2100. The models and scenarios are described in section 3.2 followed by details regarding specific climatic changes anticipated in WR (section 3.3). In section 3.4, the impact of the predicted changes on the urban tree canopy (UTC) is explored. All graphs of projection data can be found in Appendix C.

3.2 Climate Change and Waterloo Region

To assess changing climate conditions in WR two types of climate projection models were utilized. The CanRCM4 model was processed with two Representative Concentration Pathways (RCP) scenarios, and through the Environment and Climate Change Canada (ECCC) online database, the Coupled Global Climate Model 3/T47 (CGCM3/T47) was used. Projection time frames included the 2020s, 2040s, and 2080s.

The RCP scenarios represent different trajectories for global greenhouse gas (GHG) emissions which impact the radiative forcing (the balance between incoming and outgoing radiation) and are outlined in the fifth assessment report for the International Panel on Climate Change (IPCC) (van Vuuren et al., 2011; Wayne, 2019). RCP 4.5 considers stabilizing GHG emissions before the end of century as is required if we are to meet our Paris Agreement commitments and keep temperature rise well below 2°C. RCP 8.5 represents increasing emissions associated with business as usual (van Vuuren et al., 2011).

The CGCM3/T47 model from ECCC uses the A1B scenario from the Special Report on Emissions scenarios outlined in the third IPCC report (Joyce et al., 2014). With this model and scenario, the climate data is projected from GHG emissions based on a socioeconomic trend in which markets project an equal balance between fossil fuel and alternative energy (Joyce et al., 2014). With personal gains being prioritized over environmental conservation, this scenario assumes a large growth in the economy, the rapid introduction of new technologies, and population decline beyond 2050 (IPCC, 2000). By assessing the climatic changes through several different scenarios to the year 2100, this helps to reduce the uncertainty surrounding the future projections (Joyce et al., 2014).

A technical report produced by the University of Waterloo's Interdisciplinary Center on Climate Change (IC3) provides further detail regarding localized climate projections. This research from 2015 used the CMIP5 model and looked at three RCP scenarios (2.6, 4.5, and

8.5) to provide the Region of Waterloo with climate projections for the 2020's, 2040's and 2080's.

3.3 Climate Projections for Waterloo Region

An increasing temperature trend was projected for the Waterloo Region using the CanRCM4 model under RCP scenarios 4.5 and 8.5. The rate of increase was greater for RCP 8.5 than for RCP 4.5 as seen in Appendix C, Figure 2. For comparison, the baseline temperature trends are displayed in Appendix C Figure 1. Using data from Wellington A weather station in Waterloo Region, the CGCM3/T47 model under scenario A1B confirms increasing temperature predictions (Figure 3). The CGCM3/T47 model generated detailed projections of temperature increase including the number of days with temperatures greater than 30°C and 35°C throughout the 2020's, 2040's and 2080's (Figure 4). Through these temperature increases, the CGCM3/T47 model shows the impact of changing temperatures on the length of the growing season. Overall, Appendix C Figure 5 shows an increase the number of growing degree days for each time frame for Waterloo Region. The baseline growing season of 185 days is anticipated to increase to 227 days in length by the 2080's.

The precipitation profile projected through CGCM3/T47 shows reduced snowfall and increased rain days throughout all time frames (Appendix C Figure 6). Although the data collected for this report does not provide any variables for measuring the frequency of freezing rain, other work suggests a 40% increase in freezing rain events during the 2050s and 45% during the 2080s for Waterloo Region (IC3, 2015). The CGCM3/T47 projection data provides details regarding water balance within the system suggesting that water will become more available in winter months while summer months show greater likelihood of droughts (Appendix C Figure 7). The water balance graphics include total precipitation which shows a slight increase each year. This data is confirmed using the CanRCM4 model for the 4.5 and 8.5 scenario (Appendix C Figure 9). Compared to the baseline data in Appendix C Figure 8, the 8.5 scenario suggests the greatest increase in precipitation. The RCP 4.5 projection does not show a significant change in annual precipitation patterns.

A projection report for WR was produced by the IC3 and the University of Waterloo in 2015 (IC3, 2015). The report projects an increase in rainfall intensity and extreme rain events throughout the 2020's, 2040's and 2080's. This report also projects an increase in the number and intensity of storms experienced in the region.

There are many uncertainties associated with predicting wind speed due in part to a lack of baseline data as well as the complex influence of terrain and infrastructure on air movements (Suárez et al., 1999). The projection data provided by the CanRCM4 model shows a slight decrease in the annual average wind speed (Appendix C Figure 10). The CGCM3/T47 model did not include wind speed projections. However, extreme weather events are likely to be accompanied by strong wind gusts and these events are projected to increase with climate change (IC3, 2015).

3.4 Climate Change Impacts to the Urban Tree Canopy (UTC)

This section provides background information about how the changing climate will affect the vulnerability of trees. Specifically, the impacts associated with increased temperature and drought severity, susceptibility to ice storms and wind speed, as well as the effects of climate change on pest and diseases are explored.

3.4.1 Heat extremes and drought severity

Over the 21st century, temperatures are expected to increase in Waterloo Region. As heat extremes become more common, their impacts on tree health will likely increase. Examples of this impact include the European heatwave in 2003, which resulted in a 30% reduction in tree growth, as measured by gross primary productivity. Similarly, in 2010 a heat wave in Russia resulted in a 50% decrease in productivity of the ecosystem (Teskey et al., 2015).

The greatest damage to trees results from a combination of heat stress and drought which degrades the quality of tree health. When combined with low precipitation, heat stress can result in mortality. Physiologically, periods of extreme heat can result in a decrease in leaf growth and leaf development (Teskey et al., 2015).

3.4.2 Length of the growing season

The length of the growing season is anticipated to increase in WR as a consequence of climate change, with warm weather coming earlier in the spring and lasting later into the fall (See Appendix C Figure 5). These changes may affect the ecological timing of the plants life cycles. For tree growth, the timing of onset warm spring weather can be impactful specifically to bud burst and leaf out processes (Teskey et al., 2015; Tubby & Webber, 2010). Alternatively, a shortened winter season can pose challenges for tree species that require long-term cold for full bud vernalization and breaking seed dormancy (Tubby & Webber, 2010).

A local example regarding changes in seasonal temperatures is observed with Sugar Maples in Ontario, which experienced approximately 12-40% mortality of the canopy, and significantly reduced photosynthetic capacity following exposure to abnormally high spring temperatures in 2010 (Teskey et al., 2015; Filewood & Thomas, 2014). The observed

effects were species specific as other species in the area, including Red Maple, Beech, and Black Cherry were not affected by this spring heat event (Teskey et al., 2015).

3.4.3 Ice storms and wind speed

The vulnerability of trees to ice storms is related to the structural growth of the species. The amount of damage from ice loading and accumulation will have different impacts depending on variables such as branch strength, surface area of lateral branches, and type of structural crown (Hauer et al., 1994). For example, decurrent branching, where the branches extend downwards is common for deciduous trees and increases the vulnerability to damage by ice storm events (Hauer et al., 1994). Alternatively, excurrent branching, commonly seen with conifer trees, have an increased tolerance to ice loading. Figure 2.2 in Section 2 confirms a higher proportion of deciduous trees in Waterloo Region compared to coniferous species. Other structural elements that increase the resilience to ice loading include lower surface area of lateral branches and coarse branching patterns (thicker but overall fewer branches) (Hauer et al., 1994). Tree placement also plays a role in reducing the property damage that can occur due to extreme ice events. Furthermore, damage from ice accumulation can increase in strong winds (Hauer et al., 1994). Within the UTC, trees that are highly susceptible to ice damage should be maintained through pruning to decrease the structural vulnerability.

Pruning trees is important for many reasons. Weak limbs, over-extended lateral branches, and other vulnerable part of a tree should be removed. Careful pruning can decrease the risk of trees and branches coming down during ice and wind storms (Hauer et al., 1994). When limbs are torn from a tree during storms, they often tear off large pieces of bark and can compromise the integrity of the tree. The fallen branches can also damage buildings, vehicles, power lines, and block roads (Marshman, 2018; Hauer et al., 1994). While we do not have good projections about future wind intensities, Waterloo Region is expected to experience more ice storms in the coming decades with climate change (IC3, 2015). Regular inspection and pruning is a cost-effective way to reduce the potential damage from fallen trees and branches during ice and wind storms.

3.4.4 Pest and diseases

As the climate in WR changes, the prevalence and effects of pests and diseases on UTC health is also likely to change. With rising temperatures, it is anticipated that an increased abundance of pests will be observed (Meinke et al., 2013). Tree diversity plays a significant role in protecting the UTC from pests and diseases. Trees growing in a mixed forest setting demonstrate an increased resistance to pests when compared to monoculture growth

(Ramsfield et al., 2016). In Appendix F, Table 1 describes common pests/diseases that are found in Ontario and the surrounding areas. The Canadian Food Inspection Agency is responsible for developing regulations and bans to reduce migration of species, but solutions encourage homeowner identification and monitoring.

Ecologically, pests and diseases have relatively short life cycles, high reproductive potential and larger dispersal capacity when compared to trees (Tubby & Webber, 2010). As the climate changes, trees will become more stressed by environmental conditions making them more vulnerable to pests and diseases. In Table 4.1 of Appendix D provides details about susceptibility of local tree species to specific pests and diseases. For example, ash trees have been popular urban trees in the Waterloo Region as they are good shade trees. However, the Emerald Ash Borer, which originated in Asia, has been wiping out local ash trees in recent years (Alvey, 2006).

Climate change will also have an impact on the pests and diseases that attack trees (Tubby & Webber, 2010). Climate change will likely: alter the physiology of host plants, which will impact on their susceptibilities to the pests and disease; affect pest development and survival; alter the populations of natural enemies and competitors to pests; allow non-native pest and diseases to flourish and survive; change the range, distribution, and timing of breakouts of pest species; and affect the behaviours and eating habits of pests (Tubby & Webber, 2010).

Long term tree management plans need to consider how invasive species may affect the tree canopy. The devastation of Ash trees by the Emerald Ash Borer in WR reinforces the need for more research and advanced planning on potential invasive pests. Native and non-native pests/diseases are unpredictable, therefore increasing tree diversity is the recommended approach for reducing the potential impacts of future invasive species.

3.5 Conclusion

Throughout this century, WR can expect changes in temperature and precipitation patterns which will impact the UTC. During the summer months, extreme heat and drought will reduce tree development as well as defenses. Changes to precipitation patterns will alter the water balance increasing water deficit in summer months and a surplus during winter. Increased storm events are anticipated including ice storms. The vulnerability of a tree depends on numerous variables including the species, size and shape. Table 4.1 in Appendix D provides details for over 100 species to help city planners identify which tree species are more suitable for the changing climate.

Climate Change and the Tree Canopy of Waterloo Region

The activity of pest and diseases in the UTC is likely to increase with climate change. Temperature changes directly impact the interaction between pest/diseases and trees. Local awareness to identify common pests and diseases that impact WR tree species is significant step towards protection. Ultimately, increasing species diversity will reduce the vulnerability of the urban tree canopy to pest and diseases.

4.0 Climate Change and Trees

4.1 Introduction

The trees in the Waterloo Region will be impacted by climate change, and they will have an impact on the ability of the region to respond to climate change. As the climate changes in the region, it will become less suitable for many existing tree species and more suitable for species that are not common to the area at this time: plant hardiness zones have already shifted northward and will continue to do so, while range limits for particular species are also shifting. The Kitchener and Cambridge tree reports include data that suggest a lack of diversity in our urban canopy (Urban Forest Innovations Inc. & Beacon Environmental Ltd., 2015; City of Kitchener, 2019), and this is likely true for the entire region. This makes the canopy particularly vulnerable to environmental stressors, including the changing climate. Our trees help to mitigate climate change by sequestering carbon dioxide. Trees also help to build resilience toward the stresses associated with climate change through their ability to provide shade, improve air quality and improve mental and physical health. Careful selection of tree species can help to avoid the pollen and biogenic volatile organic compounds that can have a negative effect on human health. Finally, urban trees can help us to adapt to some climate change impacts by reducing the urban heat island effect and managing stormwater. We have summarized the available species-specific information for many of these factors in Table 4.1 of Appendix D.

4.2 Climate change and growing range mapping

4.2.1 Plant hardiness zones

USDA plant hardiness zone maps show the geographical ranges of climatic conditions for plant growth and survival. Each zone on the map is characterized by the extreme minimum temperature experienced annually. Since plants are highly susceptible to cold conditions, these zone ratings provide a guide to the types of plants that will survive winters in an area over the long term. These maps, however, do not consider other climate factors that impact on plant survival, including frost dates, precipitation patterns, insolation, soil conditions, or extreme maximum temperatures (Mckenney et al., 2007).

Canada developed its own plant hardiness zone maps based on extreme minimum and maximum temperatures, frost free period, rainfall, snow depth, maximum wind gust, and a winter factor (Mckenney, 2001).

Generally, plant hardiness zones of both types have been moving northward as our climate changes (Mckenney et al., 2014). Between the years 1961 to 1990, WR was in USDA zone 5a/5b and Canada's plant hardiness zone 5a/5b. By 1981-2010, the region had moved to USDA zone 5b and Canada's plant hardiness zone 5b/6a (Government of Canada, 2017a).

Figure 4.1 shows the Canadian plant hardiness zones for Southern Ontario in 1961-1990 and 1981-2010. It is likely that WR will enter new hardiness zones as the climate continues to change.

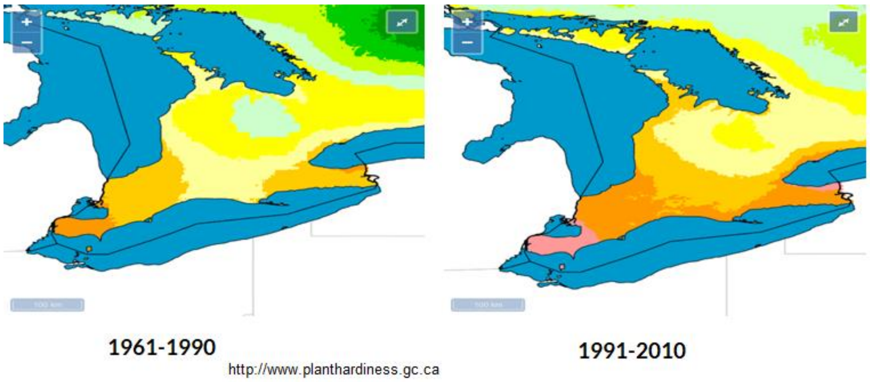

Figure 4.1: Plant hardiness zone maps for Southern Ontario showing movement of the zones between 1961-1990 and 1991-2010 (Government of Canada, 2017a).

4.2.2 Climate envelopes

An alternative to mapping general plant hardiness zones is to track the climate envelopes, which map the range limits of a particular species (Mckenney et al., 2014). Predicting the long term health of individual plant species in a changing climate is challenging, however, especially when climate projections include increasing seasonal variability. For example, a warming climate may encourage the growth of less cold-hardy plant varieties that are also more susceptible to late spring frosts (Mckenney et al., 2014). A climate envelope study of Canadian trees species showed an average 57 km northward shift between 1931-1960 and 1981-2010 (Mckenney et al., 2014), demonstrating that the ideal climate conditions for these Canadian trees are already on the move.

Natural Resources Canada has a database of current and projected climate envelopes for over 3000 plant species (Government of Canada, 2017b). Several climate projection models are available. We chose to use the ANUCLIM CanESM2 model with RCP 4.5 and RCP 8.5 conditions as these are the models that are similar to those used in other parts of this report. A list of local tree species was compiled to produce Table 4.1 in Appendix D. This table shows if WR has been (1971-2000), or will be (2071-2100 projections) within the range (core, in range, or out of range) for each tree species. Core range is defined by areas within the 5th to 95th percentile for climate values, whereas the broader range includes species growth areas that fall between the minimum and maximum climate values. The climate profile for each species is gathered using citizen science programs and professional reporting to produce the species-specific climate values. Figure 4.2 shows the current and projected climate envelopes for the Saskatoon tree.

Climate envelope data was found for 99 of the 146 WR tree species. Only five of these species are currently growing out of their normal range. By the 2080's, under scenario RCP 4.5, the WR will no longer be suitable for 7 species, but under scenario RCP 8.5 (2071-2010), that number jumps to 39 species, with spruce and pine trees being particularly vulnerable to shifts in climate (see Table 4.1 in Appendix D).

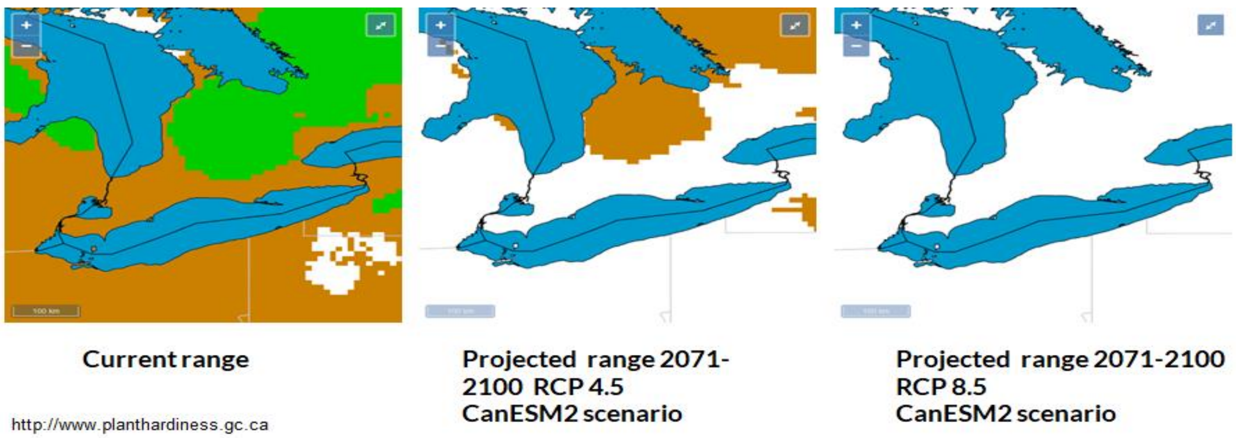

Figure 4.2. Range maps for the Serviceberry tree under current and projected (2071-2100) climates under RCP 4.5 and 8.5 scenarios (CanESM2 model used) (Government of Canada, 2017b).

4.3 Vulnerability of the urban tree canopy to climate change

The vulnerability of the UTC depends on the diversity and distribution of tree species. Over-reliance on any one species leaves the population vulnerable to pests, diseases, and climate change. A diversity of species, age, environmental tolerances, and climatic preferences is recommended to ensure that tree populations are able to survive and adapt to a variety of stresses, including changes in climate conditions (Alvey, 2006). To ensure that trees reach maturity, proper maintenance plays a large role in increasing the diversity of old and new growth species (Tubby & Webber, 2010).

Native species have traditionally been promoted for urban areas based on the assumption that these species thrive in local conditions and require less management than non-native species. There is a lack of evidence to support this, however (Chalker-Scott, 2015). Although invasive species should be avoided, non-native trees may increase the biodiversity of both the tree population and the populations of associated plants, birds, insects, reptiles and mammals (Chalker-Scott, 2015). Introduced tree species may also be better suited to urban conditions than their native counterparts, and as our climate

changes, native trees may become less suited to local conditions. A mix of native and non-native tree species is therefore recommended for the Waterloo Region.

Kitchener reports that 43% of its street and park trees are maple varieties, 9% are linden trees, 6% are lilac, 5% are honeylocust, while ash and oak each represent 4% (City of Kitchener, 2017a). Cambridge also reports a higher proportion of maple trees (40%) and ash trees (4-8%) along its streets (Urban Forest Innovations Inc. & Beacon Environmental Ltd., 2015). In both cases, the ash trees are likely to be wiped out by the Emerald Ash Borer further decreasing the diversity of species (Alvey, 2006). This demonstrates the risks associated with low diversity in the street and park trees.

Climate change is not the only stressor that will affect the future health of the UTC (Brandt et al, 2016). Site-specific conditions, including exposure to toxic compounds from vehicle exhaust and de-icing salt have a significant impact on the natural defenses and adaptive capacity of trees. Infrastructure maintenance and development can cause soil compaction, restrictions on root expansion, and the relocation or removal of urban trees (Gillner et al, 2013; Tubby & Webber, 2010). Information about species-specific vulnerabilities to some of these other factors is available in Table 4.1 in Appendix D. The survival of trees in high stress environments can be improved through human interventions such as pruning, watering and physical supports (Yang, 2009).

4.4 Urban tree canopy and climate change mitigation

In the climate change context, trees are commonly recognized as carbon sinks. Through photosynthesis, trees absorb carbon dioxide and use the carbon to build plant material while releasing oxygen. Quantifying this carbon sequestration, however, is challenging and even controversial. Rates of carbon sequestration vary by growth rate, tree species, tree size, age, health, climate, site conditions, management strategies, and much more (Boukili et al., 2017; Nowak, Greenfield, Hoehn, & Lapoint, 2013). Carbon sequestration by urban trees is also controversial because the carbon is only stored temporarily: the carbon is released back to the atmosphere when the tree dies and decomposes.

Estimates of urban tree carbon storage and sequestration are often obtained from the i-Tree Canopy software, which was developed based on data from common tree types in cities around the world (i-Tree, n.d.). According to the i-Tree report (see Table 4.2 in Appendix E), trees in the WR sequester 380 Kt of CO_2 per year and store a total of 9.53 Mt of CO_2. The Waterloo Region GHG inventory reported a total of 4.3 Mt CO_2 equivalent in 2015 (Climate Action Waterloo Region, 2019). However, since the growth rates of urban trees vary significantly between and within cities, the software results should be viewed as coarse-scale estimates (Boukili et al., 2017).

4.5 Urban tree canopy and climate change resilience

Trees help to keep people plus ecosystems healthy and thereby help to build resilience to the challenges expected with climate change. Trees provide shade, increase food security, improve air quality, and generally contribute to better physical and mental health. Conversely, they can also trigger allergies and asthma, and add volatile organic compounds to the air. Overall, urban trees are good for our cities, and careful selection of tree species can maximize the benefits while minimizing the adverse effects.

The shade from trees can provide protection from ultraviolet radiation, heat relief on hot days, and can decrease indoor air temperatures. Ultraviolet radiation is damaging to both the eyes and the skin, and can cause skin cancer (Ivanov et al, 2018). On hot days, temperatures in the shade of trees can be lower due to reduced sunlight and heat absorbed during evapotranspiration (Berry, Livesley, & Aye, 2013). Finally, the shade of trees can also reduce solar heat gains by neighbouring buildings, thereby reducing energy consumption for air conditioning or improving thermal comfort in buildings without air conditioning (Berry et al, 2013; Hwang et al, 2017).

Native and introduced fruit trees are commonly found in WR nurseries, which suggests they are popular with local residents (Heather McDiarmid, personal observations). Many community gardens have added fruit trees, and the Grand River Food Forestry manages 15 food forests and food hedges (fedges) across the Region (Grand River Food Forestry, n.d.). Increasing the number of fruit and nut-bearing trees in the region can increase local food security and place attachment (Colinas et al, 2018) thereby increasing a community's adaptive capacity toward climate disruptions. Furthermore, fruit trees can attract pollinators and support a diversity of urban wildlife.

Urban trees generally have a net positive effect on air quality. Trees can trap air pollutants and particulates on surfaces such as leaves and can absorb noxious gases through their leaf openings (Leung et al., 2011; Nowak et al, 2006). Among the pollutants removed from the air by trees and other vegetation are ozone, nitrogen dioxide, sulphur dioxide, ammonia, carbon monoxide, and particulate matter less than 10μm (PM10) (Nowak et al., 2006). The i-Tree report found in Appendix E gives broad scale estimates for the amount of pollutants removed by trees in the Waterloo Region. However, trees can also generate biogenic volatile organic compounds (BVOC) such as terpenoids that are chemically reactive and produce secondary organic aerosols such as ozone (Leung et al., 2011). Fortunately, many urban trees have low BVOC emission potential (Nowak 2006). Table 4.1 in Appendix D shows the BVOC emission ratings for various tree species (Kesselmeier, 1999).

Trees have been shown to improve both general mental and physical health. The presence of trees can improve moods as well as reduce stress and anger (Leung et al., 2011). Many studies have found higher tree densities to be positively correlated with better physical and

mental health (Ulmer et al., 2016; Willis & Petrokofsky, 2017). Furthermore, higher densities of trees are also associated with more physical activity in summertime when trees provide shade (Dzhambov et al., 2018).

Pollen from trees can causes asthma and allergic reactions in susceptible individuals (Leung et al., 2011). Pollen is produced by male plants and flowers, and is adsorbed by female flowers. The fertilized female flower then produces seeds and fruit for genetic dispersal. Cities have traditionally chosen male plants for urban planting to avoid the mess caused by the seeds and fruits from female trees (Abramson, 2018). However, this has resulted in higher levels of tree pollen. Furthermore, a recent study showed that the pollen season has been starting earlier across the United States, lasting longer, and peak pollen levels have been rising in recent decades (Schmidt, 2016; Zhang et al., 2015). Pollen allergy rates are on the rise and scientists are investigating the possibility that climate changes is playing a role in this rise (Schmidt, 2016). The Ogren Plant Allergy Scale (OPALS) was used in Table 4.1 of Appendix D to rank trees on how abundant, potent, and allergenic their pollen and or sap is. Low values represent low allergenic plants and high values represent high allergenic plants (Ogren, 2015). Therefore, choosing a mix of male and female trees and species with lower pollen ratings is recommended.

4.6 Urban trees and climate change adaptation

Urban trees can help the WR adapt to its anticipated changes in climate. Climate change will bring more intense summer heat and more frequent large scale rainfalls, for example (see Section 3). Urban trees can reduce the urban heat island effect during hot summer days, and help manage excess surface water from rainfall events.

Urban centres have been shown to be several degrees warmer than their rural counterparts on hot, sunny days through a process called the urban heat island effect. That increase in temperature can pose a health risk for vulnerable populations during extreme heat events and increase the demand for air conditioning (Brown et al., 2018). This effect is due not only to the abundance of dark surfaces that absorb heat in a city (asphalt, dark roofs), but also to the lack of vegetation. Trees and other vegetation help to keep areas cool by reflecting more light, shading surrounding surfaces, transforming light energy into chemical energy during photosynthesis, and absorbing heat for transpiration (Loughner et al., 2012). Climate projections for the WR include significantly more days with temperatures over 30°C (see Section 3) (Cadel et al, 2015). Furthermore, Figure 2.1 shows the locations in WR with impervious built up and transportation areas are more likely to produce urban heat islands. Increasing the tree canopy in WR and other urban centres is a recommended strategy for reducing the urban heat island effect (Wang & Akbari, 2016).

Trees are also important for managing surface water. Trees and other forms of vegetation recycle close to half of the precipitation that falls on them (Chahine, 1992) through interception, infiltration, and transpiration. Trees can also absorb water runoff from impervious surfaces such as roads and buildings (Szota et al., 2019), and this effect can be maximized by planting trees in depressions (Berland et al., 2017). Much of the water routed through trees would otherwise be removed from the urban ecosystems through storm sewers (Gotsch et al, 2018). During intense rainfall events, storm sewers can become overwhelmed and led to flooding. Storm water from impermeable surfaces can also carry many pollutants, such as heavy metals from emissions that can be intercepted by urban trees before they reach sensitive ecosystems (Dadea et al, 2017). Furthermore, tree roots can help to prevent soil erosion during storm events (Escobedo et al, 2011). Waterloo Region climate projections include an increase in total precipitation with more frequent large scale rainfalls (see Section 3) (Cadel et al., 2015). Trees may provide a simple and economic approach to managing stormwater in the urban centres.

4.7 Conclusions

Waterloo's tree canopy will experience stresses associated with the projected changes in climate over the next decades. Some trees will no longer be suitable for our climate under future climate scenarios, while others will experience stress from the changes in the environmental conditions. Our urban tree canopy current lacks diversity and is therefore more vulnerable to these environmental stressors. Our trees provide valuable services, however, including carbon sequestration (climate change mitigation), shade, food, and air quality improvements. Trees also help us to adapt to the projected climate change impacts by reducing the urban heat island effect and managing stormwater. To protect and grow this valuable resource, we encourage decision-makers to use the species-specific resources available in Table 4.1 of Appendix D to select a diversity of trees that best meet our current and future needs. An example of the information provided in this table is shown below for the Norway Maple tree.

Common Name: Norway Maple

Latin Name: *Acer platanoides*

Current range: in core range

Projected range 2071-2100, RCP 4.5: in range

Projected range 2071-2100, RCP 8.5: out of range

Allergen score: 8 (high)

Native: no

BVOC score: low

Mature size: 15x13m

Rate of growth: medium

Planting site locations: centre media, along streets, parks

Form: oval

Soil pH: <= 8.2

Soil moisture: medium to high

Soil compaction tolerance: no data

Shade tolerance: yes

Salt tolerance: moderate

Insect/disease factors: susceptible to tar/black spot, Verticilium Wilt, leafhoppers

5.0 Policy Guidelines and Strategies for Enhancing the Urban Canopy in WR

5.1 Introduction

Counteracting the effects of climate change on the WR tree canopy requires the development and implementation of a robust tree management strategy. The strategy should address canopy protection, planting regimes, funding, and the formation of partnerships. The absence of a current regional-level tree strategy permits Waterloo Region the advantage of building from the best practices and strategies of neighbouring municipalities' urban forest management plans (UFMP). Urban forest management plans are important tools that allow for the creation of a highly tailored vision of the future with regards to strategic goals and objectives as well as guidelines for how tree maintenance should be conducted.

5.2 Ontario Urban Forestry Management Plan (UFMP) Analysis

An analysis of Ontario's urban forestry landscape revealed that only a fraction of Ontario's municipalities have developed UFMPs. Out of the 444 Ontario municipalities, 291 do not have any tree protection policy or guidelines in place (Puric-Mladenovic, 2018). Of the remaining municipalities, 50 use tree by-laws exclusively as tools for managing their urban forests, and 103 municipalities (23%) have developed tree protection policies, strategies, or management plans beyond tree by-laws (Puric-Mladenovic, 2018; see Appendix G). The following municipalities are a selection of regions, towns, and cities in Southern Ontario that have established UFMPs as of 2017 (Puric-Mladenovic, 2017; see Table 5.1).

Table 5.1. Southern Ontario municipalities with Urban Forestry Management Plans as of 2017.

Regions	Cities	Towns
Durham, Halton, Peel, York	Ajax, Barrie, Bracebridge, Brantford, Burlington, Cambridge, Guelph, Hamilton, Kingston, Kitchener, London, Milton, Mississauga, Oakville, Ottawa, Peterborough, Pickering, Richmond Hill, Stratford, St. Catherines, Toronto, and Windsor	Aylmer, Aurora, Port Hope, and Cobourg

5.3 Recommended Urban Forestry Practices

This report reviewed UFMPs in Southern Ontario to ascertain how regional neighbours with similar landscapes and climate developed their urban forest strategies (see Appendix G).The UFMP from the cities of Guelph, London, and Peel Region were deemed as good models for WR's UFMP due to their insightful work into proactive urban forestry practices. We identified seven tree management practices that are particularly important for the development of an actionable WR tree canopy plan:

1. interdepartmental collaboration
2. comprehensive regional tree inventory
3. tree diversification
4. structural pruning & prompt reforestation after disturbances
5. engagement with landowners for canopy expansion
6. pest management strategy
7. increased funding to the urban forestry department.

These recommended practices are described in further detail below.

Recommendation 1: Regional and municipal departments collaborate towards tree canopy.

The benefit of integrating regional departments can alleviate fragmented UFMP responses or actions from being carried out by various departments and agencies (CARE International, 2009; ICLEI, 2006). Collaboration allows for departments with unique perspectives on urban forest policies to provide a level of cross-checking assessment that can better position WR's UFMP to succeed (CARE International, 2009).

Methods to increase collaboration include creating inter-departmental workshops, establishing an interdivisional tree team, or founding an inter-agency working group (City of Guelph, 2012; City of London, 2014; Peel Region, 2011). These collaborations are designed to ensure that city departments and regional agencies are operating towards a common urban forestry goal. Peel Region (2011) used monthly meetings during its inter-agency workshops to build consistency in the early stages of its regional plan. The City of Guelph's (2012) tree team is composed of staff from all city departments meet quarterly to discuss tree related issues. Furthermore, monthly tree team meetings with the parks, transit, and planning departments take place to provide added oversight (City of Guelph, 2012). London's inter-divisional tree team reported annually to city council with a State of Forest report to keep local government aware of progress (City of London, 2014).

***Recommendation 2: Complete a regional tree inventory*.**

A tree inventory is a survey that gathers information about vital tree statistics related to age distribution, species mix, tree health, and risk assessments for all public trees and a sample-based inventory for private property trees (Kenny et al, 2011). Tree inventories are necessary to ensure tree management and planning strategies are appropriate for the existing tree canopy and its present condition (ICLEI, 2006). A complete tree inventory will assist WR in guiding its urban forest management practices.

The City of London (2014) used a Computerized Maintenance Management System to complete its tree inventory and assist in chronicling the age distribution and projected life expectancy of its trees. In contrast, City of Guelph staff used contractors for a portion of its tree inventory, in conjunction with GIS and ORACLE asset management software to inventory its trees (City of Guelph, 2012). Lastly, Peel Region used i-Tree software from the USDA Forest Service to assess in surveying its regional tree canopy. Although easy and quick to perform, i-Tree reports have limited accuracy compared to ground-based tree inventories and should be used only as a preliminary diagnostic tool (Peel Region, 2011). We recommend that WR use a tree inventory method that the regional forestry department is familiar with or hire a contractor to complete the survey.

Recommendation 3: Establish a diverse tree species population.

As discussed in Section 4, increasing the diversity of urban trees can help reduce vulnerability to diseases, pests, and other stressors associated with climate change (ICLEI, 2006). Trees that are better adapted to the regional climate, and resistant to droughts are more likely to reach maturity (ICLEI, 2006). The USDA Forest Service (2016) supports selecting regionally rare tree species that are at their northern habitat boundary and planting these species to promote quick transitions of the canopy to counter the projected changes to the climate. Ensuring that seed stock is from a multiplicity of parental lineages and not bred from limited sources will generate higher rates of genetic diversity that will better positions tree species to withstand a climate disruption (USDA Forest Service, 2016).

The City of London UFMP aimed to preserve and increase the diversity of its urban tree canopy by reintroducing extirpated (locally extinct) tree species, enriching its urban forests with a diverse selection of trees, and thinning dominant species from city woodlots (City of London, 2014). London's UFMP also encouraged the expansion of fruit and nut trees in community gardens to increase canopy diversity. It also favoured the selection of long-lived trees that are climatically robust with high tolerances for temperature and precipitation ranges, as well as trees that require less overall maintenance. Lastly, Peel Region (2011) and Guelph (2012) aimed to increase species diversity in their urban forests.

We recommend WR increase the diversity of its canopy through facilitating the introduction of species that are expected to be more suitable for projected climate conditions and disincentivizing specific tree species as referred to in Appendix D Table 4.1.

Recommendation 4: Structural pruning and prompt reforestation of canopy after disturbances.

Reforesting the urban landscape after a weather or pest disturbance has passed should be prioritized to offset the loss in the urban canopy. These events also present the opportunity to populate the urban canopy with tree species that are expected to do well under projected climate conditions (USDA Forest Service, 2016). To minimize damage from disturbances such as ice storms and extreme wind events, structural pruning (as discussed in Section 3) by forest managers and property owners is essential (USDA Forest Service, 2016).

Guelph (2012) has advanced a program of prescribed structural pruning for its young trees, with scheduled trimming occurring 2-3 times over the tree's first ten years and only as-needed pruning during the rest of the tree's life. In London (2014), a contingency disaster fund was established to repair and replant trees with more reliable species capable of withstanding the projected climate. We recommend active reforestry with scheduled pruning and rapid re-establishment of the urban canopy to offset any losses from future climatic disruptions.

***Recommendation 5: Engage with private landowners to expand tree canopy*.**

The majority of Canadian municipal trees reside on private properties. Increasing the canopy and diversity of trees in any UFMP must, therefore, include engagement with private landowners (Beacon Environmental, 2016). In 2016, the City of Toronto developed a strategy for promoting tree plantings on residential and commercial properties (City of Toronto, 2016b). The strategy included subsidized professional tree planting companies, rebate programs, and an awareness campaign designed to increase public stewardship (see Appendix G for full strategy).

The City of London (2014) developed three community engagement strategies designed to encourage residents, commercial landowners, and neighbourhood organizations to plant trees. Peel Region (2011) used an incentive program to increase tree planting on private property, and connected with the private sector to increase tree canopy cover on commercial, industrial, hospital, university/college, and school board properties.

We recommend that WR actively engage with private landowners in the effort to increase its canopy through a multi-pronged campaign of rebates and developing partnerships with professional tree planting services outlined in Section 5.4 of this report.

Recommendation 6: Develop regional pest management strategies.

Developing a regional pest management strategy will help to protect the canopy from pests, disease, and invasive species (Ramsfield et al, 2016). Certain pesticides have low levels of effectiveness at eradicating pests due to high rates of pesticide resistance and the negative impacts to non-target species in the application process (Ramsfield et al, 2016). Integrated Pest Management (IPM) is an approach that reduces or eliminates pesticide use through biological (ie. ladybugs) or mechanical controls (ie. sanitation of tree service) (City of Guelph, 2012).

In London's (2014) management plan, IPM was selected to improve urban forest health, with the plan recommending including private properties into the city's overall IPM strategy. Guelph (2012) developed a Invasive Species & Pest Management Strategy within its UFMP with a special focus on the emerald ash borer. We recommend that WR create an IPM strategy for its canopy which can be informed by Sherman's (2015) document *Creating an Invasive Plant Management Strategy: A Framework for Ontario Municipalities*.

Recommendation 7: Increase funding for urban forestry departments.

In contrast to other municipal infrastructure, the value of an urban tree canopy investment grows with time, enhancing the overall quality of neighbourhoods (ICLEI, 2006). Healthy trees have multiple benefits as described in Section 4 and thus requires sufficient and sustained funding.

Peel Region (2011) recognizes that urban forests are a form of natural infrastructure that require stable and long-term funding to ensure that the proper management of its tree canopy is maintained. The City of London (2014) also supports an increase in funding for urban forestry in the city's capital projects and provides additional funding for community-scale tree plantings. We recommend that WR hire more forestry staff and increase its budget to allow for many of the aforementioned practices to be carried out in rapid succession.

5.4 Possible WR Partnerships for Urban Forest Expansion

Developing partnerships is an avenue that WR should actively pursue to expand and maintain the region's canopy. This can be achieved by contacting non-for-profit organizations. Toronto-based LEAF (Local Enhancement & Appreciation of Forests, for example plants local native trees matched to each residential property's unique site conditions (LEAF, 2018). LEAF exclusively reforests on residential properties and has the ability to plant 1000-1400 trees per year, but requires municipal government subsidies (Oakvillegreen Conservation Association, n.d.).

Another possible partnership model is the Toronto and Region Conservation Authority's Sustainable Neighbourhood Action Program (SNAP) that takes a holistic approach to the watershed, municipality, and climate change at the neighbourhood level. (TRCA, 2019). One of the neighbourhood-based solutions embedded in SNAP is the expansion of the urban forest on private properties within designated SNAP projects (TRCA, 2019). Presently, the TRCA (2019) is branching out of its mandated area to the City of Peterborough and will be working with GreenUp to establish the program and its canopy initiative. This holistic approach to tree expansion on private properties could be an approach that WR could explore or partner with the GRCA in providing support for developing a private tree canopy strategy similar to the TRCA.

Our team recommends WR find financial partnerships to assist with outreach, public stewardship, and municipal activities. The Tree Canada *TD Green Streets Program* is open to municipalities to fund tree inventory, maintenance, or education initiatives (City of Guelph, 2012). Other possible partnership organizations include Tree Canada funds, the Ontario Trillium Foundation *Community Grants Program*, and Tree Ontario private landowner fund (City of Guelph, 2012).

Waterloo Region should also connect with all regional utilities (Waterloo North Hydro, Kitchener-Wilmot Hydro, Cambridge & North Dumfries Hydro, Bell Canada) that conduct maintenance on trees abutting utility connections to ensure that the same regional goals of canopy enhancement are being met during utility's general tree maintenance.

Lastly, other stakeholders that WR should contact to advance any tree canopy initiatives include: GRCA, Ontario Ministry of Natural Resources, Greater Kitchener Waterloo Chamber of Commerce, Waterloo Region Catholic and District School Boards, University of Waterloo, Laurier University, Conestoga College, all regional governments, hospitals, golf courses, and newspapers.

5.5 Perceived Urban Forestry Challenges

The City of Guelph (2012) highlighted key challenges that affected the success of its tree policies: competing pressures for land-use as well as conflicts with utilities and municipal infrastructure restricted the planting of new trees; limited budgets for planting and proper maintenance of trees; and inadequate urban soil for tree growth (City of Guelph, 2012). Peel Region (2011) noted limited space to sustain trees due to restricted root zones and overhead impediments that prevented trees reaching maturity or caused early mortality. Additionally, Peel Region (2011) cited the lack of federal government leadership, vague provincial financial support for urban forestry expansion (outside of protected natural heritage features), improper urban pest infestation interventions, and a lack of regional and municipal collaboration towards urban forestry. Identifying and addressing these

challenges early in the Waterloo Region's UFMP planning phase will hopefully lead to a better urban forestry strategy.

5.6 Suggested Indicators for Monitoring Urban Forest Canopy

Urban forestry indicators are tools used to measure progress towards an objective, with good indicator characteristics being relevant, credible, measureable, and cost-effective (Barron et al, 2016). A selection of relevant urban forestry indicators include urban tree diversity (age, species, etc) measurements, percent canopy cover, extreme weather stormwater control, air quality measurements, urban area energy conservation, and percent plantable space (Barron et al., 2016). Moreover, Dobb et al. (2011) used ecosystem service indicators to quantify the urban forest with the most pertinent criteria being: air quality using designated city plots to measure ozone, carbon monoxide, carbon dioxide, and others; tracking community temperature changes that correlate to canopy cover extent; percent crown diebacks of canopy; productivity of planted urban forest through biomass calculations; and percent of trees at risk of damaging infrastructure and human safety.

Another evaluation tool is the *Criteria and Indicators for Strategic Urban Forest Planning and Management* by Kenny et al. (2011) which uses three management approaches: vegetative (tree), community, and resource management to provide qualitative performance indicator assessments for a municipality's tree canopy. Kenny et al. (2011) espouses the use of tree indicators other than percent tree canopy to depict a variety of pertinent information like species mix, age distribution, and species suitability to the local urban environment, that would better inform forestry managers as to the true state of the urban forest. Community framing assesses the involvement of large landowners, neighbourhood-level action, and regional cooperation to urban forestry goals (Kenny et al, 2011). Resource management reflects upon how municipal wide funding and staffing among others will lead to successful urban forest management (Kenny et al, 2011).

Lastly, the Canadian Council of Forest Ministers (2007) promote re-establishing regionally rare tree species that have been locally extirpated through land-use changes. They recommend using the following indicators for urban forest surveys: noting distribution of selected at-risk species, assessing distribution of invasive species, and promoting genetic diversity of seedlings for reforestation efforts.

5.7 Conclusion

The recommendations and indicators outlined in this section will help WR develop a resilient urban forest management plan. Taking into consideration the perceived

challenges to implementation early on will better position WR to avoid them. Connecting with regional stakeholders and building partnerships to advance Waterloo Region's UFMP is a vital element for success that should be actively pursued. If implemented, we believe these recommendations will help to build a strong and vibrant tree canopy for Waterloo Region.

6.0 Conclusions

Climate change will have major impacts on WR, including on its tree canopy. In this report, we used GIS analysis and a review of the literature to assess the current tree canopy in WR. The cities of Kitchener and Cambridge have existing urban forest management programs which are described here.

Climate change projection data was analyzed from 2011 to 2100. This data allows for conclusions to be made regarding the future climatic setting for urban trees within WR. The impacts include changing temperature and precipitation patterns which can influence tree growth, development, and survival. An increase in storm events including ice storms and extreme wind will have direct impacts on the UTC.

The projected changes in climate will increase the stress experienced by trees, making them vulnerable to pests and diseases. The ideal geographic ranges of some tree species will move out of the area with time. Table 4.1 in Appendix E can be used to select trees suitable to future growing conditions and community needs. Reducing the vulnerability of the UTC to climate change requires increasing the diversity of tree species and tree age. Trees can also help build resilience toward the challenges of climate change by sequestering carbon, improving air quality, reducing the urban heat island effect, and managing water after extreme rainfall events.

Many recommendations are made with the goal of developing a successful tree canopy management plan. These recommendations are based on UFMP from neighbouring communities. Challenges that these communities have encountered are outlined.

The role of homeowner maintenance and proper pruning practice is significant to reduce susceptibility in the urban setting. Partnerships and regional stakeholder connections are significant for implementation of the management strategy. Overall, the recommendations suggested in this report can be used to develop and implement a strong and effective urban tree canopy management plan for Waterloo Region.

Trees are important assets in our community but are threatened by climate change. This report provides the tools and knowledge to support our urban trees but it will require investments of money and time.

7.0 References

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APPENDIX A: Tree Canopy Coverage Calculation

The amount of tree canopy coverage percentage is determined by dividing the total area of the location under study by the total area covered by the wooded area dataset. The Wooded Area dataset produced by the Ontario Ministry of Natural Resources (2006) provides the area covered by trees greater than 2 metres tall. This value provides insight on the extent of the tree canopy to assess its quality. To calculate the percentage of tree canopy coverage utilizing GIS software:

1. Download vector datasets for Wooded Area from the Ontario Ministry of Natural Resources
2. Open the dataset and a vector file containing the area to be assessed for tree canopy coverage in GIS software such as ArcGIS or QGIS. QGIS was utilised for this project.
3. Once open in the GIS software, ensure that the two datasets are utilising the same coordinate reference system (CRS) so that they can be compared
4. Calculate the total area of the vector file to be assessed opening the data attribute table and enabling edits. With this edits enabled, use the field calculator to determine area by inserting a new column which uses the operator $area to calculate area for each of the rows (North River Geographic Systems Inc, 2019).
5. With the two datasets prepared, to calculate the tree canopy coverage you must know the amount of wooded area present in the vector polygon. This is done by using the clip tool to section off the portion of the wooded area which is located in the polygon. The input layer is the wooded area and the overlap layer is the area under analysis. Once done running this tool, it will produce a new layer of the selected feature.
6. With the newly clipped wooded area, open its attribute and enable editing. Calculate the amount of area of the clipped wooded area by using the operator $area to add a new column with the total area of each row (North River Geographic Systems Inc, 2019).
7. With these values determined, open Excel and paste the attribute tables for the clipped wooded area and total area under analysis in the document.
8. Calculate the total tree canopy area by adding all of the values together for the clipped wooded area. Then divide the total tree canopy area by the total area under analysis to determine the tree canopy coverage percentage.
9. With this value determined, add the tree canopy coverage percentage to the specified vector polygon through adding a new column to the attribute table and inserting the tree canopy coverage percentage to create a visual depiction of the tree canopy coverage in Ontario.

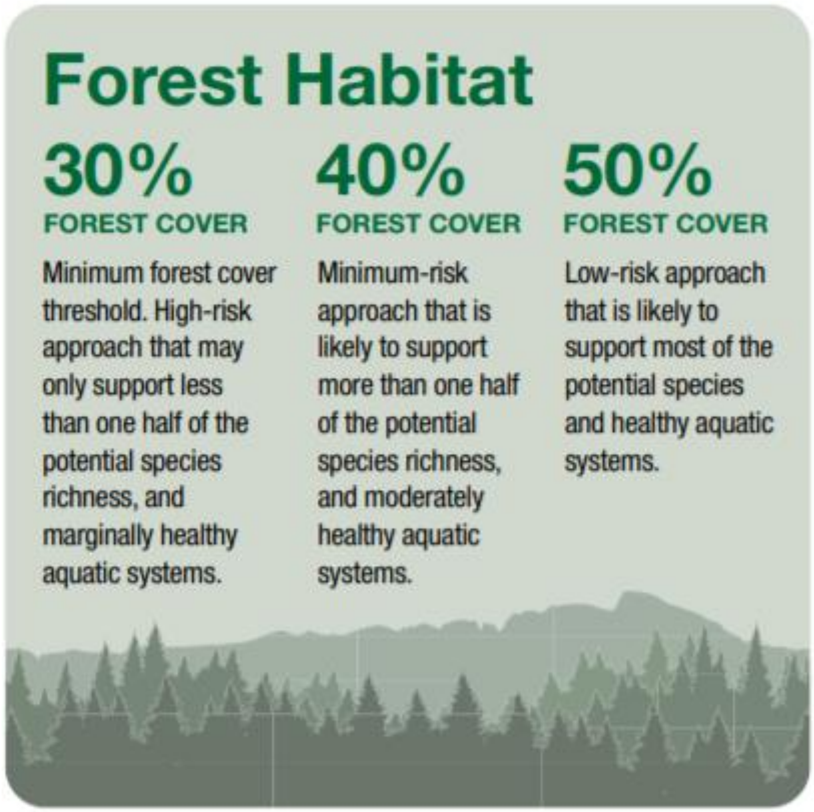


Figure 2.10. Healthy canopy thresholds and the implications of poor health (Environmental Commissioner of Ontario, 2018).

Table 2.1

Tree canopy coverage percentage by Region of Waterloo cities and towns (Ontario Ministry of Natural Resources, 2006; Region of Waterloo, 2019b). Data from this table is used in Section 2.3.3 Figure 4.

Community	**Tree Canopy Coverage (%)**
Ayr	16.71
Baden	8.79
Bamberg	1.81
Bloomingdale	9.14
Branchton	12.32
Breslau	9.02
Brown's	2.37
Cambridge	13.38
Clyde	0.42
Conestogo	10.44
Floradale	0.03
Greenfield	16.01
Haysville	9.66
Heidelberg	0.25
Heidelberg	1.54
Kingwood	1.96
Kitchener	11.08
Linwood	0.00
Mannheim	0.00
Maryhill	1.98
New Dundee	8.59

New Hamburg	8.04
North Dumfries	20.90
Petersburg	10.95
Philipsburg	13.92
Reidsville	18.19
Roseville	0.55
St Clements	0.65
St Jacobs	6.64
Wallenstein	0.40
Waterloo	10.35
Wellesley	10.88
Wellesley	3.15
West Montrose	4.28
Wilmot	13.97
Winterbourne	4.50
Woolwich	14.08

Table 2.2

Tree canopy coverage percentage by planning area for southern Ontario (Ontario Ministry of Natural Resources, 2006; Ontario Ministry of Natural Resources, 2012a; Ontario Ministry of Natural Resources, 2012b).

Planning Area	**Designation**	**Tree Canopy Coverage (%)**
Barrie	City	16.61
Belleville	City	33.82
Brant	City	16.33
Brantford	City	8.98
Brockville	City	16.85
Chatham-Kent	City	4.57
Cornwall	City	20.23
Greater Sudbury	City	63.97
Guelph	City	11.40
Hamilton	City	19.01
Kawartha Lakes	City	35.44
Kingston	City	29.09
London	City	10.26
Orillia	City	16.17
Ottawa	City	29.35
Pembroke	City	9.40
Peterborough	City	10.89
Prince Edward County	City	34.24
Quinte West	City	32.81
St. Thomas	City	14.70
Stratford	City	2.47

Toronto	City	7.30
Windsor	City	4.56
Bruce	County	35.90
Dufferin	County	23.88
Elgin	County	18.37
Essex	County	5.26
Frontenac	County	64.60
Grey	County	39.01
Haldimand	County	14.71
Haliburton	County	75.18
Hastings	County	73.62
Huron	County	16.09
Lambton	County	12.93
Lanark	County	16.61
Leeds and Grenville	County	42.90
Lennox and Addington	County	60.62
Middlesex	County	13.71
Norfolk	County	23.95
Northumberland	County	30.90
Oxford	County	13.39
Perth	County	8.88
Peterborough	County	53.57
Prescott and Russell	County	24.80

Renfrew	County	68.61
Simcoe	County	36.43
Stormont, Dundas and Glengarry	County	28.92
Wellington	County	17.93
Algoma	District	83.78
Manitoulin	District	65.16
Muskoka	District	70.89
Nipissing	District	75.64
Parry Sound	District	74.33
Sudbury	District	80.49
Timiskaming	District	81.33
Durham	Region	26.27
Halton	Region	25.61
Niagara	Region	18.18
Peel	Region	18.82
Waterloo	Region	13.55
York	Region	23.25
Gananoque	Town	36.04
St Marys	Town	5.27
Prescott	Town	0.80
Smith Falls	Town	16.61
Pelee	Township	20.14

APPENDIX C: Climate projection graphs

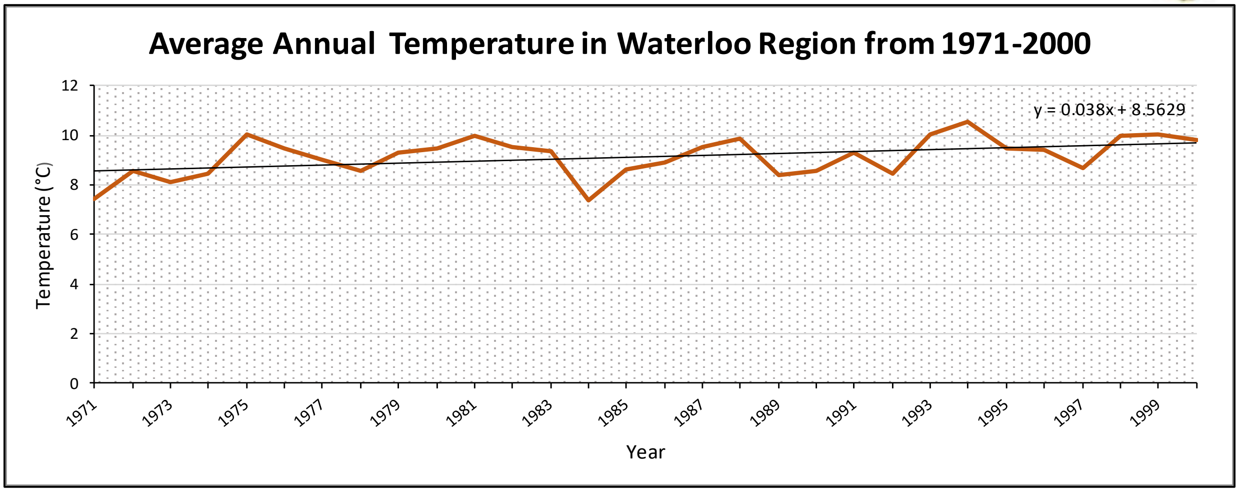
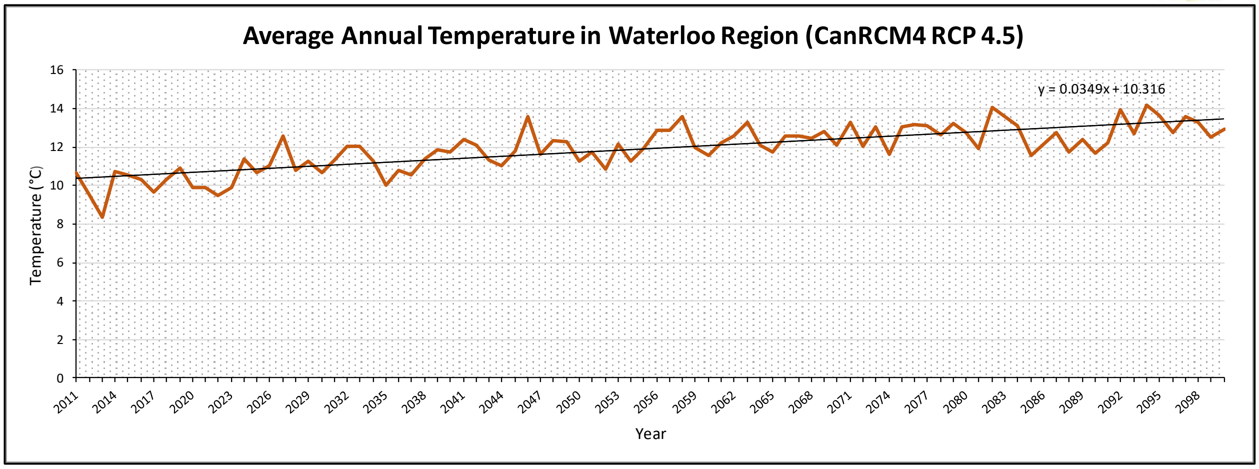


Figure 3.1: Average annual temperature for the baseline 1971-2000 in Waterloo Region, collected from historic climate data.



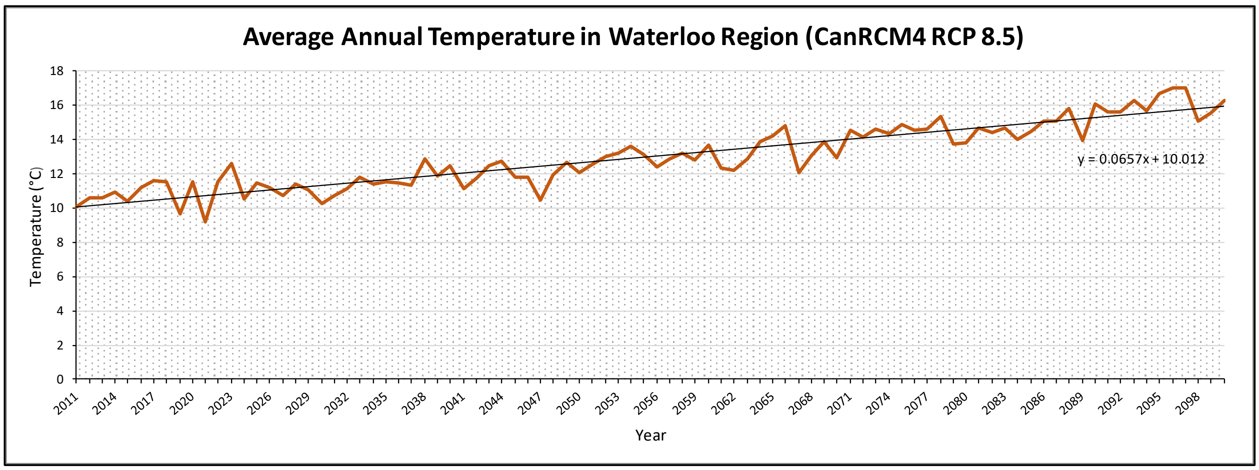


Figure 3.2: Projected annual average temperature from 2011-2100 for Waterloo Region. Climate projection data was generated from CanRCM4 model for two RCP scenarios, 4.5 (top) and 8.5 (bottom). The rate of temperature increase for the business as usual scenario, RCP 8.5, is significantly greater than the increase seen in scenario 4.5. The slope of the trendline indicates the increase in temperature for both scenarios.

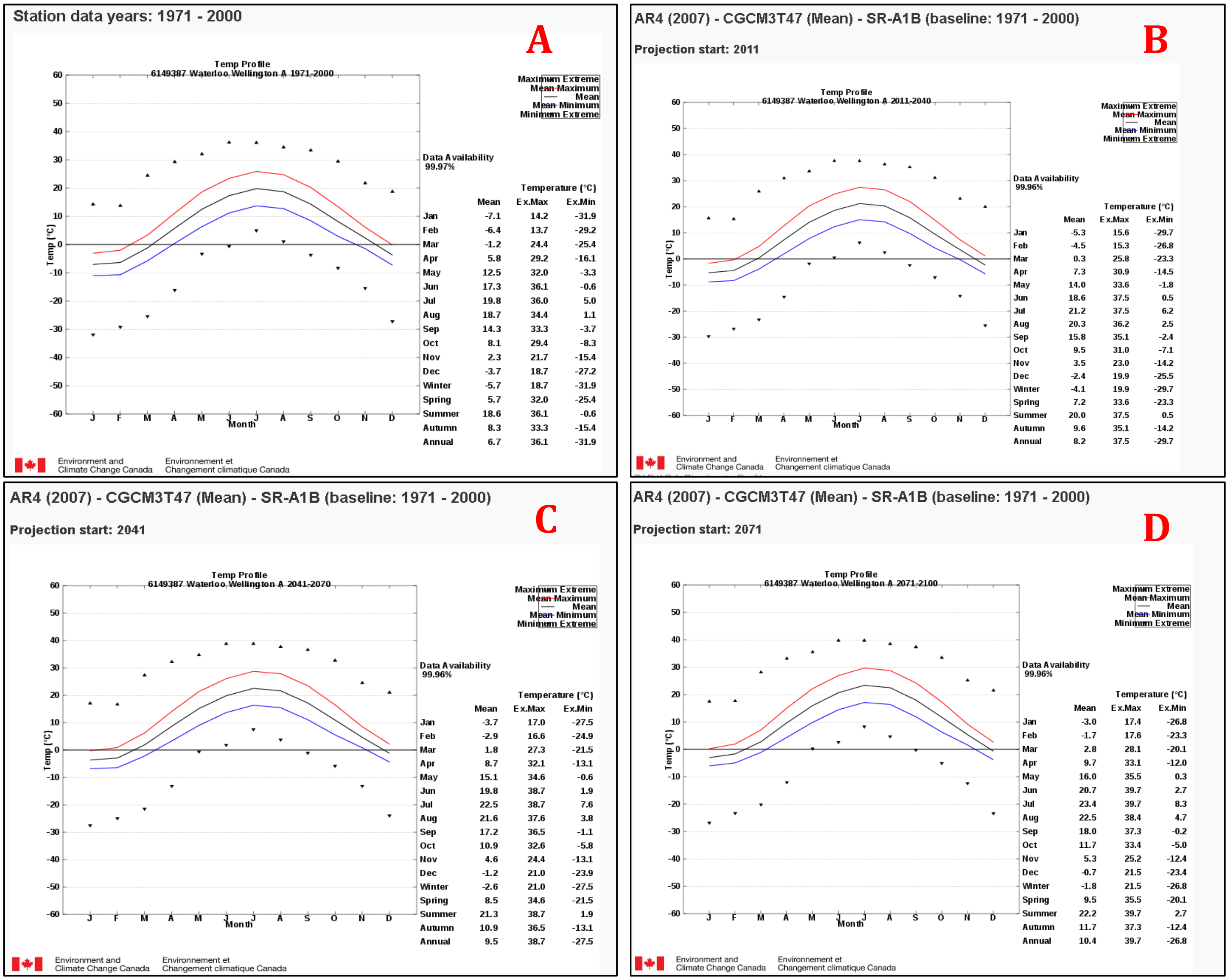


Figure 3.3: Temperature profile data collected from the CGCM3/T47 model under scenario A1B from Environment and Climate Change Canada. (A) displays the baseline 1971-2000 average, maximum, minimum and extreme temperatures. (B), (C) and (D) show the temperature variables for the 2020's, 2040's and 2080's respectively. The table included in the graph displays the extreme maximum and minimum temperatures monthly for the timeframe investigated. By 2071-2100 the average temperature shows an increase from approximately 20°C during the baseline years (A) to approximately 23°C (D).

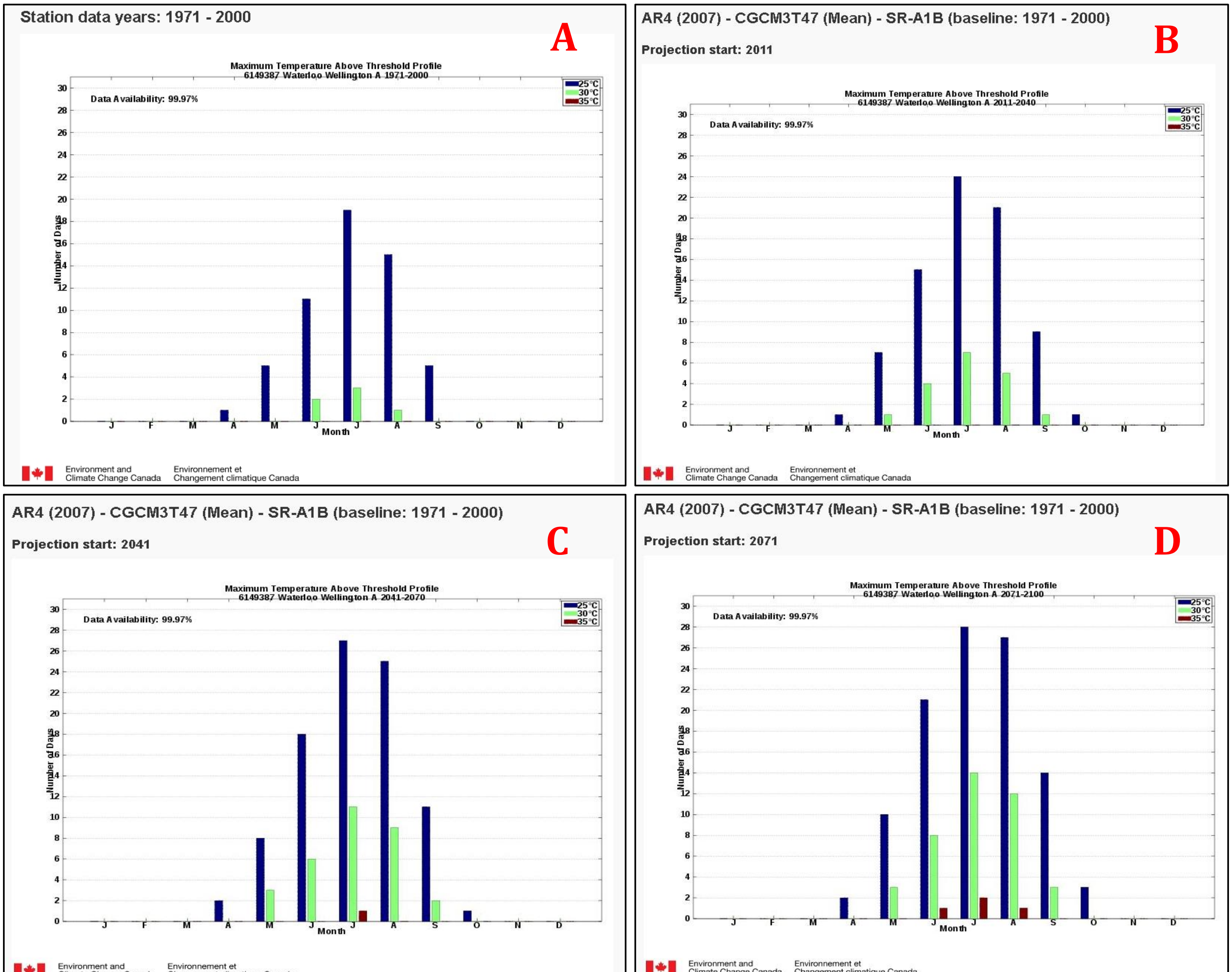


Figure 3.4: The number of days with extreme temperatures is displayed for the (A) baseline, (B) 2020's, (C) 2040's and (D) 2080's. This data was collected from the CGCM3/T47 model under scenario A1B from Environment and Climate Change Canada. The graphs display temperatures greater than 25°C (blue), 30°C (green) and 35°C (red). As the century progresses, the number of days with temperatures above 30°C increases significantly during summer months and in 2071-2100 (D) June, July and August show more days with temperatures greater than 35°C. The number of days greater than 25°C in April and October are indication of the extended growing season.

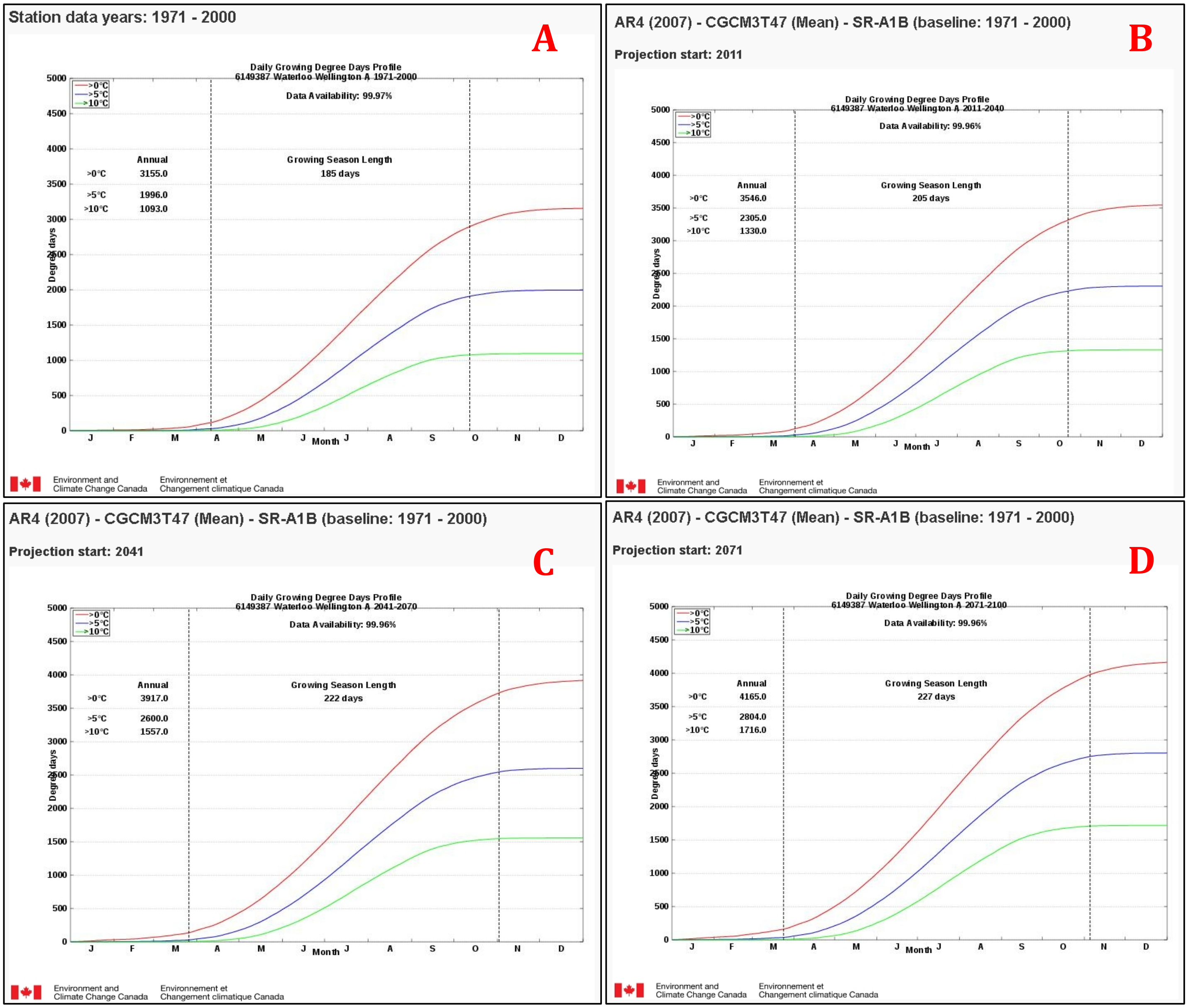


Figure 3.5: The growing degree days per year is displayed for three different temperatures, 0°C, 5°C and 10°C for the (A) baseline, (B) 2020's, (C) 2040's and (D) 2080's. The number of degrees days per month shows an increasing trend, supporting an increase in the length of the growing season. This data was collected from the CGCM3/T47 model under scenario A1B from Environment and Climate Change Canada.

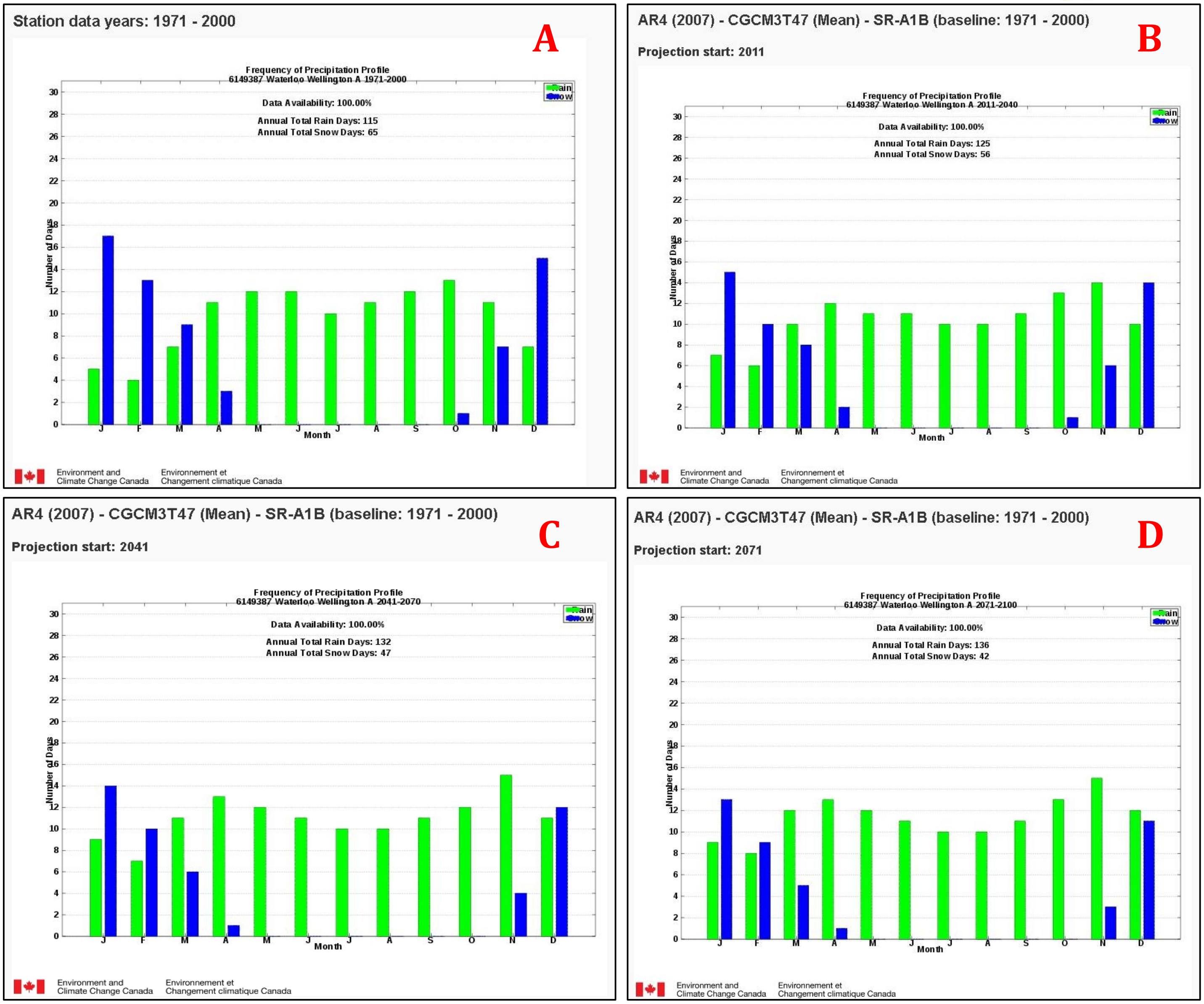


Figure 3.6: Monthly precipitation trends are displayed in for the baseline, 2020's, 2040's and 2080's (A, B, C, D respectively). The data indicates a decrease in days with snow and an increase in the number of precipitation days, particularly in the winter months. The data was collected from the CGCM3/T47 model under scenario A1B from Environment and Climate Change Canada.

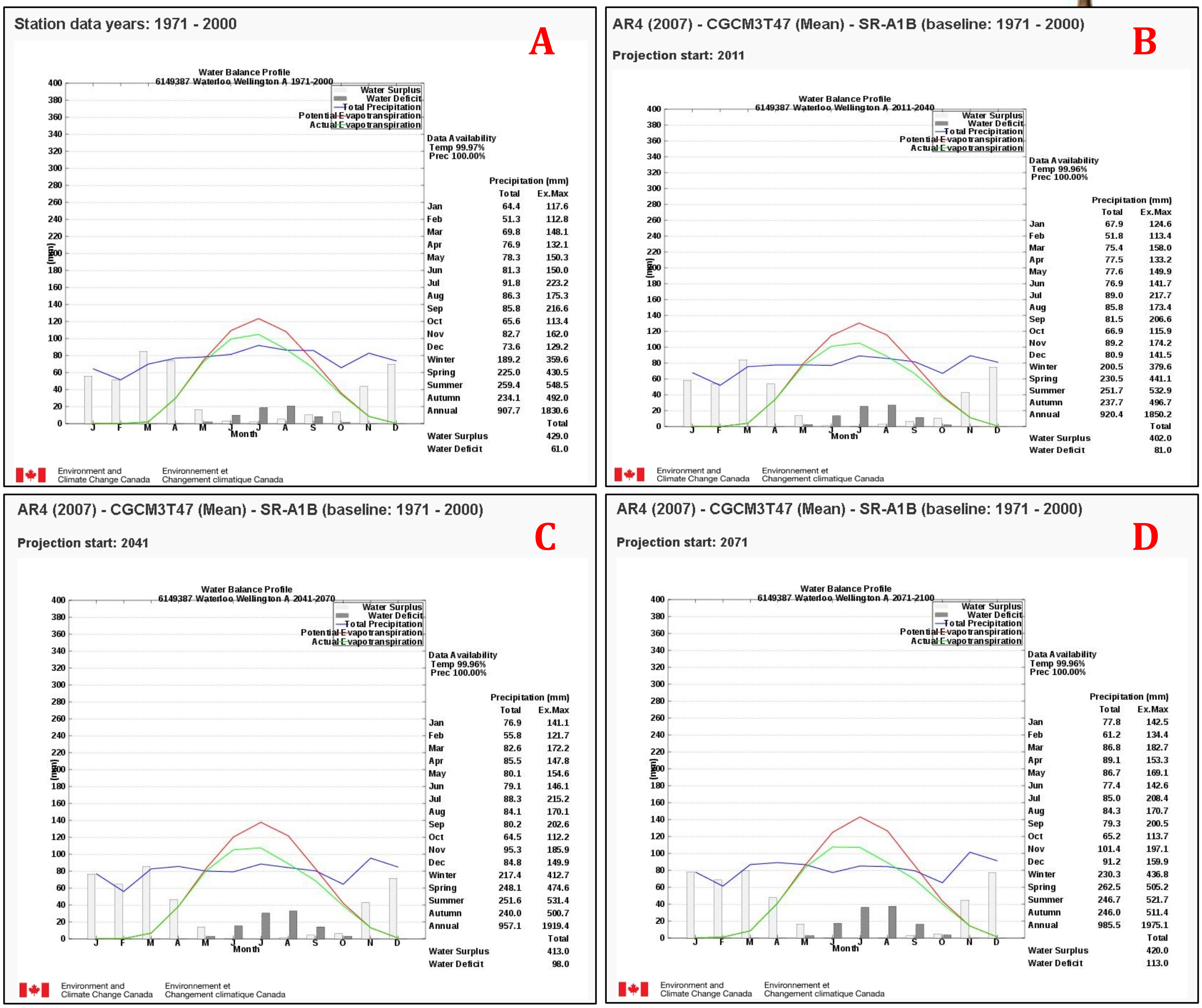


Figure 3.7: Water balance profiles were generated from the CGCM3/T47 model under scenario A1B from Environment and Climate Change Canada. A surplus of water can be observed in the winter months while the summer shows a deficit indicating the potential for droughts. Increased water surplus in the winter can be attributed to higher liquid precipitation (see figure 8).

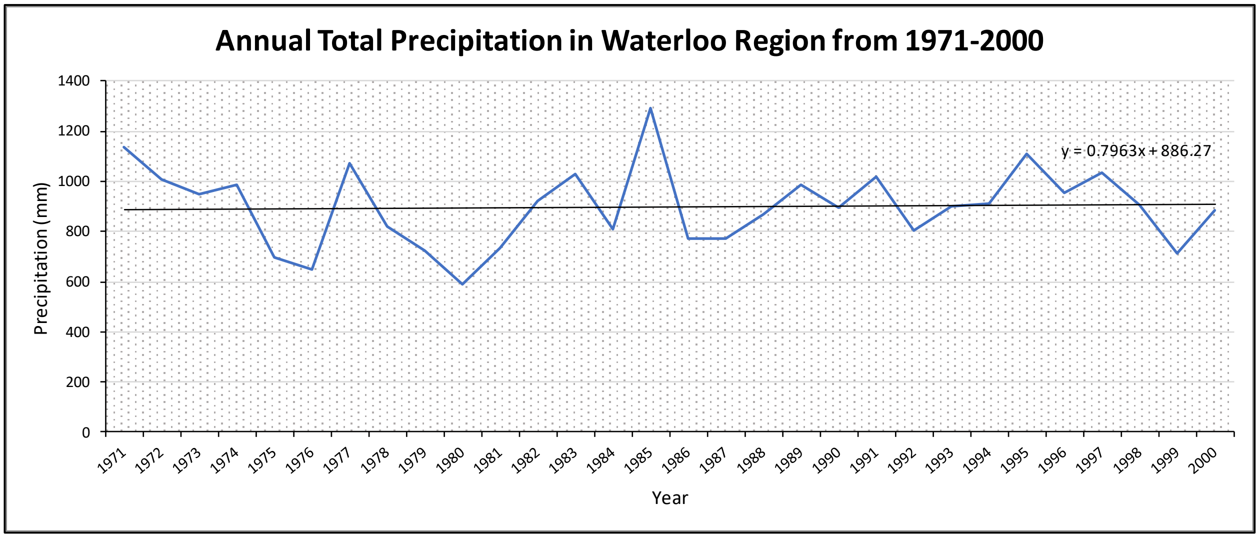


Figure 3.8: Total annual precipitation in Waterloo Region for the baseline timeframe. Data is collected from historical climate records and includes both solid and liquid precipitation.

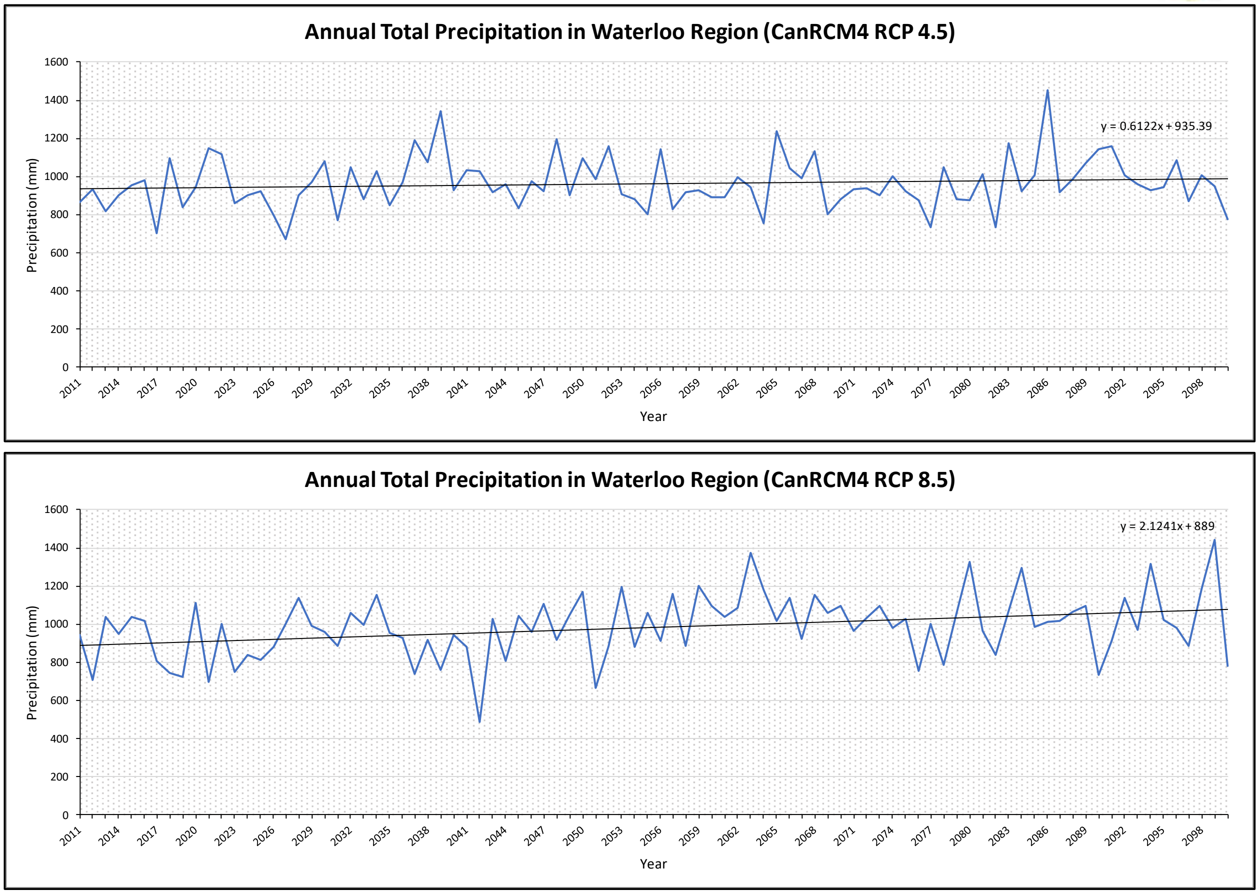
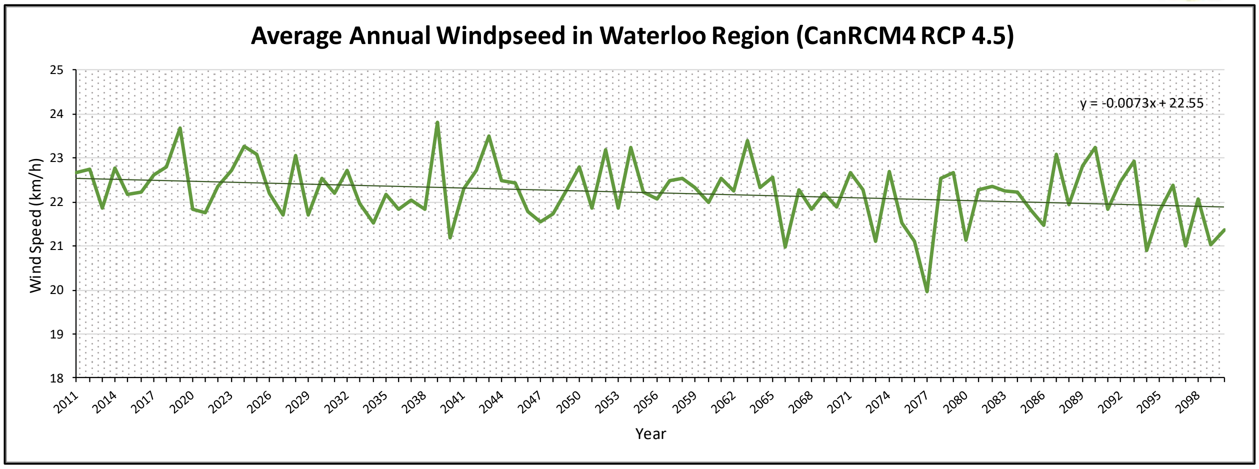


Figure 3.9: Projected total annual precipitation for Waterloo Region collected from the CanRCM4 model under RCP 4.5 and 8.5 projection scenarios. Based on the trendline, RCP 4.5 (top) has a slight increase in annual precipitation amounts however RCP 8.5 (bottom) shows a greater increasing trend. Both data scenarios show variability throughout the timeframe 2011-2100.



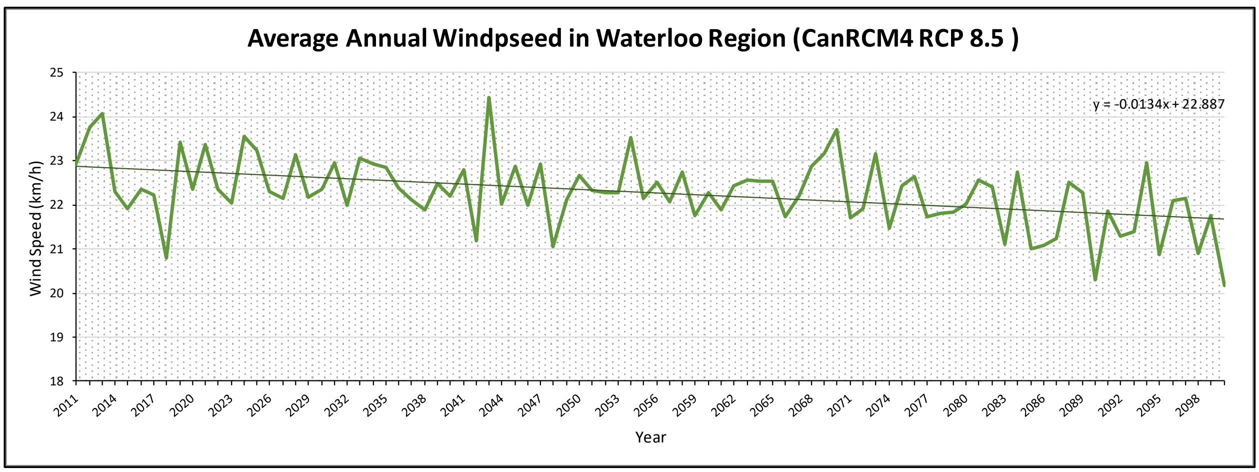


Figure 3.10: Wind speed projection data collected from the CanRCM4 model shows a slight decrease in windspeed for both RCP 4.5 and 8.5 projection scenarios. This data shows high variability and high uncertainty has been associated with wind speed predictions (Suárez et al, 1999). For this report, results from the IC3 localized projections for WR was used to verify the impact of climate change on wind speed patterns (IC3, 2015).

APPENDIX D: Table of Waterloo Region tree species with climate related characteristics

Table 4.1 contains information on local tree species that can help decision-makers choose tree species that are suitable to the current and projected environment for Waterloo Region. The species included on the list were sourced from the Waterloo Region Shade Audit, the Region of Waterloo Native Trees and Shrubs list, and the Waterloo Region Preferred Species List (Region of Waterloo, 1993; Region of Waterloo, n.d.a; Region of Waterloo, n.d.b). Current and projected ranges were obtained from the Government of Canada Climate Envelopes website using ANUCLIM CanESM2 climate model with RCP 4.5 and RCP 8.5 scenarios. Ogren's allergen score was used (Ogren, 2015) to rate pollen production and Kesselmeier's report (1999) was used to rate the biogenic volatile organic compound production. Tree growth characteristics are also included in the table, as is tolerance of the species to soil compaction, shade, and salt: all factors to consider when planting urban trees. Finally, available information about insect and disease susceptibility are listed. Efforts were made to source as much of the information as possible from sources that use consistent methods. However, there are many blank cells in the table where we could not find reliable data.

The table for this section is found in a separate document: finaltreespecieslistWR.pdf

APPENDIX E: i-Tree Canopy report for Waterloo Region

i-Tree Tools is a software program developed by the USDA Forest Service to quantify the environmental benefits of trees in urban and rural settings (i-Tree, n.d.). It was developed to help with forest management and advocacy. Over 6,000 groups in Canada and 232,000 groups in the United States have use the i-Tree tools and many municipalities have used i-Tree values in their tree reports (i-Tree, n.d.).

The i-Tree Canopy report shown below was generated using the free software on the i-Tree website (i-Tree, n.d.). The program selected 500 sample points on a Google map of the Waterloo Region, and the user classified the land cover of the point as tree or non-tree based on visual assessment of the map. The default removal rate values and monetary values for the United States was chosen with mixed urban and rural land use. Calculation of environmental services was based on percentage tree coverage and measurements of metabolic and growth rates for trees in the project area. Since the growth and metabolic rates of urban trees vary significantly between and within cities, the software results should be viewed as coarse-scale estimates (Boukili et al., 2017).

Using GIS maps and the Ontario Ministry of Natural Resources wooded area dataset, our estimate of the tree canopy coverage in Waterloo Region is 14% (see Section 1). This is significantly lower than the 24% shown in the i-Tree Canopy report below (See Table 4.2). Our estimate (see Section 2) would appear to be based on a larger dataset which more accurately defines trees than what was used in the i-Tree Canopy report. If the tree canopy coverage estimation is overstated by the i-Tree Canopy program, then it can be concluded that the tree benefit estimates based on tree canopy coverage are also overstated. We therefore recommend that the benefits of the Waterloo Region trees be reported in qualitative, not quantitative terms.

Table 4.2. Tree benefit estimates for the urban canopy of Waterloo Region generated using the i-Tree Canopy program (i-Tree, n.d.).

Cover Class	Description	Abbr.	Points	% Cover
Tree	Tree, non-shrub	T	122	24.4 ±1.92
Non-Tree	All other surfaces	NT	378	75.6 ±1.92

Tree Benefit Estimates

Abbr.	Benefit Description	Value (CAD)	±SE	Amount	±SE
CO	Carbon Monoxide removed annually	4,221.37 CAD	±332.30	34.19 t	±2.69
NO2	Nitrogen Dioxide removed annually	7,267.62 CAD	±572.10	186.44 t	±14.68
O3	Ozone removed annually	378,482.87 CAD	±29,793.89	1.86 kt	±0.15
PM2.5	Particulate Matter less than 2.5 microns removed annually	782,393.44 CAD	±61,589.43	90.23 t	±7.10
SO2	Sulfur Dioxide removed annually	1,270.23 CAD	±99.99	117.49 t	±9.25
PM10*	Particulate Matter greater than 2.5 microns and less than 10 microns removed annually	274,768.83 CAD	±21,629.60	621.96 t	±48.96
CO2seq	Carbon Dioxide squestered annually in trees	25,619,181.20 CAD	±2,016,722.89	379.57 kt	±29.88
CO2stor	Carbon Dioxide stored in trees (Note: this benefit is not an annual rate)	643,393,769.03 CAD	±50,647,479.00	9.53 Mt	±0.00

i-Tree Canopy Annual Tree Benefit Estimates based on these values in g/m²/yr and CAD/t/yr: CO 0.101 @ 123.46 CAD | NO2 0.551 @ 38.98 CAD | O3 5.489 @ 203.83 CAD | PM2.5 0.267 @ 8,671.52 CAD | SO2 0.347 @ 10.81 CAD | PM10 1.838 @ 441.78 CAD | CO2seq 1,122.000 @ 67.49 CAD | CO2stor is a total biomass amount of 28,177.630 @ 67.49 CAD*
Note: Currency is in CAD
Note: Standard errors of removal amounts and benefits were calculated based on standard errors of sampled and classified points.

About i-Tree Canopy

The concept and prototype of this program were developed by David J. Nowak, Jeffery T. Walton and Eric J. Greenfield (USDA Forest Service). The current version of this program was developed and adapted to i-Tree by David Ellingsworth, Mike Binkley, and Scott Maco (The Davey Tree Expert Company).

Limitations of i-Tree Canopy

The accuracy of the analysis depends upon the ability of the user to correctly classify each point into its correct class. As the number of points increase, the precision of the estimate will increase as the standard error of the estimate will decrease. If too few points are classified, the standard error will be too high to have any real certainty of the estimate.

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APPENDIX F: Table of pest and diseases common for Ontario

Table 3.1. Review of common pests and diseases in Ontario with potential to impact the urban tree canopy in Waterloo Region. Species source and location information, impact to the tree and the updated status is detailed.

Species	When and Where?	Impact	Status/Solution
Emerald Ash Borer (Lockhart, 2017)	First found in Windsor 2002. Originates in eastern Asia.	Larvae will borrow through inner bark, young beetles feed on leave ultimately mortality of the ash tree.	Ban on the movement of wood throughout Ontario.
Woodwasp (Invasive Species Center, 2015)	Found in southern Ontario and Quebec in 2005. Transported in wood packing materials, this pest originates from Eurasia and Africa.	Females lay eggs in outer sapwood, where the larvae thrive on fungus and mucus, that weaken the tree. Pne species are the main host but can also impact spruce, fir, larch and douglas fir. Can be detected by reduced foliage and round exit holes on the host.Can result in tree mortality.	Mechanical and biological controls have been attempted but are considered generally ineffective. Regulation on the import of wood packing materials by the Canadian Food Inspection Agency.
Asian Gypsy Moth	Introduced to North America in late 1860's from	Defoliation by gypsy moth caterpillars resulting is loss of canopy and	Use to insect predators and biological control but outbreaks still occur. Local awareness and

(Ontario's Invasive Species Awareness Program, 2019)	Europe and Asia.	weakened defenses. Ultimately tree mortality.	monitoring of trees.
Dog-Strangling Vine (Ontario's Invasive Species Awareness Program, 2019)	From Eurasia, brought to eastern US as a gardening plant.First found in Ontario in the late 1880s.	Crowds out native plants and young trees. Negative impacts to wildlife.	Restricted in Ontario's Invasive Species Act. Awareness and community level control.
Asian Long-horned Beetle (Lockhart, 2017) (Ontario's Invasive Species Awareness Program, 2019)	First found in 2003 in Toronto. Originates in China and brought in shipping materials.	Adults lay eggs inside hardwood trees (elm, maple, poplar and willow) and larvae will tunnel out through the tissue restricting nutrient and water flow, ultimately resulting in mortality.	Thought to be eradicated in 2013 through removal of 27 000 trees but can still be seen. Restrictions on movement of hardwood and firewood by Canadian Food Inspection Agency.
Dutch Elm Disease	Fungal disease found in Ontario but more scattered in northern and eastern areas. Not yet found in	Can spread through roots or by insects and will block the water system of the tree ultimately resulting in high mortality.	Local awareness to reduce transport of elm products and firewood.

(Ontario's Invasive Species Awareness Program, 2019)	British Columbia or Alberta.		
Oak Wilt (Ontario's Invasive Species Awareness Program, 2019)	Fungal pathogen found in northwestern USA and along the Great Lakes but not yet in Canada.	Northern red oak, northern pin oak, spanish oak.Can spread from unhealthy trees to underground roots. Also spread by insects. Ultimately results in tree mortality.	Strict regulation on the import of oak materials by the Canadian Food Inspection Agency

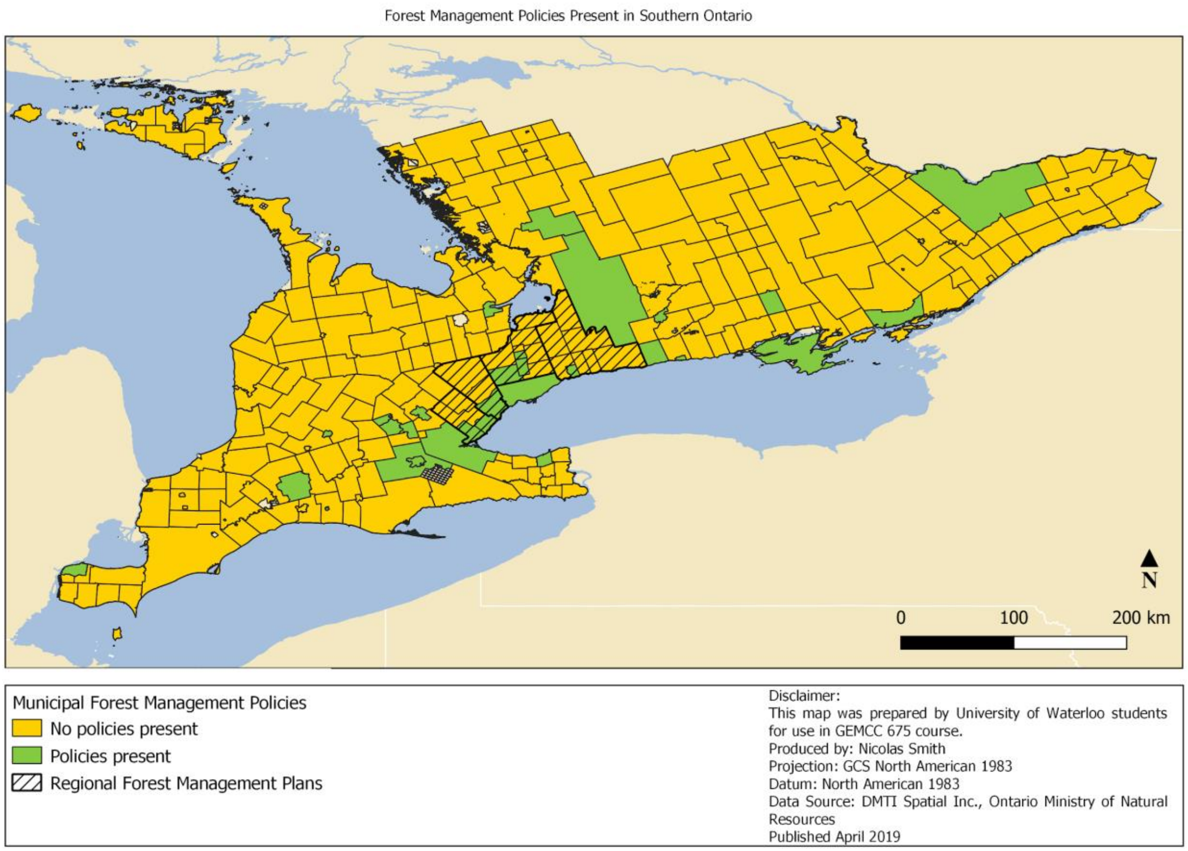

Figure 5.1. Urban Forest Management Policies in Ontario Municipalities as of 2017 (Canada's Urban Forestry Footprint, 2017; DMTI Spatial Inc., 2014; DMTI Spatial Inc., 2018b; Ontario Ministry of Natural Resources, 2006; Ontario Ministry of Natural Resources, 2012a; Ontario Ministry of Natural Resources, 2012b).

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<u>Recommended Policies & Guidelines Reading List</u>

A detailed document created by ICLEI- Local Governments for Sustainability titled *Talking Trees - an Urban Forestry Toolkit* (2006) is a source of information for essential urban forest management, planting, and maintenance guidelines. This report also chronicles urban forestry case studies that followed ICLEI's toolkit, highlighting how positive results were achieved.

1. *Management guidelines*
    a. Increase public involvement and environmental stewardship.
    b. Develop a database of information that will help define, detect, and predict the health of the urban forest.
    c. Encourage inter-agency collaboration.

2. *Planting guidelines*
    a. Give trees as much space as possible to grow.
    b. Look for innovative ways to incorporate trees into built landscape design.
    c. Plant trees in wide soil bands between the curb and sidewalk and avoid planting trees into individual tree pits.
    d. Consider planting trees in small groves to minimize stormwater runoff.
    e. Use permeable pavement around streetscape trees.
    f. Plant trees to help reduce and calm vehicular traffic speeds.
    g. Provide one cubic yard of soil volume for every five cubic yards of crown volume of a mature tree.
    h. Meet or exceed minimum width requirements for tree planting root zone.
    i. Use low fencing, bark mulch, or herbaceous plants to protect the soil underneath trees from compaction and erosion.
    j. Use tree grates to allow for soil protection along sidewalks.
    k. Ensure that soils remain healthy and aerated.
    l. Use structural soils along streetscape or build environment for street trees.
    m. Plant the right tree species for the location.

n. Select large shade trees to help surrounding built environment save energy via shading and other benefits that large trees provide.

o. Ensure the urban forest has a high diversity of species.

p. Plant native species that are drought tolerant.

q. Plant low maintenance trees that require less pruning.

r. Plant trees that emit low amounts of biogenic volatile organic compounds (BVOC).

s. Choose trees that are in-leaf when precipitation is greatest to maximize water storage capacity and reduce run off.

3. *Maintenance guidelines*

   a. Utilize volunteers and nonprofits to assist with tree planting

   b. Establish a graduated maintenance cycle that includes all trees within the region.

   c. Prune earlier after sapling establishment to train young trees to develop a strong branching structure that requires less frequent trimming in the future.

   d. Reduce use of maintenance activities that release greenhouse gases during tree maintenance.

   e. Protect trees in construction zones, especially root protection.

   f. Survey trees for pest infestation and disease to reduce impact.

   g. Create a list of resources.

The City of Toronto has developed an approach for private tree establishment in *Growing Toronto's Tree Canopy – Tree Planting Strategy* published in 2016. The following is a list of actions within the City of Toronto's tree planting strategy that Waterloo Region could utilize to recruit more private landowners to tree planting on their properties in order to expand the Region's tree canopy.

1. *Tree planting and support program for residential landowners*. Subsidize private tree planting and tree care in partnership with community partners such as LEAF.

2. *Direct tree rebate program for residential landowners*. Provide direct rebate for tree planting on residential lots in conjunction with education and outreach activities.

3. *Tree planting and support program for industrial, commercial, and institutional landowners*. Subsidize tree planting and tree care for landowners and property managers to encourage conversion of underused lands to tree cover.

4. *Direct tree rebate program for industrial, commercial, and institutional landowners*. Provide direct rebate for tree planting on underused industrial, commercial and institutional lands.
5. *Tree planting and support program for schools*. Expand existing tree planting and stewardship in partnership with school boards and other educational institutions.
6. *Develop an "Every Tree Counts" campaign*. Develop an engagement campaign to raise public awareness about the benefits of trees, tree planting opportunities, and tree stewardship.
7. *Leverage Partnerships to Expand Outreach and Promotion*. Maximize impact of education and outreach initiatives by leveraging existing partnerships with stakeholders.
8. *Undertake outreach and education events for the "Every Tree Counts" campaign*. Utilize existing outreach and education models to develop tree planting opportunities and stewardship events on private lands.
9. *Expand street tree and park tree adoption programs*. Support and build on established tree planting and tree care initiatives carried out by neighbourhood volunteers.

The United States Department of Agriculture (USDA) Forest Service has developed an outstanding document in *Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers* in 2016, describing strategies that urban forest managers in the US Northeast-Great Lakes region can employ to proactively respond to projected climate disruptions. The following strategies are a summary of a detailed list of urban forestry management actions that incorporates approaches to urbanized (streetscapes, residential and business zones) and natural urban areas like parks or river corridors that Waterloo Region should be made aware of.

1. Sustain or restore fundamental ecological functions by maintaining or restoring soils and nutrient cycling in urban areas. Retaining proper hydrology by directing water from buildings onto land adjacent to trees or utilizing permeable surfaces in highly built areas.
2. Reduce the impact from pests or pathogens through advancement of tree diversity which can reduce susceptibility of the urban landscape to biological stressors. Early detection by forest managers to limit and remove existing invasive species will also decrease biological stressors on the urban forest.
3. Reduce the risk and long-term impacts of severe disturbances by continuing maintenance efforts through structural pruning to prevent damage to trees from ice or wind and establishing ‘soft edges’ in appropriate areas to limit impact from severe winds damaging mature trees.

4. Prioritize and preserve sensitive or at-risk species/communities by establishing artificial reserves (arboretums or botanical gardens) for at-risk and displaced species.
5. Maintain and enhance species and structural diversity through promotion of a diverse age structure of canopy with younger trees among mature stands. Restoring diversity of native species can decrease the vulnerability to climate change as well as enhancing the intensely fragmented urban landscape with ecological appropriate canopy for habitat and corridors.
6. Increase ecosystem redundancy across the landscape in order to manage habitats over a range of sites and conditions and developing buffer zones to increase diversity in urban areas.
7. Promote landscape connectivity by reducing fragmentation and increasing gene transfer between species on both public and private properties. Creating habitat corridors for species that will allow for migration, especially in areas like ravines or riparian environments.
8. Enhance genetic diversity from the use of seeds sourced from a wide geographic area which favour existing genotypes that are better adapted to future conditions. Ensuring that seed stock is from multiple parental lineages and not bred from limited sources by working with nurseries will generate higher rates of diversity that can withstand a climate disruption.
9. Facilitate composition adjustments through species transitions by favouring or restore native species that are expected to be adaptable to future climate. Selecting southern regionally rare tree species that are currently at their northern boundary in planting will promote quick transition of the forest canopy. Also, removing species that will be maladapted to the projected conditions like higher severe wind or ice storms occurrences as well as picking species or genotypes with wide moisture and temperature tolerances.
10. Reforest urban ecosystems promptly after a disturbance with the opportunity to plant diverse species as well as realigning significantly disrupted ecosystems to meet expected future conditions with the appropriate mix of species slated to succeed in the forthcoming change.

Reading list

The Canadian Urban Forest Network (CUFN) and Tree Canada are jointly working towards a Canadian Urban Forestry Strategy with a series of working groups tasked with enabling a pan-Canadian urban forestry vision. The network is comprised of municipal foresters, provincial and federal agencies, professional organizations, educational institutions, and

community groups. The goal of the CUFN is to promote proper urban forestry practices, facilitate the exchange of ideas between various municipal urban forestry departments, and increase awareness of urban forestry. We recommended that Waterloo Region join the CUFN to take advantage of this important resource.

The USDA Forest Service has an excellent online urban forestry resource centre that has sections devoted to urban forestry education, forest service tools and apps for urban forestry management, adaptation approaches and planning toolkits, and a library of recommended reading. The *Compendium of Adaptation Approaches* in the Climate Change Resource Center in this website is full of ideas and actions that municipal forestry staff can utilize, all within the lens of climate change. However, since this site is directed towards American forests there is a limit to some of the information that a Canadian audience could use but we suggest using data or scenarios from western New York State, Ohio, and southern Michigan as proxies for Waterloo Region.

The Ontario Invasive Plant Council (OIPC) is an non-profit that provides individuals and organizations assistance with dealing with invasive plants. This resource would be invaluable to WR to protect against the expansion of noxious weeds. We recommend WR considering join this council.

The following are additional UFMPs that WR might refer to when drafting its management plan:

- York Region UFMP
- Milton UFMP
- Kitchener UFMP
- Cambridge UFMP
- Oakville UFMP

Organizations

The Ontario Urban Forest Council (OUFC) is an organization that works towards partnering with all sectors to unite forest managers, industry, governments, and academics to develop approaches to various urban forest issues. Seminars, workshops, and conferences are available to members of the OUFC and we recommend that Waterloo Region join this council.

References for Appendix G

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