A GIS-based decision-support model linking urban forest benefits with sustainability goals: an application to Thunder Bay, Ontario

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By

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Abstract

Urban forests are a key piece of a city's green infrastructure, highly valued for their socioeconomic and environmental benefits. Current research demonstrates their structure and function are considerable assets to the health and livability of a city (e.gs., energy savings, stormwater mitigation, decreased crime rates). Cities are also now beginning to recognize the importance of these benefits in managing and maintaining their urban forests. However, the ways in which these benefits are tabulated fall short of providing city foresters and municipal planners schemes by which to prioritize tree planting and tree care regimes that will optimize benefits to the community. This proposes a method by which this may be accomplished.

An Urban Forest Benefits Model (UFBM) has been developed to integrate the research on the benefits of an urban forest into a GIS decision-supported tool. The UFBM is intended to guide cities in prioritizing their greening efforts so as to maximize the level of net environmental, economic and social benefits. It will also help municipalities integrate green infrastructure in a way that contributes toward their urban sustainability objectives.

There were three key objectives associated with this research: (1) to develop an inventory and framework of urban forest benefits calibrated for a specific city; (2) to develop a prioritized list of the city's sustainability goals and identify how greening efforts contribute toward these goals through use of a link table; and (3) to develop the GIS-based UFBM that will assist with the sequencing of greening activities (planting, maintenance and protection) in order to optimize community benefits and attain long-term community sustainability goals.

The prototype UFBM was applied using a case study approach to the City of Thunder Bay, Ontario. Review of urban forestry and sustainability literature and several focus groups aided in the development of seven custom standard and link table tasks to help achieve a variety of Thunder Bay's sustainability goals through decision-supported greening. The seven management tasks chosen were: (1) stormwater mitigation; (2) planting near higher population concentrations; (3) emerald ash borer crisis management; (4) economic development; (5) greening of Central Business Districts; (6) greening for children engaging in active-commuting to and from school; and (7) greening for those with special needs. Each task was modeled individually using ESRI's ArcGIS, producing an independent set of recommended planting, maintenance and/or protection locations based on the task's objective (e.g., stormwater mitigation). These recommended locations for each of the seven management tasks were then combined to form a final comprehensive map demonstrating optimum locations for greening (planting, maintenance, and protection) in Thunder Bay. The combined results indicate areas requiring a high level of tree cover to ensure an optimal level of desired environmental and socioeconomic benefits. The most important areas identified in this study that require sustained greening are the two downtown cores of Thunder Bay and significant areas in Carrick, Vickers and West End neighbourhoods. Recommendations for operationalizing the model's results to the City of Thunder Bay are provided as well as for applying the UFBM to another jurisdiction.

Key words: forest benefits, community sustainability, decision support system, GIS, green infrastructure, planning, urban forests.

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1.0 Introduction

1.1 Overview of the Issue

Over the past three decades a growing body of literature has demonstrated the multiple values of growing trees in urban environments. Through various forms of social and biophysical research, a wide range of the environmental goods and services produced by an urban forest are now being calculated (Dwyer and Miller 1999; Nowak and Dwyer 2007; Wolf 2007a). Urban trees are commonly referred to as "green infrastructure" because of the many benefits they provide to society, similar to other "hard" infrastructure (e.gs., benches, culverts). Studies focused on green infrastructure and their benefits are not only providing communities with an understanding of the value of an urban forest, but they are demonstrating green infrastructure's contribution toward more sustainable urban environments. A dramatic increase in land pressure and other urban problems in Canada and the US have provided a platform on which to showcase the value of green infrastructure in cities. Urban forests have been shown to counteract and provide significant solutions to urban challenges such as sprawl, economic decline, social inequality, violence, obesity, environmental degradation and crumbling infrastructure (Bolund 1999; Bourne 2001; Wang 2005; Day and Dickinson 2008; Morani *et al.* 2010). Now, in some regions, cities are using healthy urban forests as biotechnology to perform sustainable regenerative services within the community (Bolund 1999; Sorrell 2006; Joye *et al.* 2010; Locke *et al.* 2010). Part of what makes green infrastructure such an ideal option and investment is that, with routine maintenance and at minimal expense, they provide solutions at a fraction of the cost it would take to engineer with hard infrastructure (e.g., concrete storm drains). Consider an urban forest's ability to reduce stormwater runoff and water management costs, moderate the microclimate, calm traffic, stabilize and denature air and soil pollutants and reduce noise (Dwyer *et al.* 1992; Pulford and Watson 2003; Escobedo and Nowak 2009).

The type and amount of function (or benefits) provided by an urban forest is influenced by its structure (e.g., tree canopy diameter, height and condition, tree species) and tree placement. For the most part, a tree's structure has been the most understood aspect that enables a tree to produce benefits. The larger and healthier a particular tree, the more services it generally will render (Nowak *et al.* 2008). Larger, fuller trees have more leaf area, which allows them to perform more services like filtering air, cooling hot urban areas, capturing rainfall, and stabilizing soil.

Although it is under-studied, tree placement with respect to other infrastructure, buildings, pollution sources and people is also another significant determinant in the amount of benefit a tree will contribute. For example, a tree growing in a busy downtown core provides significantly more services to its surrounding environment (reducing smog and noise and moderating the urban heat island) than the same tree located in a farmer's field. Although all large, healthy trees produce benefits regardless of where they are planted, the closer trees are to people and pollution source, the more they will provide ameliorating and beneficial services to the community (Dwyer *et al.* 1992; Maller *et al.* 2002; Sorrell 2006; Rappe 2007).

The paradigm of maximizing a tree's benefits by altering its structure and placement, however, has hardly been a focus or practice until recently. Municipal planners, landscape architects, and urban foresters planted trees primarily for the benefit of aesthetics and gave little forethought to optimizing other urban forest goods and services in a community. While studies focusing on urban forest benefits have existed for decades, few have demonstrated methods to optimize these benefits or the means to practically integrate green infrastructure and their considerable benefits into long term community planning.

1.2 Research Problem

With recent advances in urban forest research, the structure, function and resulting value of an urban forest are now better understood. Simultaneously, the recent development of a suite of new GIS-based tools has allowed decision makers to analyze and query new types of spatial information in regard to an urban forest (McPherson *et al.* 1994; Nowak and Dwyer 2007; Escobedo and Nowak 2009). In the past decade, computer models such as i-Trees' Eco®, Streets®, and Hydro® models have provided planners, foresters, and decision makers with detailed analyses of the environmental goods and services an urban forest produces within a community.

Existing urban forest tools help demonstrate that green infrastructure is a considerable asset to the health and livability of the urban fabric. The tools, however, fall short of helping urban foresters and planners prioritize locations for tree planting, maintenance, and protection that will maximize an urban forest's benefits to a community. The author, who has firsthand experience working as an urban forest professional at the City of Thunder Bay, has encountered the lack of available tools to aid in developing city-wide greening plans. Existing tools only provide a current snapshot (or evaluation) of an urban forest's benefits and have only a limited ability to allow a user to model potential adjustments to the urban forest to increase these benefits. In addition, due to the strong interconnection of tree benefits and the sustainability goals of a community (e.g., reducing building energy costs, mitigating stormwater management costs, and increasing active transportation), there is also a need to develop a research framework that can incorporate urban forest benefits into sustainability planning (James *et al.* 2009). Currently, there are limited tools and research that provide a methodology to use strategically urban forest benefits to help accomplish the sustainability aims of a city.

With the advancement in both urban forest benefit research and GIS, there is significant potential to intertwine these emerging disciplines into a decision-support tool that will guide urban forest planning to maximize benefits. This research proposes a prototype community development tool called the Urban Forest Benefits Model (UFBM) that integrates the latest urban forest benefit research within a GIS so as to enhance the environmental goods and services of an urban forest. The UFBM will prioritize tree planting, maintenance, and protection efforts at a neighbourhood scale to maximize the biophysical and socioeconomic returns to the community. By doing so, it will provide urban planners and urban foresters the means to use trees to help simultaneously achieve a variety of community sustainability objectives (e.g., mitigating stormwater runoff and increasing active transportation).

1.3 Research Objectives

There are three key objectives associated with this research: (1) develop an inventory and framework of urban forest benefits calibrated to the case study city – the City of Thunder Bay, (2) develop a prioritized list of Thunder Bay's sustainability goals and identify how greening efforts contribute toward these goals and, (3) develop the UFBM that will sequence planting, maintenance, and protection efforts in order to optimize community benefits and attain long-term community sustainability goals. The following sections provide the methodology by which the three research objectives are achieved. A more elaborate discussion of the methods can be found in Chapter 3: Conceptual Model.

1.3.1 Method One - Urban Forest Benefit Framework

A thorough literature review facilitated the development of a list of contributions that urban trees and greenspace make to urban communities. The compiled benefit list, gathered from arboriculture and urban forestry research, was used to create a framework presented in chart format using Microsoft Excel®. All benefits found in the literature were summarized and a framework was established providing details such as: a description of each benefit; the category of benefit; costs incurred to the community; cited-research; further examples of indirect benefits; and any other background details pertaining to the research.

Upon completion of the framework, a calibration exercise identified the benefits that are realized in Thunder Bay. Given that the framework includes urban forest benefits that were extracted from research performed throughout the world, most notably in the United States and Europe, this exercise was used to understand how urban forest benefits can be realized in different climates, and more specifically, in Thunder Bay. A focus group consisting of eight local urban forest professionals and academics were used to rank these benefits. This exercise resulted in a ranked list of benefits that subsequently would be used in the link table (see following section).

1.3.2 Method Two – Sustainability Framework

To understand how an urban forest contributes to the sustainability goals of a community, several steps were carried out to identify and rank community sustainability goals. Part of the process was achieved through a literature review of the City of Thunder Bay's major guiding documents, which identified the core goals and direction of the City that pertained to sustainability. Similar to method one, all pertinent goals were summarized and a framework was established providing details such as: goal category, goal description, documents cited, and other supplementary explanatory notes about the sustainability goal. A focus group ranking exercise comparable to that of method one was performed in order to achieve some level of goal priority. The participants were composed of various city managers and decision makers, including the mayor's assistant and urban planning managers.

Upon completion of the prioritized urban forest benefits (method one), and sustainability objectives (the first component of method two), the results were summarized in a matrix called the link table. The link table was used to display connections, both visually and statistically, between the benefits provided by trees and the sustainability objectives of the municipality. The literature was used to determine the strength of connection in the link table between an urban forest benefit and a sustainability goal. The linkages were scored based on a weighting scheme (score categories between 1 to 5; 5 being a strong connection) and provided an indication of which linkages were most valuable. A combination of academics and professionals from the previous focus groups were given the results of the link table. They were then given the opportunity to provide feedback, make changes, and confirm the most valuable connections. These valuable connections, also called management tasks, were later used in method three.

1.3.3 Method Three – GIS Mapping

The prototype UFBM is made up of management tasks derived in part from the link table. As discussed above, the link table is the process where the most pressing and valuable management tasks are chosen for inclusion within the UFBM. The other tasks that make up the UFBM are derived from the standard tasks section, established by the user (Figure 1.1).

The selection of standard tasks is derived in part by reviewing popular criteria that are employed by other municipalities to mitigate an urban challenge through greening. In reality, there are very few municipalities who manage their urban forests to increase their potential benefits, although this practice is now gaining more recognition. The standard tasks used in this case study were chosen because of their high value or benefit to the community, hence the "user" wanted to secure their place in the UFBM by ensuring they were not filtered out in the link table process. The "user" for this case study was a collaborative effort between the researcher and the City Forester for the City of Thunder Bay. The selection process for the standard and link table tasks is called the task generator (see Figure 1.1).

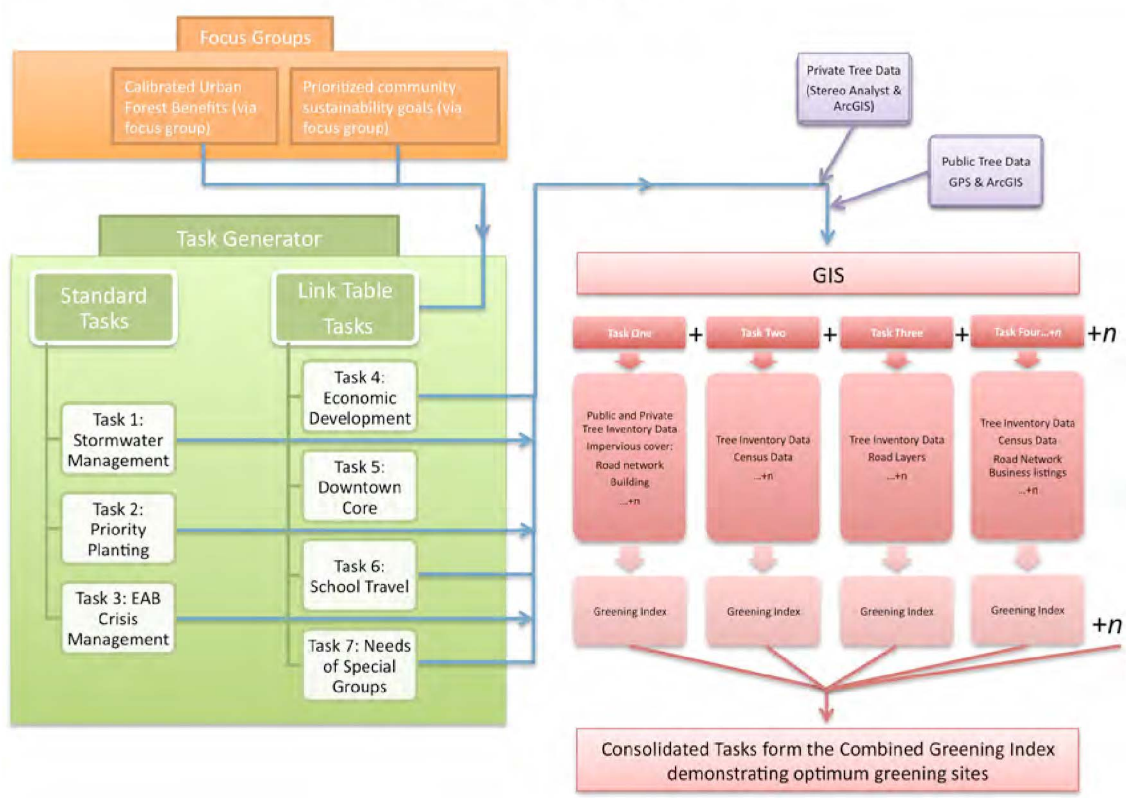

Figure 1.1. The conceptual model displaying the components of the prototype Urban Forest Benefits Model (UFBM). The task generator is comprised of the tasks derived from the standard and the link table processes (the link table processes were informed by the focus groups). The selected tasks are inputted into a GIS where the relevant data are spatially analyzed, mapped and consolidated to demonstrate optimum greening locations.

Prior to operationalizing the tasks into the GIS, each are reviewed to identify the various data requirements necessary for spatial processing. The tasks and their corresponding data sets are then inputted into the GIS for spatial analysis. In this case study, the spatial analysis techniques changed for each task depending on the available data and task objectives. Once each task is analyzed to demonstrate a greening scheme based on the task's objective, the prototype UFBM is then realized when all greening schemes are merged together to form a combined greening index.

The City of the Thunder Bay was used in the case study for this research for two main reasons. First, the author has firsthand experience working as an urban forest professional at the City of Thunder Bay and is familiar with the City's tree inventory and related datasets required for this research. Second, cities in the northern latitudes are exposed to cold and sometimes hostile climates that make livability and sustainability more difficult. Trees play a major role in the livability and permanence of northern communities by fostering a sense of place and by mitigating the extreme climate. Therefore, Thunder Bay is a good candidate to demonstrate how green infrastructure can be used to create more livable and sustainable conditions in a medium-sized, cold-climate city.

1.4 Conclusion

Urban forests can provide many types of regenerative solutions to the urban challenges that communities face. However, through professional experience, the author has encountered few studies and models that have provided the methods to adequately integrate the urban forest with sustainability planning. The prototype

UFBM is a combination of computer-based and non-computer based components (e.g., focus groups) to provide a customized tool for communities to allow them to use green infrastructure more powerfully to mitigate the challenges they face. Due to the diverse range of community goals the UFBM supports (e.gs., hydrology, crime prevention, health care, education) and the wide array of socioeconomic and biophysical goods and services it can theoretically model, a significant review of urban forest benefits, decision support systems, and sustainability concepts were necessary for the study. Chapter two presents a review of the literature and provides a substantial base for the creation of the UFBM as well as supporting evidence to justify the model's development. Chapter three provides the detailed methodology required to develop the model. Chapters four and five then provide additional and technical information on how the model was implemented for the City of Thunder Bay. Chapter six discusses the integration of results from the previous fourth and fifth chapters and provides formal recommendations based on the Combined Greening Index for the City of Thunder Bay. Chapter seven provides concluding remarks that include various limitations associated with this project and potential opportunities for future research.

2.0 Literature Review

2.1 Introduction

In the past couple of decades there has been considerable growth in research on urban forests. Increasingly, trees are seen as integral parts of a city because of the wide range of services they provide to both humans and wildlife (Dwyer *et al.* 1992). Not only are trees getting noticed for their ecological and environmental benefits to society, but a large body of research has exposed the social and economic benefits they provide. Today, trees are seen as an essential tool in the fight against climate change, and air and water pollution, and as a significant contribution toward developing sustainable communities (Kuo 2001; McPherson *et al.* 2006; Nowak and Dwyer 2007).

This chapter provides a review of the various elements associated with urban forest management and sustainability. The first section provides a discussion of the biophysical and socioeconomic goods and services (i.e., benefits) provided by the urban forest. This is followed by a review of the computer models used to valuate and measure these services, the development of decision support systems (DSSs) for sustainability and urban forestry objectives. Decision support tools are playing an increasingly important role in both urban sustainability and urban forestry, by providing decision makers the ability to explore and manage their particular activities. Finally, because principles of sustainable communities directed which management tasks were selected within the developed UFBM, issues pertaining to urban sustainability and the context of the UFBM within broad sustainable policies are explored.

2.2 Benefits of the Urban Forest

Trees are highly-prized for many socioeconomic and environmental contributions to society (Dwyer *et al.* 1992). Research has demonstrated trees' ability to mitigate air pollution (Escobedo and Nowak 2009), increase community attractiveness (Antonelli *et al.* 2006), reduce road and industrial noise (Fang 2003), strengthen business districts (Wolf 2005), and reduce anxiety (Kuo and Sullivan 2001; Taylor *et al.* 2001). These are just a fraction of the urban forest benefits purported in the literature. Over the past decade, researchers have begun to quantify these benefits and have been able to generate very specific and measurable results. Through the use of Geographic Information Systems (GIS) and other computer models, tools such as i-Tree Eco (Nowak *et al.* 2007) and CityGreen (American Forest 2011), foresters and other managers can now calculate the structure, environmental effect, and value of the urban forest (Nowak and Crane 2000).

The benefits gained from an urban forest are optimized through proper planning, site design, tree species selection, and management (Nowak and Dwyer 2007). In contrast, improper planning, incorrect site and species selection, and inadequate maintenance could actually result in a net loss of overall benefits, and in some situations, come at a cost to society (Nowak and Dwyer 2007). Impacts such as excessive production of tree pollen, volatile organic compound (VOC) production, increased building energy use, and infrastructure damage can result without proper planning and management of the urban forest (Mcpherson *et al.* 2006). However, with the use of appropriate planning and management principles, trees can produce a variety of benefits that significantly outweigh their costs. These benefits can be categorized into two main types: biophysical and socioeconomic.

Along with proper planning and management, the sum of benefits produced by a tree is directly related to three biophysical elements: the tree's structure (e.gs., branches and leaf area), the species, and its geographical placement (Dwyer 1999; James 2009). Tree structure, primarily referring to the leaf area, provides an estimate of the strength and amount of benefits a tree produces (Bolund 1999). The leaf area is the estimated measurement of total surface area of each leaf on a tree. Generally a tree that is larger will have more leaf area, and as a result, it can filter out more pollution, intercept more rain, block noise, and provide better shade, etcetera, than smaller trees with less leaf area (Bolund 1999). The type of tree species also influences the type and amount of benefit generated to the community. For example, mulberry (*Morus* spp.) is very effective at filtering out ground-level ozone (Nowak 1994) but does not perform well in addressing issues relating to stormwater management. Trees also have many more benefits to society when they are close to people (i.e., in urban versus rural areas). Trees and shrubs are typically in cities for their beauty or shade properties, but they could also be placed in areas to optimize a number of other potential functions they can provide. For example, large shade trees could be placed strategically around and within areas that contain large areas of impervious cover (i.e., parking lots); such plantings serve to minimize the damages of stormwater runoff, to protect paving surfaces, and to lessen the urban heat island effect (Arthur *et al.* 1995). Understanding how a tree's structure, type, and location affect its overall function provides a good framework for planting the right tree in the right place.

As mentioned previously, trees can either have a net benefit or net cost to society depending on the species, site characteristics, and the amount and type of planning and design involved. If these planting steps are accounted for at the time of tree planting, then the overall costs normally remain well below the net benefits gained over the lifetime of the tree (Akbari *et al.* 2001). Tree maintenance expenses generally add up to a small portion of the yearly costs. A case study by Mcpherson *et al.* (2006) indicated that the municipalities of Jacksonville FL, Savannah, GA and Chareleston, SC, spent on average about $18 a tree per year. Most of this amount was for pruning, planting, removal, disposal and administration (Mcpherson *et al.* 2006). There are also other larger expenses incurred with inappropriate design, species selection, or site selection. Costs for damaged sewer lines, building foundations, parking lots and various other hard infrastructures can be an incurred expense (Randrup *et al.* 2001). These costs, and others, like tree litter pickup and tree pollen, can all be a nuisance and can be an expense difficult to measure. Despite the annual and other costs listed here, the net biophysical and socioeconomic benefits will be shown to outweigh these costs the next two sections.

2.2.1 Biophysical Benefits

Biophysical benefits are those that relate to the physical and biological environment, such as moderating climate, reducing building energy use, air filtration, and noise reduction. The same study by McPherson *et al.* (2006) discussed above indicated that average biophysical benefits (e.gs., heating and cooling energy savings, carbon dioxide reduction) alone were up to six times greater than tree care costs. A large tree planted on the east or west side of a house, for example, was valued at $108 annually and produced $4,320 worth of services over a 40-year period (McPherson *et al.* 2006). Below is a description of some of the most compelling measured biophysical benefits reported in the literature. The descriptions focus mainly on how trees influence the local atmosphere (air temperature, microclimate, reduced air conditioning costs) but also provide brief summaries of other important benefits. The benefits of an urban forest pertaining to the specific management tasks that are part of the UFBM will be discussed in greater detail in their respective chapters (i.e., chapters 4 and 5).

Trees influence the atmosphere in a variety of ways. First, they affect the temperature and microclimate of local environments (Fraser and Kenney 1985; McPherson *et al.* 1994; Escobedo and Nowak 2009). A tree's natural evapotranspiration in conjunction with its leaf-area and shade provide a cooling effect moderating hot summer temperatures found in many urban areas (McPherson and Muchnick 2005). Second, this influence on the microclimate leads to the conservation of the energy that would normally be required to cool homes in the summer (Akbari 2001). Similar benefits have also been realized to reduce building heating costs in winter with the proper site and species selection. Third, trees remove common air pollutants – including sulfur dioxide, nitrogen dioxide, carbon monoxide, and carbon dioxide (Beckett *et al.* 2000; Morani 2010) via their uptake through the leaf stomata where they are stored (or sequestered) by the tree

(Brack 2002). A variety of factors affect trees' ability to uptake air pollutants, including the health and size of leaf surface area, the concentrations of pollutants, and local meteorology (Nowak and Dwyer 2007). According to Nowak (1994), New York City's urban forest removed an estimated 1,821 metric tons of air pollutants in 1994 having an estimated annual value to society of $9.5 million in 1994. Large healthy trees greater than 77 cm in diameter removed approximately 70 times more pollutants annually than small healthy trees less than 8 cm in diameter (Nowak 1994). Hence, there is considerable benefit in the maintenance of a healthy mature forest.

Stormwater mitigation is another significant biophysical service performed by trees. Tree canopies intercept rainwater on their leaves and branches, and create favourable conditions on the ground that slow runoff and allow more water to percolate into the soil (Dwyer *et al.* 1992; McPherson *et al.* 1994). As a result, trees and the surrounding soil and vegetation help to reduce the effects of surface runoff by storing, filtering and denaturing pollutants such as car oil, gas, antifreeze, bacteria, and pesticides. Consequently, pollution loading downstream is significantly reduced (Nowak 2006). By reducing the overall amount of stormwater, trees significantly diminish stormwater management expenses by minimizing the associated engineering and infrastructure costs and by reducing the volume of water entering water-treatment facilities (Xiao *et al.* 1998). Further discussion concerning stormwater is found in Chapter 4.

Society also benefits from a variety of other biophysical goods and services generated by trees. Trees help conserve water (Dwyer and Miller 1999), lower energy use (Mcpherson and Simpson 2003), decrease noise and vibration along busy roads (Cook and Haverbeke 1997; Fang *et al.* 2003), and increase the beauty of the streetscapes (Mcpherson *et al.* 2006). In addition, trees stabilize, denature, and compartmentalize pollution in brownfields and contaminated industrial grounds (Pulford and Watson 2003) and provide habitat for wildlife (Dwyer *et al.* 1992). These benefits also contribute toward some of the socioeconomic benefits received from trees, such as increased tourism and economic development (further discussed in section 2.2.2).

2.2.2 Socioeconomic Benefits

Socioeconomic benefits are those that aid the social, health, or economic fabric of a community. There are a myriad of direct and indirect ways humans benefit from the interactions with trees. In some cases these benefits can be difficult to quantify, such as tree's ability to encourage more regular use of active, non-vehicular transportation in a community by beautifying and shading roads and calming traffic (Hartig and Staats 2006; Hansmann *et al.* 2007; Rappe 2007). Conversely, researchers have demonstrated that some influences are more easily measured than others, such as a decrease in crime (Kuo 2001) or the increase in property values (Wolf 2007a). Numerous studies have demonstrated that homes with trees are preferred to comparable homes without trees. Although price is variable and depends on how tree presence is defined, according to Wolf (2007a) after a review a multiple studies, house prices had increased on average by seven percent with the presence of yard and street trees.

A growing body of evidence has also shown trees to improve the symptoms of Attention Deficit Disorder (ADD) and Attention-Deficit/Hyperactivity Disorder (ADHD) in children and adults (Taylor *et al.* 2001; Kuo and Taylor 2004;). Both ADD and ADHD disrupt cognitive function that affect school performance, and social development including relationships with peers and family members. These effects can persist into adulthood if untreated, and therefore have become a focal point of study for many public health and education-related researchers. Trees and the natural environment appear to reduce ADD, ADHD and fatigue and allow the brain's 'directed attention', purported by Kaplan (1992) to be more effectively restored (Kuo and Sullivan 2001; Taylor *et al.* 2001; Maller *et al.* 2002; Hansmann *et al.* 2007). Kuo and Taylor (2004) have shown that exposure to green natural settings during daily activities is widely effective in reducing attention deficit symptoms in children. Their study, which included 56 analyses of variance (ANOVAs), demonstrated that green outdoor activities received more positive ratings than did activities taking place in other settings 54 out of the 56 analyses. This included reductions of ADHD symptoms among both boys and girls; children in the 5- to 6-year, 7- to 10-year, 11- to 13-year, and 14- to 18- year age groups; and children from 4 separate household income brackets (ranging from less than $25,000 to $75,000 or more per year) (Kuo and Taylor 2004).

Other studies of their socioeconomic benefits have demonstrated how trees increase sales in and attract business customers to retail environments (Wolf 2004a; Wolf 2007b), decrease traffic speeds (Bunn *et al.* 2003; Wolf and Bratton 2006), increase tourism (Dwyer *et al.* 1992), provide healthy social space and increase people's well-being (Sorrell 2006), and increase children's school performance (Taylor *et al.* 2002; Taylor and Kuo 2006). Table 2.1 provides an extensive list of the socioeconomic and biophysical benefits that have been attributed to the urban forest. This list is expanded upon in Appendix V. In addition, there is more detailed discussion of the other benefits pertaining to the UFBM case study in their respective standard and link table task chapters.

Table 2.1. Biophysical and socioeconomic benefits attributed to the urban forest.

Benefit Category	Benefit Description	Research Cited
Biophysical Benefits		
Urban Hydrology		
Stormwater Flow Control	Trees control stormwater runoff by intercepting and retaining flow of precipitation reaching the ground. Trees reduce stormwater rate and volume and increase wastewater facility performance.	Fraser and Kenney 1985; Nowak and Dwyer 2007; Kirnbauer et al. 2009; Dwyer et al. 1992.
Stormwater Cleaning and Phytoremediation	Trees clean stormwater runoff that can improve the quality of water. Trees absorb and retain toxins in water and decrease the amount of overall contaminated water entering the sanitary sewer system and natural waterways	Nowak and Dwyer 2007; Kirnbauer et al. 2009.
Water Temperature	Tree shading lowers water temperature, vital for riparian ecosystem stability and the survival of many organisms.	LeBlanc 1997; Sweeney 1993.
Water Habitat Protection	Trees preserve and enhance fish and wildlife habitat, as well as flora environs. Insects that dwell in treed areas provide a rich asset to these aquatic environments.	Sedell et al. 1988; Sweeney 1993.
Lands		
Erosion and Slope Stability	Trees control erosion especially on steep areas and maintain stability on slopes.	Dwyer et al. 1992; LeBlanc 1997; Sedell et al. 1988; Wolf and Bratton 2006; Escobedo and Nowak 2009; Pulford and Watson 2003.

Table 2.1 continued…

	Benefit Category	Benefit Description	Research Cited
	Building Temperature/Energy Savings	Trees lower ground temperature, minimizing the need for air conditioning in the summer. Proper planting around buildings also reduces heating needs by sheltering buildings in the winter from cold winds.l	Dwyer and Miller 1999; Dwyer et al. 1992; Nowak and Dwyer 2007.
	Road Pavement Life	Tree shading extends the life of road pavement and decreases resurfacing costs.	McPherson and Muchnick 2005.
	Soil Contamination (Phytoremediation/ Phytoextraction)	Some tree species are effective at absorbing soil contaminants especially heavy metals on contaminated sites such as along railroads, highways near ESA's, etc.	Pulford and Watson 2003; Nowak and Dwyer 2007.
	Food	Trees provide food for humans (apples, pears, nuts, mulberries etc.)	Schreckenberg et al. 2006.
	Food	Trees provide food and habitat for wildlife	Dickman and Doncaster 1987.
	Increase property value	Trees consistently add value to a home and property (between 3-15%).	Wolf 2007.
	Air Quality		
	Particulate	Trees remove particulates from the air (ten microns or less).	McPherson et al.1994; Nowak 1994; Escobedo and Nowak 2009; Nowak and Dwyer 2007.
	Atmospheric Pollutants	Trees reduce CO_2 by sequestration, and other pollutants (Trees sequester many pollutants from the atmosphere, including nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), carbon monoxide (CO).	McPherson et al. 1994; Nowak 1994; Escobedo and Nowak 2009; Nowak and Dwyer 2007.
	Air Temperature/Micro Climate	Trees lead to temperature reduction and other microclimatic effects	McPherson and Muchnick 2005; McPherson et al. 2006; Sweeney 1993; Escobedo and Nowak 2009; McPherson et al. 1994; Nowak and Dwyer 2007.
	Vehicle VOC emissions	By shading asphalt surfaces, trees minimizes carbon emissions caused by automobile gas tank evaporation.	Nowak 1994b; McPherson and Simpson 2003.
	Vehicle VOC emissions	Trees minimize interior car off-gas toxins.	Akbari et al. 2001; Chien 2007.

Table 2.1 continued…

	Benefit Category	Benefit Description	Research Cited
	Noise	Trees help reduce noise in the city	Fang et al. 2003; Moll 1995; Dwyer et al. 1992; Nowak and Dwyer 2007; Cook and Haverbeke 1977.
Socioeconomic Benefits			
	Economic Development		
	Attract business investment	Trees attract business investment through increased aesthetics and through increased traffic/tourism.	Yannick et al. 2010; Wolf 2004a; 2006; 2007.
	Stimulate downtown business	Trees support the creation of a positive climate for business, institutions and employees, in order to develop a diversified, growing economy. Trees positively influence consumer behavior; customers are willing to pay more for parking, stay longer, and spend more on goods and services.	Wolf 2004a; 2005; 2007; 2009
	Tourism	Trees positively affect tourism through influence on consumer behaviour and beautification.	Wolf 2004a; 2005; Dwyer et al. 1992;
	Worker Productivity	Trees improve worker/employee productivity at the workplace.	Sorrell 2006; Kuo and Sullivan 2001; Taylor, et al. 2002; Lohr 1996; Shibata and Suzuki 2002.
	Building lifecycle costs	Tree shade/wind/rain diminish some forms of weathering on anthropomorphic surfaces such as shingles, siding, wood decks, roads etc. and allow for longer material lifecycle.	Rosenfeld et al. 1995.
	Beautification and Design		
	Beautification	Trees beautify the neighbourhood.	Regan and Horn 2005; Hartig and Staats 2006; Dwyer et al. 2000; Hansmann et al. 2007; Dwyer et al. 1992; Dwyer, et al. 1991.
	Beautification	Trees make street corridors more attractive and appealing.	Wolf 2004a; 2007; Dwyer et al. 2000; Hartig and Staats 2006;
	Beautification	Trees improve the condition and appearance of buildings or structures which require upgrading & rehabilitation	Regan and Horn 2005; Yannick 2010; Wolf 2005; 2007

Table 2.1 continued…

Benefit Category	Benefit Description	Research Cited
Urban Sprawl/Intensification	Trees increase the value and aesthetics of inner-city properties, thus making them more desirable for higher income families, which leads to more families settling in cities rather than building outside the urban core.	Dwyer et al. 1992; Dwyer et al.1991.
Sense of Place "Genius Loci"	Trees make corridors more attractive and appealing and connect a community with its locality (sense of place)	Wolf 2004a; 2009; Dwyer et al. 1992; Paterson and Connery 1997; Nowak and Dwyer 2007; Velarde et al. 2007; McPherson et al. 2006.
Civic Pride	Trees transform neighbourhoods (social, economic, ecological) and are a catalyst to attaining civic pride that brings further change and community interaction (Wolf 2005)	Wolf 2004a Dwyer et al. 1992; Dwyer et al. 1991; McPherson et al. 2006.
Public Health and Safety		
Overall Health	Trees increase the well being of humans. Patients with views or interaction with greenspace heal and are released more quickly, trees reduce air pollution which causes respiratory complications, reduces the number of patients with heat stroke and other over heating complications (heart attacks in seniors etc.), encourages more active transportation and reduces illness relating to obesity and cardiovascular disease.	Velarde et al. 2007; Hansmann et al. 2007; Sorrell 2006; Taylor et al. 2001; Rappe 2007; Taylor et al. 2002; Akbari et al. 2001.
Hospital and Injury Recovery	The visible landscape and association with greenspace is believed to affect human beings in many ways, including aesthetic appreciation, health and well-being which contributes toward faster recovery times.	Ultirch 1984; Hansmann et al. 2007; Erja Rappe 2007; Sorrell 2006; Kuo and Sullivan 2001; Velarde et al. 2007.
Traffic	Trees calm traffic (slow speeding) and increase road safety	Wolf and Bratton 2006; Bunn et al. 2009; Pharaoh and Russell 1991.
Active transportation	Trees encourage active transportation as sidewalks/paths are cooler, more protected from vehicles, more attractive and quieter (trees reduce traffic speeds and absorb noise).	Hansmann et al. 2007.

Table 2.1 continued…

	Benefit Category	Benefit Description	Research Cited
	Pedestrian safety	Trees provide a safety corridor between roads and sidewalks protecting pedestrians and giving the perception of safety.	Wolf and Bratton 2006; Bunn 2009; Pharaoh and Russell 1991.
	Glare	Trees act as glare control in work, road and living environments, cutting down on irritability and work distraction.	Wolf and Bratton 2006; Akbari et al. 2001.
	UV Light	Reduced exposure to cancer-causing UV radiation, lowering the risk of skin cancer and cataracts.	Saraiya 2004; Nowak and Dwyer 2007.
Psychological			
	Stress	Trees improve mental health by providing stress reduction, privacy, etc.	Velarde et al. 2007; Hansmann et al. 2007; Sorrell 2006; Kuo and Sullivan 2001; Shibata and Suzuki 2002.
	Mood	Trees positively affect mood.	Sorrell 2006; Velarde et al. 2007; Hansmann et al. 2007; Wolf 1997; 2004; Kuo and Sullivan 2001; Dwyer et al. 1991; Shibata and Suzuki 2002.
	Fatigue	Access or views of natural elements and greenery lower mental fatigue.	Kuo 2001; Shibata and Suzuki 2002; Kuo and Sullivan 2001.
	Aggression	Access or views of natural elements and greenery reduce aggression.	Velarde et al. 2007; Kuo and Sullivan 2001; Dwyer et al. 1991.
	Depression	Access or views of natural elements and greenery alleviate the affects of depression.	Sorrell 2006; Kuo and Sullivan 2001; Dwyer, et al.1991.
	Cognitive Function	Green settings replenish cognitive function throughout the day. Research also indicates that children have highest cognitive function when exposed to green settings.	Wells 2000; Velarde, et al. 2007; Sorrell 2006; Kuo and Sullivan 2001; Shibata and Suzuki 2002.
Food			
	Food Source	Fruit trees, if properly placed in backyards, parks and pathways, can produce edible fruit (apples, pears, cherries, nuts, mulberries, etc.).	Thaman 2002; Ellis 1998; Bolund 1999.

Table 2.1 continued…

	Benefit Category	Benefit Description	Research Cited
	Encourage active transportation to grocery stores (reduce impacts of food deserts).	Tree lined streets encourage active transportation by providing protection to pedestrians from cars and high winds, keeping them in the shade, and provide a more meaningful and beautified route. People are willing to walk/bike further in protected/beautified routes to grocery stores rather than relying on unhealthy convenience store food.	Hansmann et al. 2007; Taylor et al. 2001.
Education			
	Attention-deficit/Hyperactivity	Children with ADHD show fewer symptoms when exposed to natural/treed settings and have Improved ability to cope with ADHD.	Kuo and Sullivan 2001; Taylor et al. 2001; Wells 2000; Velarde et al. 2007; Sorrell 2006; Shibata and Suzuki 2002.
	Performance	Children's school performance is improved with views of, and interactions with, green settings.	Wells 2000; Kuo and Sullivan 2001; Taylor, et al. 2001; Taylor et al. 2002; Kuo et al. 2004.
	Enhance Children's play	Urban parks and trees provide more opportunity and encourage children, parents, and grandparents to participate in outdoor activities. It also provides meaningful and educational environmental activities (i.e. tree planting efforts)	Dwyer et al. 1991; Taylor et al. 1998; Kuo 2003; Taylor et al. 2001.
Crime and Other Social			
	Aggression - Violence	Fatigue may increase chances of outbursts of anger and violence. Contact with nature has been reported to mitigate mental fatigue and reduce domestic violence	Taylor et al. 2001; Kuo and Sullivan 2001; Kuo 2001; Wells 2000; Velarde et al. 2007.
	Aggression - Violence	Contact with nature has been reported to mitigate mental fatigue which can reduce outbursts of aggression on the road (road rage)	Sorrell 2006; Taylor, Kuo and Sullivan 2001; Kuo 2001; Wells 2000; Velarde et al. 2007.
	Neighbourhood Safety	Trees are among the most important features contributing to the aesthetics of a street and neighbourhood. Their presence increases the perception of care and safety.	Kuo and Sullivan 2001; Kuo 2003; James et al. 2009; Kuo et al. 1998; Dwyer et al. 1992; Velarde et al. 2007.

Table 2.1 continued…

	Benefit Category	Benefit Description	Research Cited
	Neighbourhood Safety	Trees increase social ties and neighboring in public and private lands. Trees provide relief from the sun (cool areas to interact), aesthetics, and appearance of hospitality and care. The various activities surrounding trees, such as leaf raking, tree planting and pruning can increase neighbourhood involvement and ties.	Kuo and Sullivan 2001; Velarde et al. 2007; Kuo et al. 1998; Kuo 2003;
	Cultural and Spiritual	Trees are significant to many cultures, communities and spiritual groups; enriching and complementing cultures and spiritual experiences. Trees also provide creative inspiration to artists, writers, poets and singers.	Dwyer et al. 1991; McPherson et al. 2006; Fraser and Kenney 1985;

2.3 Computer Models of the Urban Forest

As discussed earlier, since the late 1990s a number of computer-based models have been developed to equip city foresters with superior information to manage the urban forest. The following sections present a variety of different software models and decision support systems.

2.3.1 Decision Support Systems

A decision support system (DSS) is a set of methods that includes a computer-based system that provides intelligence to organizations to better equip them in their decision-making activities (Densham 1991; Eom *et al.* 1998; Sefino *et al.* 1999). DSSs play an increasingly important role in both urban sustainability and urban forestry, by providing decision makers the ability to explore and manage their particular activities (Geertman and Stillwell 2004).

The components of a DSS usually include a combination of data sets, computer-based algorithms and software, but they also can include theoretical knowledge and modeling capabilities (Geertman and Stillwell 2004). DSS development in 1970s gave rise to a variety of applications in accounting, business and marketing groups (Van Bruggen 1998), agriculture (Delarosa 2004), environmental and natural resource planning (Varma *et al.* 2000; Brack 2002), among others. The main intent was to develop a computer-based interactive human-computer decision-making system that, 1) supports decision makers rather than replace them; 2) uses data and models; 3) solves complex problems; and 4) focuses on effectiveness rather than efficiency in decision processes (Alter 1980; Bonczek 1981; Spraque and Carlson 1982).

In the late 1990s, at the same time DSSs were gaining strength and popularity, Geographic Information Systems (GIS) were continuing to mature and were becoming more accessible and used by organizations. Although these two systems were mutually exclusive from each other at that time, the potential to merge them presented great benefit. GIS are pieces of software that provide a variety of analysis for spatial data and can offer a meaningful cartographic display of the data. However, they do not provide the tools to help users select the proper functions needed to apply or interpret the results (Seffino *et al.* 1999). In its early development (pre-1990), GIS also lacked breadth in its analytical modeling capabilities and did not easily accommodate variations in the context or process of spatial decision-making (Densham 1991). In this regard, the potential to couple a DSS with a GIS led to the development of the term spatial decision support system (SDSS), which integrates informed decision making and spatially-referenced data (Densham 1991; Seffino *et al.* 1999).

At present a variety of SDSSs are being used by community decision makers and foresters to provide meaningful analysis of urban forestry data. These models (i.e., i-Tree Hydro, CityGreen) will be discussed.

2.3.1.1. i-Tree Tools Suite®

In 2006 the USDA Forest Service released a peer-reviewed software suite that provides urban forestry analysis and benefits tools for communities. The suite is made up of various software tools that quantify the environmental services and structure of the urban forest (USDA 2011). The software helps communities recognize the various types of ecosystem services provided by trees in their jurisdiction, and it helps inform forest management activities that are applicable to many other sustainability concerns like stormwater and air pollution. These tools within the i-Tree Tool Suite are discussed below, namely i-Tree Eco; i-Tree Streets; and i-Tree Hydro.

i-Tree Eco

i-Tree Eco is a tool that calculates the structure, environmental effects, and values of an urban forest (Escobedo and Nowak 2009). It was developed in the late 1990s under the name UFORE (Urban Forest Effects) to provide accurate estimates of urban forest structure (composition and diversity, diameter distribution, tree density and health, leaf area, leaf biomass, and other structural characteristics)(Nowak and Crane 2000); pollution removal; volatile organic compound emissions of trees; carbon sequestration rates; building energy savings due to tree shading; compensatory value of the forest (and pollution removal); tree pollen allergenicity index; and the potential impact of pests. At the time of its development, i-Tree Eco had four main modules: (1) UFORE-A: Anotomy of the Urban Forest (species composition, tree health, leaf area); (2) UFORE-B: Biogenic Volatile Organic Compound (VOC) Emissions (emissions that contribute to ozone formation); (3) UFORE-C: Carbon Sequestration (net carbon sequestered by trees); and (4) UFORE-D: Dry Deposition of Air Pollution (quantifies hourly pollution removal) (Nowak and Crane 2000). Since its initial development, USDA Forest Service teams have added further models to provide comprehensive assessments of trees, such as pollen costs or tree shade and energy savings. Initially i-Tree Eco was developed for cities and street tree inventories, however its methods can be applied to areas of any size or area, including urban or rural areas.

Four types of data are required to run the first four modules: field, tree cover, meteorological, and pollution concentration data (Nowak and Crane 2000). The tree cover data can be in the form of either a complete (100%) sample to calculate values for each tree for a total population, or a partial sample inventory to calculate estimates for a total population (USDA 2010; Nowak, pers. comm., 2011). Once the tree data are collected and entered into the i-Tree Eco database along with other data such as local hourly weather and air pollution concentration data, scientific equations and algorithms are used to calculate structural and functional information pertaining to the estimates (i.e., carbon calculations, air pollution) listed above.

The i-Tree Eco model uses the estimates of environmental value calculated in the first part of the model to convert them to an economic value. This is done through a variety of complex methods depending on the module (Nowak and Crane 2000). For instance, the dry deposition of air pollution conversion calculates the hourly dry deposition of ozone, sulfur dioxide, nitrogen dioxide, PM10, and carbon monoxide to tree canopies throughout the year based on tree cover data, hourly weather data, and pollution-concentration monitoring data. It requires a set of algorithms to determine the pollutant flux, deposition velocity, aerodynamic resistance and quasi-laminar boundary-layer resistance (USDA 2010).

As described here, i-Tree Eco uses a variety of technical data inputs and calculations to determine a benchmark of urban forest structure and value and has different objectives than the UFBM discussed in this thesis (see discussion in Chapter 3). The data needed to operate the i-Tree Eco model can be difficult or costly to access, dependent on the size and location of the jurisdiction. Although i-Tree Eco can be applied to any size of community, its significant data requirements limit its use to municipalities with the means to collect and manage the necessary data.

i-Tree Streets

Another tool offered by the USDA i-Tree software suite is i-Tree Streets (formerly STRATUM), which focuses on the benefits provided by a municipality's street trees. Like the described i-Tree Eco tool, it too can use either a complete or sample inventory to evaluate a dollar value of the annual environmental and aesthetic benefits provided by trees. Users import the public tree inventory and community specific information (e.gs., price of electricity, program management costs), into the model. Although some street tree inventory attributes are optional, the species, diameter at breast height (DBH) and street segment ID attributes are mandatory (USDA 2010). i-Tree Streets then uses tree growth and benefit models for predominant urban tree species in 16 US climate zones (USDA 2011) to calculate a variety of baseline estimates. Its main outputs focus on (1) forest structure (species composition, extent, and diversity), (2) function (the services trees provide to the community), (3) value (the monetary value of these services) and (4) management needs (evaluations of diversity, canopy cover, planting, pruning) (McPherson *et al.* 2006; Wolf 2007a; USDA 2011). Streets provides baseline data that can be used by decision makers to manage the resource, set priorities, leverage investments, and gain public support (McPherson *et al.* 2006). A comparison between i-Tree Streets, and other i-Tree models will be discussed in the next section.

i-Tree Hydro

i-Tree Hydro is a GIS-based beta tool that assesses changes in streamflow and water quality based on changes in tree cover and impervious cover within a watershed (Wang *et al.* 2008) and is a combination of two modules. The first module simulates hourly changes in stream flow due to changes in tree and impervious cover, and the second module simulates water quality based on the module (USDA 2011). The recent release of this beta model is the first of its kind to integrate trees into the urban stormwater modeling process (Wang *et al.* 2008). The software uses a digital elevation model in conjunction with local weather station data to quantify vegetation and impervious cover effects on hydrology (Nowak 2006). It differs from CityGreen's stormwater utility (see next section), which uses TR-55 stormwater modeler (Natural Resource Conservation Services 1975) to simulate and assess the performance of a stormwater management system. Although i-Tree Hydro has simplified the modeling and user interface, it still requires significant input data and complex algorithms to calculate the processes of each hydrological unit: precipitation, interception, evaporation, infiltration, and runoff (Wang *et al.* 2008). For example algorithms are used to determine runoff volumes based on different land and soil conditions (Nowak 2006).

There are differences between i-Tree Hydro and the other i-Tree software tools. The most significant difference is that the i-Tree Hydro analysis area is confined to a watershed (with gauging station flow data) boundary and cannot be defined by the user (Vargas 2005). It also requires a comprehensive understanding and technical expertise in data preparation (e.g., formatting the DEM), and in hydrology as its modeled results are presented as changes in hourly stream flow or water quality (Vargas 2005). The results are not presented in spatial (map) format and can make their interpretation difficult. Other limitations for its wide use include, 1) data acquisition and 2) lack of a planting scheme required. First, although the i-Tree Hydro tool is designed for municipal land-cover managers, the inputs are still at times considerable and are difficult for small- or medium-sized

Canadian cities to obtain. Second, i-Tree Hydro does not provide new planting and maintenance schemes as its output lacks a spatial component as discussed above.

2.3.1.2. CityGreen®

CityGreen software analyzes the ecosystem services of an urban forest and produces easily understandable results for municipalities. It is a useful tool for cities to plan and manage their urban greening progress and provide baseline reports, like those of the i-Tree Suite. The model is mapped-based and works as an extension to ESRI's ArcGIS 9 and uses many of the formulas found in i-Tree Tools developed by David Nowak (American Forests 2002). The analysis is based on landcover dataset, such as aerial photography, that has a resolution of 4m or better. The dataset must be classified by the user (i.e., tree cover, grass, impervious cover) before it can be processed with CityGreen (Dwyer and Miller 1999). CityGreen can process a combination of variables, similar to those discussed in the i-Tree Tools suite (see previous section), such as stormwater runoff, air pollution removal, carbon storage and sequestration and landcover breakdown.

The model provides a report of the overall stormwater runoff volume and dollar value associated with removing any access stormwater resulting in changes to the tree cover. Air pollution removal calculates the removal capacity of a tree canopy and similarly to i-Tree, the model estimates the amount of ozone, sulfur dioxide, nitrogen dioxide, PM10 and carbon monoxide that is deposited in tree canopies or sequestered into the woody tissue (American Forests 2002). The carbon storage and sequestration module calculates the amount of carbon stored in the trees and represented in the land cover map (American Forest 2011). The model also provides a breakdown of the landcover and provides an estimate of impervious cover, tree cover and open spaces (American Forest 2011). It is designed to analyze alternate scenarios, as landcover maps change, the influences can be determined regarding each of the test variables.

However, the model is not without its limitations. The process to model those variables (e.g., air pollution removal) is mostly dependant on lookup tables and the data are also inferred from curve-based results. For instance, if the model was being run for Halifax, it would use the data from the nearest neighbouring reference city (i.e., Boston) to determine the species and air pollution absorption rates. Also, within the CityGreen model, stormwater runoff is the sole variable calculated, as compared to i-Tree Hydro, which analyzes precipitation, interception, evaporation, infiltration amounts, along with runoff. CityGreen uses TR-55 to determine stormwater flow, which has been criticized by researchers for inaccurately measuring the effects of urban forest management on runoff volume and peak rate (Xiao *et al.* 1998).

Although similar to i-Tree suites, CityGreen has some advantages and disadvantages. CityGreen has been designed to provide simplified, easily understandable and spatial results in the form of graphs, maps, and charts in its final report. i-Tree Suite tools does not have a map and spatial component as of yet. Perhaps the most compelling difference between these two is the data types required for analysis. The USDA has developed i-Tree Tools to use real, local field-data (e.gs., local air quality and weather data) as inputs, not estimates or look-up tables used by CityGreen (e.g., braod weather and pollution normals for large areas of the US). This difference allows i-Tree Tools to provide more appropriate and meaningful results that better reflect the actual condition of the study community, rather than estimating or interpolating data from specific neighbouring reference cities.

As it can be inferred from the model discussion above, the current i-Tree and CityGreen models provide only a benchmark of data with some extended non-spatial features to simulate a change in environment or canopy cover. Their focus is aimed at biophysical aspects of the environment (e.gs., air pollution, stormwater) and do not account for social influences of trees in cities. The main benchmark of data presented by i-Tree and CityGreen provide insight into the distribution, extent, structure, function and resulting value of a community's urban forest. They do not, however, provide the means to adequately forecast and target areas for increased canopy to achieve a particular objective within the urban environment/community urban problem (e.g., stormwater reduction or traffic calming).

2.3.2 Applications of DSSs in Urban Forestry and Sustainability

The use of DSSs or SDSSs provides strong intelligence to support and enhance a variety of industries' and organizations' goals. Of these, private and public environmental planning and sustainability organizations find considerable support from GIS-based DSSs and are turning to them to assist in complex spatial problem solving (Densham 1991).

The use of SDSS in urban sustainability is diverse, ranging from predicting regions of land for future sustainable development (Banai 2005) to choosing the process of urban development that meets people's needs while avoiding unacceptable social or environmental impacts (Hamilton *et al.* 2010). Banai (2005), for example, developed an SDSS that assesses incremental land development plan proposals within the long-term community priority of sustainable growth. The system uses other models and GIS to facilitate an assessment of urban form within multiple variables of sustainability. The resulting land-use sustainability scores indicate whether or not a desirable urban form will exist long-term, and helps determine land resource for future sustainable development (Banai 2005). It is similar to the research concept advocated in this paper in that the prototype SDSS incorporates multiple sustainability criteria, weighted to local public policy and accounts for varied directions of development. The SDSS developed in Banai (2005) also uses a variety of data and other models, including GIS, to provide weighted scores that improve decision making.

Upon review of the current literature, there is arguably a large number of SDSSs with objectives toward urban sustainability and planning, but there is a lack of models relating to the combination of urban forestry and sustainability objectives. The few planning tools or methods that focused on greening (Brack 2002; Randall *et al.* 2003; Li *et al.* 2005; Kirnbauer *et al.* 2009) had different objectives with respect to greening, however none incorporated GIS and the research of urban forest benefits to mitigate a particular urban problem. Kirnbauer *et al.* (2009) was the closest, in that it used a variety of methods to evaluate potential planting sites to provide users with the tools to improve the micro-management of trees around structures. It used GIS and other models to locate ideal planting sites based on above and underground conflicts (e.gs., gas lines, streetlighting). Its objective, however, was to locate a planting site based on physical obstructions, not to maximize a tree's goods or services.

Most of the forestry-related DSSs that exist pertain to the commercial forestry sector, like that of Næsset (1997), Varma *et al.* (2000) and Seely *et al.* (2004). DSSs in a commercial setting differ greatly from the focus needed in an urban setting. That is, many commercial DSSs converge on sustained long-term management, silvicultural practices, sustained yield and profit, and forest health. Part of the reason there has been little development of urban forestry DSS is due to the lack of government support and funding of urban forestry in many global jurisdictions, especially in Canada (Kenney and Idziak 2000; Kenney 2003). In recent years, urban forest value and research has been recognized by the United States, and has led to a surge of new research that has contributed toward other management tools, such as i-Tree. These models, although not technically labeled a DSS by their developers, do provide significant support for management and complex decision-making.

2.3.3 Other Urban Forest Modeling Approaches

A recent study by Locke *et al.* (2010) identifies a variety of GIS-based methods that were used to identify optimum planting locations to increase tree cover or the urban forest. Their modeling approach is not packaged as a stand-alone software program (such as i-Tree Tools or CityGreen), but is a series of methods using GIS and remote sensing to calculate its results. Their approach described here has some conceptual similarities to the developed UFBM in that it is designed to target areas for increased tree cover in order to mitigate a particular urban problem. The locations that were targeted by Locke *et al.* (2010) were selected to achieve the programmatic goals based on a number of New York City tree planting organizations (i.e., New York City Department of Parks and Recreation's Natural Resources Group, the Central Forestry and Horticulture division, and the not-for-profit organization New York Restoration Project) and the specific needs of the community. The GIS data relevant for tree planting were based on two tiers. Tier 1 values were used to assess whether urban trees can help address a neighbourhood's current needs. Examples of Tier 1 values include the urban heat island, biodiversity, and air quality. Tier 2 values are calculated to identify the suitable planting spots for each of the three organizations involved in the project. Both Tier 1 and 2 are combined to form a set of parcel rankings for each stakeholder group and the results are displayed on maps (Locke *et al*. 2010).

Using high-resolution imagery in conjunction with LIDAR, it was possible to do an automated (rather than manual) classification for detailed features including roads, buildings, grass, and trees (O'Neil-Dunne pers. comm., 2011). The high level of detail in classification helped determine 'possible' and 'preferable' areas for planting. This classification process and given set of methods resulted in a targeted greening plan for each of the three planting organizations. As a result it helped achieve various community needs like reducing flooding problems and increasing air quality.

Locke's et al. (2010) research methods require the use of expensive LIDAR imagery. Many small and medium-sized cities do not have access to this type of data nor do they have the software or expertise required for processing it. Locke *et al.* (2010) also uses only the strongest benefits reported in the literature, and the model does not prioritize or target the most important sustainability goals of a community nor do they use a sustainability approach (i.e., environmental, economic, social) when choosing the benefits. The model's results are then displayed in census areas, and therefore are generalized over large regions, which do not provide adequate detailed results (e.g., 1 ha areas) for some decision makers.

2.4 Sustainability in Urban Environments

Cities continue to grow at significant rates in Canada and it is projected that approximately 88% of Canadians will live in cities by the year 2030 (Statistics Canada 2009). As these urban areas grow, so too will the challenges that threaten a city's health, livability, and ultimate existence. Cities occupy approximately 2% of the world's land surface, but they use a significant amount of the world's resources (Newman and Jennings 2008). This growth and consumption of resources have amplified the environmental and social problems across the globe and within cities. In light of these challenges, new ways of thinking, including toolkits, models, and organizations are emerging to combat the crises caused by cities. This review of sustainability systems and approaches provides some examples.

2.4.1 Goals and Objectives of Urban Sustainability

The development of sustainability theory and research, particularly in the 1980's, brought about the 'traditional' view of sustainability – an equal integration of the economy, society, and environment. This construct was useful, but researchers agreed (e.gs., Newman 1999; Seymoar 2004), that it did not communicate a central understanding of the world – humans are not separate from nature but are part of the natural environment (Glavic and Lukman 2007). An alternative view of sustainability agreed upon by many scientists has since evolved, which suggests that the economy and society can only function within a healthy natural environment. This 'systems' view of sustainability places the importance on the environment, which provides life to the other economic and social systems (Seymoar 2004; EarthWise Thunder Bay 2008).

However, the perspectives pertaining to sustainability are complex, and experts have not yet reached any form of consensus. Researchers and other experts have tried to, for example, understand urban growth and define sustainable form (shape, size, density and uses) but the opinions are diverse and approaches are still disputed, such as centralized versus decentralized or high versus low urban densities (Alberti 1996; Williams *et al.* 2000). Glavic and Lukman (2007) also demonstrate that the terminology is also widely disputed and is used inaccurately at times.

As a result of, or possibly in spite of, the controversy and divergent thinking, a variety of sustainable perspectives and approaches have emerged in recent years (Glavic and Lukman 2007). This section provides the background of some of the more popular sustainable systems. Sustainable systems are used in this text as a fundamental concept – a broad term to explain a complex system that contains approaches and principles.

Three systems of long-term urban sustainability will be reviewed. Each of the following systems has been endorsed and used globally by civic leaders. They were chosen because of their prominence and widespread use around the world, and because they have their own formal networks and set of criteria that support their work. Elements of the systems discussed below, were also used in different capacities to shape the UFBM (various elements influenced the City of Thunder Bay's goals, which were used in this research). They all incorporate a long-term (generational) timeframe; a holistic approach; application at a regional (city) level; and an adaptive management approach.

A variety of other approaches, principles and systems have been developed that are not as prominent as the systems described below (e.gs., +30 Plus, the Earth Charter Initiative, and the Natural Step) and additionally, they were not used in the construct and development of the UFBM or Thunder Bay's guiding goals, and therefore will not be discussed here.

2.4.1.1. Cities as Sustainable Ecosystems (CASE)

Cities as Sustainable Ecosystems (CASE) is an initiative of the United Nations Environment Programme, International Environmental Technology Centre (IETC). In May 2002, IETC along with ICLEI – Local Governments for Sustainability, the Environment Protection Authority Victoria (Australia), and Environment Canada, tabled the project, framework, and set of principles referred to as the Melborne Principles - Sustainable Communities, at the UN World Summit on Sustainable Development in Australia (Seymoar 2004). Each principle offered decision makers a few paragraphs that provided a starting point and framework for a city's journey toward sustainability (Newman and Jennings 2008). The abbreviated principles for CASE are:

Principle 1: Long-term vision for cities.
Principle 2: Long-term economic and social security.
Principle 3: Intrinsic value of biodiversity and natural ecosystems.
Principle 4: Minimize ecological footprint.
Principle 5: Build on the characteristics of ecosystems.
Principle 6: Recognize and build on the distinctive characteristics of cities.
Principle 7: Empower people and foster participation.
Principle 8: Expand and enable cooperative networks.
Principle 9: Sustainable production and consumption.
Principle 10: Enable continual improvement.

CASE is the 'objective, multidisciplinary study of urban and economic systems and their linkage with the natural system' (Newman and Jennings 2008). Its basis is focused around cities having a limited carrying capacity. While it embraces the interactions of all urban activity and the environment and how these can be transformed into a sustainable relationship (UNEP 2003), it does so without compromising or eroding away the carrying capacity of a city. CASE provides the information and a framework, via the Melbourne Principles, for cities to assist in the prioritization and reordering of environmental and social values (e.g., employment, private property rights)(UNEP 2003).

2.4.1.2. ICLEI

The Melborne Principles for Sustainable Communities used in CASE have also been adopted worldwide by a variety of cities and organizations, including ICLEI -

Local Governments for Sustainability, who used them in their framework to help cities achieve higher levels of sustainability. ICLEI's foundation is based on the Local Agenda 21, the action plan resulting from the 1992 United Nations Conference on the Environment and Development (the Earth Summit) in Rio de Janeiro. The Local Agenda 21 mission is described here by ICLEI (2011, p 48):

> Local Agenda 21 seeks to generate tangible results and increase standards of local performance at the local level through the institution of long-term, broad-based participatory planning processes aimed at achieving sustainable development.

More recently in 2002, at the World Summit on Sustainable Development (WSSD) Local Government Session in Johannesburg, South Africa, world leaders joined ICLEI in launching Local Action 21 as the next chapter to Local Agenda 21.

> The Local Action 21 framework builds on the entrenchment of Local Agenda 21 and positions principles, policies and sustainability management mechanisms at the heart of "achieving unwavering commitment" to developing and maintaining sustainable communities while protecting global common goods (ICLEI 2011, p 49).

Since the Local Action 21, ICLEI has developed a large body of methodologies, procedures, and tools based on The Earth Charter Initiative and Melbourne's Principles to measure, plan, manage, and monitor sustainability at a local level (ICLEI Global 2011). The Earth Charter Initiative provides principles for supporting ethical and ecological issues that focus on developing just, sustainable, and peaceful societies (Earth Charter Initiative 2011). The Earth Charter Initiative, in accord with the Melbourne's Principles are used as a significant force for ICLEI in transitioning global cities to more sustainable ways of development and living. ICLEI's main tenet is to build sustainable cities by enabling local governments to achieve justice, security, resilience, viable economies, and healthy environments (ICLEI Global 2011).

2.4.1.3. Smart Growth

Smart growth is a practical approach to issues of land use and economic development. It is a theory and collection of land use development principles that advocate for the concentration of growth in compact, walkable urban centres to avoid urban sprawl, enhance quality of life, and preserve the natural environment (Seymoar 2004). According to Downs (2005) smart growth was originally conceived as a reaction to what many planners believed to be undesirable features, such as urban sprawl, lack of choice among housing types, and failure to redevelop existing and under-utilized urban lands. Smart growth has clear linkages to other more sustainable development patterns such as, but not limited to, New Urbanism, Compact City, and New Community Design (Downs 2005; Smart Growth Online 2011).

Smart Growth has similarities to ICLEI, in that they both provide their training and tools to help communities implement the framework. Some if its main objectives focus on preserving forested and agricultural land, improving public transit, creating affordable housing, and increasing citizen participation in community development (Smart Growth Online 2011). An outline of their ten core principles are:

1. Mix land uses
2. Take advantage of compact building design
3. Create a range of housing opportunities and choices

4. Create walkable neighborhoods
5. Foster distinctive, attractive communities with a strong sense of place
6. Preserve open space, farmland, natural beauty, and critical environmental areas
7. Strengthen and direct development towards existing communities
8. Provide a variety of transportation choices
9. Make development decisions predictable, fair, and cost effective
10. Encourage community and stakeholder collaboration in development decisions (Downs 2005).

Smart Growth, ICLEI and CASE are systems that are specifically focused on regional planning. Because of their municipal focus, a variety of the principles and approaches discussed above have been used in some form in the development of City of Thunder Bay's strategic vision.

2.4.2 Local Thunder Bay Examples and Progress

The City of Thunder Bay has committed to sustainable practices in a variety of ways and has developed documents articulating specific goals and objectives with respect to sustainability. Earthwise Thunder Bay developed the "Community Environmental Action Plan – A living document" (2008), which has built upon existing initiatives and foundations laid by the City and was adopted by the City of Thunder Bay in 2008 (Earthwise 2008). The plan takes a 'systems' approach to creating a more sustainable community and has adopted the Melbourne Principles as the basis for their plan. During a three-year process, working groups throughout the community developed a series of goals and recommend actions pertaining to each working group's foci. As a result, a comprehensive set of objectives ranging from active transportation and air and water quality, to education and land use, were developed for the City. Many of the objectives articulated in the Earthwise Thunder Bay CEAP (Earthwise 2008), were identified in this research. Those specific goals are identified in Appendix V.

In 2003, the City of Thunder Bay joined the Partners for Climate Protection program, a joint program between the Federation of Canadian Municipalities and ICLEI Local Governments for Sustainability (Earthwise 2008). This partnership committed the City of Thunder Bay to reducing the municipal and community emissions through the creation and implementation of a plan (Earthwise Thunder Bay 2008). Part of the plan was fulfilled through the Earthwise Thunder Bay CEAP, but also other proponents of it will be worked into the upcoming Official Plan (Cartlidge, pers. comm., 2011).

The City of Thunder Bay has also committed to a variety of sustainability objectives as articulated in the 2005 Official Plan (Thunder Bay 2005). The Official Plan is the principal land use policy document for the City, intended to guide the public and private development decisions within Thunder Bay. These goals are wide-reaching, ranging from water habitat protection and the reduction of soil contamination, to increasing tourism and traffic calming strategies in the City. Many of the plan's goals and objectives relating to sustainability were used in the UFBM and can be found in Appendix V. In 2007, the Mayor developed the "Mayor's Strategic Plan" (2007), another document articulating the City's mission including a set of broad and specific goals and principles that focus on the economy, environment, quality of life, and management of the corporation. A variety of these goals relate to sustainability and have been included in the UFBM (see Appendix V).

The focus on sustainability through the CEAP, Official Plan and Mayor's Strategic plan and the embrace of support from organizations like ICLEI are a testament to the City's commitment to enhancing sustainable practices. Although there are a number of other plans and documents that exist that pertain to sustainability, the three documents reviewed in this study were the most prominent and provided adequate detail for the prototype model. As discussed above, these plans and sustainability documents were reviewed so as to identify the sustainability aims that could be used within the UFBM, that is to identify those aims that could be supported by a model or decision-supported greening (i.e., the UFBM). The goals and objectives taken from these documents are summarized in Table 2.2, with a more detailed table in Appendix V.

Table 2.2. The goals and objectives found in the City's various guiding documents that could be influenced by urban greening.

Goal Category	Goal Description	Sustainability Citation
NATURAL CAPITAL		
Lands and Water		
Water	Build watershed partnerships that enhance stakeholder roles and responsibilities and encourage a soft path approach to water resource management.	Earthwise Thunder Bay Annual Report 2009. p25
Water Quality	Policies will be developed to support the City's Pollution Prevention Control Plan and to protect the quality of water in the streams and rivers passing through the City and in Lake Superior.	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 11.6 Servicing

Table 2.2 continued…

Goal Category	Goal Description	Sustainability Citation
Water Conservat-ion	Policies will be developed to encourage conservation in the use of treated water and to minimize the impact on the natural environment through the operation of the City's water system.	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 11.6 Servicing
Water Discharge	In the case of new development, no surface water, ground water or building foundation drains will be discharged to the City's sanitary sewer system. To the fullest extent practical, this policy will also be applied to existing development.	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 11.6 Servicing
Water Collection System	The collection of surface water and sanitary sewage shall be, to the fullest extent practical, achieved through two collection systems completely separate from each other.	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 11.6 Servicing
Surface Drainage	To the fullest extent practical, the quality and quantity of stormwater leaving a site shall be maintained or improved as a result of development.	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 11.6 Servicing
Surface Drainage	Changes in peak runoff rates and the timing of peak flows are to be minimized so as to reduce downstream impacts and the associated threat to life, property and natural resources.	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 11.21 Servicing
Water Habitat Protection	Preserve and enhance fish and wildlife habitat, as well as flora environs	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 14. Environmental Protection Areas
Erosion and Slope Stability	Protect people and property from the risks associated with steep or unstable slopes, poor soil conditions, wave impacts, flooding and erosion.	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 14.3. Environmental Protection Areas
Protection of Wetlands	Protect provincially significant wetlands from any use or development that could result in a negative impact on those attributes for which the wetland has been identified.	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 14.12 Environmental Protection Areas
ANSI's (Areas of Natural and Scientific Interest)	Ensure the preservation of "Areas of Natural and Scientific Interest" through the use of appropriate development controls	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 14.15 Environmental Protection Areas

Table 2.2 continued…

Goal Category	Goal Description	Sustainability Citation
Open Space Areas	Achieve a highly integrated system of recreational areas and trails throughout the City.	CTB Official Plan- May 30, 2005Official Plan Section 2 Page 15. Open Space Areas
Pursue green procurement	A strategic priority for the CTB: Making Thunder Bay Greener	2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008. p9
Community Greening	Develop, implement, and provide sustained funding for a comprehensive Urban Forest Master Plan (UFMP) that integrates people, the environment, trees and their continual change and interaction with each other	Earthwise Thunder Bay Annual Report 2009. p22
Natural Environment	1) maintain and improve, where possible, the diversity of natural heritage features within the City and the natural connections between them; 2) improve property owners' awareness of the value of natural heritage features and increase their understanding of their role in ensuring the protection of these features	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 2.3 The Natural Environment Chapter 2
Soil Contaminati on	Improve the condition of soil contamination (selection criteria for Community Improvement Project Areas)	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 8.3 Community Improvement
Soil Contaminati on	Seek to ensure, in co-operation with the appropriate government authorities, if necessary, that contaminated soil and groundwater do not create a hazard for the health of natural ecosystems or the people who live, work or play within the City	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 12.1 Soil Contamination
Human and Environmental Health		
Air Quality	To Improve outdoor and indoor air quality by reducing air pollutants and greenhouse has emissions.	Earthwise Thunder Bay Annual Report 2009. p32
Pesticides	To protect the health and well-being of the environment and local citizens today, and ensure a sustainable future, by eliminating the use of pesticides on public and private property.	Earthwise Thunder Bay Annual Report 2009. p33

Table 2.2 continued…

Goal Category	Goal Description	Sustainability Citation
Noise, Vibration and Emissions	Minimize or prevent, through the use of various abatement techniques and mitigation measures, the exposure of any person or property to adverse effects associated with noise, vibration or emissions; and encourage the implementation of appropriate mitigation measures to minimize existing compatibility problems;	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 13.1 Noise, Vibration and Emission
PHYSICAL CAPITAL		
Energy and Building		
Energy	Reduce total energy usage by 35% within the CTB, and 10% within the community at large, below 2005 levels by 2017	Earthwise Thunder Bay Annual Report 2009. p18
Energy	Reduce fossil fuel generation by adopting practices that reduce electricity demand during peak periods.	Earthwise Thunder Bay Annual Report 2009. p19
Energy	Encourage the development and use of renewable energy technologies.	Earthwise Thunder Bay Annual Report 2009. p20
Energy	Reduce energy consumption at large City facilities. A strategic priority for the CTB: Making Thunder Bay greener	2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008. p9.
Green Building	Achieve long-term savings to the citizens of Thunder Bay through reduced operating and life-cycle costs of municipal and private facilities.	Earthwise Thunder Bay Annual Report 2009. p15
Beautification and Design		
Beautification	Improve image routes through Site Plan Control. A strategic priority for the CTB: Making Thunder Bay more beautiful	2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008. p10.
Beautification	Design and create Gateways to welcome people to the City. A strategic priority for the CTB: Making Thunder Bay more beautiful	2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008. p10.
Beautification	Improve appearance of Water Street Terminal. A strategic priority for the CTB: Making Thunder Bay more beautiful	2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008. p10.
Revitalization	Revitalize Fort William Downtown. A strategic priority for the CTB: Thunder Bay will have a High Quality of Life	2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008. p12.

Table 2.2 continued…

Goal Category	Goal Description	Sustainability Citation
Intensification/Housing	Encourage efficient residential land use within the City by facilitating the creation of new residential accommodations within existing buildings or on previously developed and serviced land.	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 6.3 Housing
Appearance of buildings	Improve the condition and appearance of buildings or structures which require upgrading, rehabilitation or redevelopment;	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 8.3 Community Improvement
Appearance of buildings	Improve the presence of residential, commercial, industrial or institutional areas which require streetscape and/or facade improvement;	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 8.3 Community Improvement
Residential Areas	Support the provision of services and amenities that enhance the quality of the residential environment.	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 17. Residential Areas
Urban Residential	Enhance compatibility between dwelling types at different densities and minimize potential conflict between incompatible land uses.	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 17. Residential Areas
Urban Sprawl	Curb Thunder Bay's urban sprawl to reduce energy consumption and greenhouse gases.	Earthwise Thunder Bay Annual Report 2009. p29
Institutional Areas	Ensure that major institutional uses are located and designed in such a way as to adequately serve the needs of the residents; the provision of adequate outdoor amenity area; the provision of on-site landscaping, fencing, planting, and other measures to lessen any impact the proposed development may have on adjacent uses;	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 18.1. Institutional Areas
Commercial Grounds	Minimize the impact of commercial development on adjacent land uses and on the traffic carrying capacity of adjacent roads; promote aesthetically pleasing forms of commercial development	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 19.1. Commercial Areas
Downtown Core	Maintain and enhance the downtown areas as unique focal points of activity, interest and identity for residents and visitors through the provision of the fullest range of urban functions and amenities;	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 19.1. Commercial Areas

Table 2.2 continued…

Goal Category	Goal Description	Sustainability Citation
Industrial Areas	Co-ordinate development to minimize any potential conflicts between industrial and non-industrial land uses and between uses within industrial areas themselves;	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 20. Commercial Areas
Industrial Areas	Promote an aesthetically pleasing form of industrial development along major road entrances to the City	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 20. Commercial Areas
ECONOMIC CAPITAL		
Food	Increase the amount of food grown, hunted, gathered, processed, and consumed locally.	Earthwise Thunder Bay Annual Report 2009. p34
Food	Reduce the transportation requirements and environmental impacts of the food system	Earthwise Thunder Bay Annual Report 2009. p35
Cost Effective-ness	An over arching principle in the CTB Strategic Plan	2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008. p3.
Tourism	Attract and retain visitors to the community	2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008. p8.
Tourism	The establishment of the City as part of a strong network of communities and businesses which work together to promote and deliver quality tourism experiences in Northwestern Ontario will be promoted.	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 7.1 Economic Development
Economic Develop-ment	Support the creation of a positive climate for business, institutions and employees, in order to develop a diversified, growing economy; City will rely more upon secondary and tertiary support industry, retail and service functions, and small business, rather than the traditional sources of employment.	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 7.1 Economic Development

Table 2.2 continued…

Goal Category	Goal Description	Sustainability Citation
HUMAN CAPITAL		
Transportation		
Active Transporta-tion (AT)	Improved Safety for people who are engaged in AT	Earthwise Thunder Bay Annual Report 2009. p11
Active Transporta-tion (AT)	Improve the number of people walking, biking, or travelling by other human-powered means	Earthwise Thunder Bay Annual Report 2009. p11
Active Transporta-tion (AT)	Develop infrastructure that supports AT	Earthwise Thunder Bay Annual Report 2009. p13
Active Transporta-tion (AT)	Improve Active Transportation: A strategic priority for the CTB: Thunder Bay will have a High Quality of Life	2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008. p12.
Active Transporta-tion (AT)	Encourage the use of energy efficient modes of travel such as public transit, car-pooling, bicycles and other non-motorized forms of transportation.	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 10.1 Transportation
Active Transporta-tion (AT)	The City will encourage linkages between the university, college, commercial, and open space areas.	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 10.58 Transportation
Pedestrians	Provide a rationalized system of pedestrian walkways and corridors, which allow safe, effective, convenient and aesthetically pleasing pedestrian movement.	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 10.50 Transportation
Transport-ation	Minimize the adverse effects of the transportation system on the natural and urban environments, especially in established residential neighbourhoods;	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 10.1 Transportation
Transport-ation	Effect appropriate segregation of truck traffic, for environmental and safety reasons, while at the same time, minimizing the cost of movement expenditures.	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 10.32 Transportation
Traffic Calming	Council shall support the use of traffic calming techniques that help to slow down traffic; reduce through traffic in residential areas; promote pedestrian, bicycle and transit use; and improve the real and perceived safety of the City's streets.	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 10.1 Transportation

Table 2.2 continued…

Goal Category	Goal Description	Sustainability Citation
Parking	Appropriate standards for off-street parking and loading facilities for all forms of land use activities shall be established in the implementing Zoning By-law. The intent of such standards shall be to achieve safe access, efficient usage, improved aesthetics and reduced impact on adjacent land uses.	CTB Official Plan- May 30, 2005 Official Plan Section 2 Page 10.1 Transportation
Community Sustainability		
Education	Using education and community awareness as a means to achieving a sustainable community	CEAP
Education	Increase public awareness of environmental issues and actions people can take by promoting environmental education and training, and participating in projects that promote water and energy conservation, waste reduction, pollution prevention and urban green-spaces.	Statement of Environmental Principles: Envinronment and Conservation Corporate Policy (Pt 6)
Planning for Children	Give priority to the needs of children and youth	A Call to Action:Ontario Professional Planners Institute
Planning for Children	Plan for children and youth as pedestrians	A Call to Action:Ontario Professional Planners Institute
Planning for Children	Plan for children and youth on bicycles (and other wheels)	A Call to Action:Ontario Professional Planners Institute
Planning for Children	Plan for children and youth as transit users	A Call to Action:Ontario Professional Planners Institute
Planning for Children	Focus on journeys to and from school.	A Call to Action:Ontario Professional Planners Institute
Planning for Children	Reduce transport's adverse impacts on children and youth	A Call to Action:Ontario Professional Planners Institute

Table 2.2 continued…

Goal Category	Goal Description	Sustainability Citation
SOCIAL CAPITAL		
Safety		
Crime	To reduce crime as indicated in Objective 1.0, 3.1 and 4.1, 4.9 of Thunder Bay Police Service Business Plan	Thunder Bay Police Services 2008-2010 Business Plan. P1-28
Speeding	To reduce speeding as indicated in Objective 4.5 of Thunder Bay Police Service Business Plan	Thunder Bay Police Services 2008-2010 Business Plan. P1-28
Safe Neighbour-hoods	An over arching principle in the CTB Strategic Plan	2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008. p3.
Safe Neighbour-hoods	Enhance Security at Parkades with better lighting - A strategic priority for the CTB: Thunder Bay will have a High Quality of Life	2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008.p11.
Safe Neighbour-hoods	Enhance Security at Transit Terminals - A strategic priority for the CTB: Thunder Bay will have a High Quality of Life	2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008.p11.
Informed and Involved Citizens	An over arching principle in the CTB Strategic Plan	2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008. p3.
Community Services		
Needs of Special Groups	Encourage consideration of the needs of special groups, and in particular persons with disabilities, in the design and construction of buildings and other facilities.	CTB Official Plan- May 30, 2005 Official Plan Section 4 Page 4.1 Community Services and Facilities
CULTURAL CAPITAL		
Cultural Diversity	2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008. p3.	2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008. p3.
Heritage Resources	1) conserve the historic, archaeological, architectural and cultural heritage resources of the City;	CTB Official Plan- May 30, 2005 Official Plan Section 3 Page 3.1 Heritage Resources

Table 2.2 continued…

Goal Category	Goal Description	Sustainability Citation
Heritage Resources	2) preserve and enhance structures, buildings or sites deemed to have significant historic, archaeological, architectural or cultural significance and, where practical, preserve significant public views and cultural heritage landscapes	CTB Official Plan- May 30, 2005 Official Plan Section 3 Page 3.1 Heritage Resources
Increase Pride in Thunder Bay	A strategic priority for the CTB: Making Thunder Bay more beautiful	2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008. p10.

Notes:
(1) In documents cited above, CTB = City of Thunder Bay

2.5 Conclusion

This chapter has provided the researcher a substantial base for the development of the UFBM. It has also indentified the gaps in the literature that support the development of such a model. The literature surrounding the benefits of urban forests has demonstrated the ability of living green infrastructure to provide a wide array of socioeconomic and biophysical goods and services to the community. These benefits are determined by a few key factors (e.gs., leaf area, species selection, design, location); however with these in place, the substantial benefits produced by trees can be optimized significantly. GIS, decision-support tools and other models have been used to manage and evaluate the benefits of the urban forest. However, few tools or sets of methodology have been developed to optimize the potential benefits of trees. The approach of Locke *et al.* (2010) was the exception, and provides a meaningful process to maximize the potential of New York City's urban forest. However, it uses a highly technical approach usually not affordable to small and medium-sized municipalities nor does it use a sustainability approach (i.e., environmental, economic, social) when choosing the benefits to model. Locke's *et al.* (2010) approach also generates results that are summarized over large regions and therefore provide fewer details to decision makers.

The various models and decision support tools described in this chapter have also indicated that tree benefits serve as a means to mitigate many urban sustainability-related problems (e.gs., filtering air pollution, reducing the volume of stormwater). Various sustainability systems and approaches were reviewed, including a variety of principles and approaches adopted by the City of Thunder Bay such as Melbourne's Principles and ICLEI – Governments for Local Sustainability.

In summary, this chapter has reviewed literature on the benefits of urban forests and their potential contributions to community sustainability. The prototype UFBM, to be fully explained in subsequent chapters, includes a process (i.e., the link table) that was developed to make connections between these benefits and goals. This model and its case study application to a medium-sized, cold climate city represent a unique conceptual approach to urban forest modeling, representing a means to support a community's quest for sustainability through intelligent greening.

3.0 Conceptual Model

The Urban Forest Benefits Model (UFBM) was designed to target urban sites for greening that would produce multiple benefits simultaneously and further the sustainability goals of a community. This model consists of a set of methods and a framework which can be replicated in any city. The following chapter will provide the detailed methods required to develop the model. Chapters four and five, will then provide additional and technical information on how it was implemented for the City of Thunder Bay.

Three key objectives were fulfilled in association with this research. First, a review of urban forest literature assisted in the development of a comprehensive list and framework of urban forest benefits. By way of a focus group, the urban forest benefits relevant to Thunder Bay were identified and retained for the next objective. Second, by means of a review of municipal guiding documents and a focus group, a prioritized list of Thunder Bay's sustainability goals was determined. These goals were paired with the benefits derived in the first objective to form a link table, demonstrating the connection between urban forest benefits and sustainability goals. More specifically, the link table provides a means of identifying the benefits that most strongly contribute toward of a particular sustainability goal. Third, by means of a Geographical Information System (GIS), the strong connections discovered in the link table are analyzed, resulting in a planting, protection and maintenance strategy to optimize community benefits and attain long-term community aims.

As previously discussed in Chapter 1, a variety of GIS and remote-sensing based models are now available that provide detailed benchmarks of an urban forest's composition, extent, distribution and health. These models provide precise results that allow for long term monitoring, setting of goals, increased awareness and prioritization, and provide the means for further correlations to be made about trees (Dwyer and Miller 1999; Nowak *et al.* 2002; Wolf 2007; Nowak *et al.* 2008; Wang *et al.* 2008; Kirnbauer *et al.* 2009). Although these benchmarking models are helpful in planning, they are limited in providing the intelligence needed to target locations that optimize tree value. In addition, the UFBM provides a standard framework and a set of methods for small- and medium-sized cities (although it could be applied to larger cities) to strategize new management regimes based on spatial urban forest planning, with the tools the cities already possess. Dense, large cities often have more opportunity to use expensive imagery and sophisticated canopy cover models (e.g., LIDAR) to help target planting areas, like that of Locke's *et al.* (2010) new technique used for New York City. Both the UFBM and Locke's *et al.* (2010) technique are new methods that integrate urban forest benefit research with GIS to allow trees to reach their optimized level of goods and services. Locke *et al.* (2010), however, use highly sophisticated and costly technology, unattainable to a majority of municipalities. The intent of the UFBM research was to focus on common technology, like ESRI's ArcMap, to enable small- and medium-sized communities in Canada to spatially plan for their urban forests in order to attain their sustainability aims. So while the design and data requirements of the UFBM are simpler than other tools available to planners and foresters, its strength over other approaches is its simplicity (and potential wider accessibility), its use of local knowledge and experience, and its ability to help determine planting locations that optimize tree value.

The UFBM is also unique by concentrating on the long term program goals of municipal agencies and NGOs, while most urban forest models are normally centered solely on urban forest goals. The process and framework that allow an urban forest to be connected with an array of sustainability goals are accomplished through focus groups and the link table (see section 3.1 for a more full description of these). These processes are a new contribution to the literature as they provide a better understanding of the simultaneous contributions an urban forest makes towards the goals of a city. The connections developed in the link table are both visible (using Microsoft Excel's conditional formatting) and statistical, allowing for easy interpretation by non-urban forest decision makers. It is rare for urban forest models and research to integrate both social and natural science methods (Kenney, pers. comm., 2010) as is accomplished in the UFBM through focus groups and the link table. As discussed earlier, the use of GIS to blend the results of the two focus groups and link table to form a customized decision support tool for a community, is also particularly unique.

The UFBM also provides a method that will allow urban forest research to be further applied in the 'real world' and allow for it to optimize the very services the trees were purported for providing. The UFBM makes urban forest benefit research more valuable by providing a process to maximize the benefits found in academic research. For example, the research that indicates a tree's ability to remove ground level ozone and nitrogen dioxide from the air (e.g. Beckett *et al.* 2000) may be inputted into the UFBM, and subsequently the model would project the ideal locations to allow for trees to maximize its air filtering services to the community.

The medium-scale (i.e., block scale or 100 x 100m) of modeling within the UFBM and its use of commonly available GIS software to determine planting sites, make it compatible with some existing smaller-scale models such as Kirnbauer *et al.* (2009). Kirnbauer *et al.* (2009) developed a micro-scale decision support tree planting system, at the individual lot level, to aid in determining planting sites around homes and buildings. Consequently the UFBM can be used in conjunction with other fine-scale models to facilitate a comprehensive identification of planting sites at both the fine (i.e., parcel) and medium (i.e., block or neighbourhood) scales. This research also compliments and extends the usefulness of the Priority Planting Index (PPI) method (Morani *et al.* 2010). The PPI, which determines the best location to plant trees based on the population density, tree stocking levels, and tree cover per capita, could be further developed with additional link table tasks to create a more comprehensive greening regime.

The UFBM is one of the first models of its kind that is applying more comprehensive types of social and physical science and newer technology in a manner that strategically increases tree cover. As GIScience (such as remote sensing and LiDAR technology) advances, this model, and others who use tree cover to achieve urban regenerative solutions, will be an important tool to continually apply and optimize the latest urban forest benefit research in Canada's communities.

3.1 Model Development

3.1.1 Focus Groups

Part of what gives the UFBM its strength and originality is the contribution from local experts and professionals to the research. Two focus groups were incorporated into the research's methods in order to properly achieve objectives one and two and develop a model that reflects the geographic characteristics and values of the community being studied. Local knowledge and understanding surrounding urban forest and community sustainability issues are integral to attaining meaningful results (Beckett 2000; Raciti *et al.* 2006).

The use of focus groups for this research was chosen over other qualitative methods after consideration of their desirable features and strengths. According to Morgan (1996), the use of focus groups is a research method concentrating specifically on data collection that evolves from group collaboration and discussion. Other procedures that use multiple participants (such as group interviews and Delphi groups) are primarily used to determine outcomes such as behaviour change or therapeutic effects and do not allow for interactive discussion (Kitzinger 1994; Morgan 1996). A setting that encouraged group interaction was important within the UFBM modeling process to allow new information to be quickly circulated around the group to inform others in their decisions. The intended outcome of the focus groups that informed the UFBM was also specifically geared toward data collection and data organization. For these reasons, focus groups were used over other methods, such as email surveys or questionnaires. Additionally, focus groups were used to ensure all participants had a supportive environment to interact within. A Delphi group was used as a final step to review and combine the results from the two focus groups, which involved email-mediated discussions with focus group participants. This method is discussed in more detail in this Section 3.1.2. The typical disadvantages associated with focus groups as discussed by Smithson (2000) and Morgan (1996) – such as individual domination, conflicts, and arguments – were minimized by ensuring the moderator was well prepared and had strategies to mitigate these common problems if they developed.

The first focus group provided input in regards to the types of urban forest benefits that are relevant and realized in Thunder Bay. It was an important first step which determined if and how the multitude of benefits documented in the literature apply in Thunder Bay. For example, McPherson and Muchnick (2005) studied the effect of tree shading on Californian streetscapes and found that it dramatically reduced pavement fatigue and cracking thereby increasing road lifespan. In Thunder Bay, roads have limited exposure to the damaging effects of UV light and heat of the sun in comparison to California. Californian road lifespan is strongly influenced by heat and UV rays caused by sun, whereas in Thunder Bay, water and frost heaving strongly influence the longevity of roads (Jones 1980; Adams, pers. comm., 2011).

The process to determine if and how the multitude of benefits found in the literature apply to a jurisdiction is a difficult task given the complexity of the issue, and arguably requires many types of experts. Without resource and budgetary limitations faced by municipalities and researchers, the ideal methods would not stop short of developing individual studies to determine if green infrastructure does in fact deliver the benefits purported in the literature to a particular study area (e.gs., a research trial would be set up to test the socioeconomic effects trees have on increasing property value in a city, or a test would be set up to test a tree's ability to filter ground-level ozone). Resource limitations do exist, and therefore focus groups are used to generate the wisdom needed on a local scale and are an innovative and alternative method to accomplishing the research objectives. As in any complex research environment, focus groups, interviews and other qualitative methods have a strong importance in providing certainty in research (Gibbs 1997; Morgan 1996). Although none of the participants had the comprehensive knowledge to answer the questions exhaustively by themselves (regarding urban forest benefits and their interactions with a community), as an entity, the group could provide a clearer direction and stronger sense of certainty.

The participants in the first focus group were recruited by telephone and were required to have either academic or professional experience in urban forestry as well as have been employed in Thunder Bay. Those who met these criteria and were willing to participate were provided with an introductory letter describing the research and their obligations. The researcher required their consent before participating (See Appendix I for cover letter). The first focus group was composed of eight participants and was held at the City of Thunder Bay Community Services Board Room on August 4, 2010 (Table 3.1). After an introduction to the meeting, participants were provided with a framework on paper in tabular form, which displayed an exhaustive list of benefits produced by trees. The framework was classified into various biophysical and social categories (see Appendix II for the framework). The participants were given the task to categorize the benefits into five

Table 3.1. Focus group participants and their affiliation.

Focus Group	**# of participants**	**Affiliation/group represented**	**Partnership in both focus groups**
FG#1 (Urban Forestry Group)	2	City of Thunder Bay, Parks Department[1]	No
	1	Lakehead University, Forestry[1]	No
	1	Landscape architecture consultant	No
	2	Forestry consultant	No
	1	Retired City of Thunder Bay, Environment Division employee[1]	Yes
	1	Private arborist[1]	No
Total	8		
Focus Group	# of participants	Affiliation/group represented	Partnership in both focus groups
FG#2 (Sustainability Group)	1	City of Thunder Bay, Planning Division[1]	No
	1	Lakehead University, Geography Department	No
	1	Retired City of Thunder Bay, Environment Division employee[1]	Yes
	1	Thunder Bay Health Unit	No
	2	City of Thunder Bay, Environment Division[1]	No
	1	City of Thunder Bay Corporate Services	Yes
	1	EcoSuperior (environmental NGO)	No
Total	8		

[1]the organizations that were included in the Delphi method (see Section 3.1.2)

classes (1, Can't be applied; 2, Possibly applied; 3, applied; 4, strongly applied; 5, fully applied in Thunder Bay). They used the summary table provided to them for more details pertaining to the benefit, the various costs associated with the benefit, the research cited, and other indirect services relating with the particular benefit. After each participant had completed the exercise, the results were tallied immediately within the meeting and presented to the group for overall feedback. Opportunity was provided to have a round-table discussion to talk about (1) the benefits, whose average scores possessed a large standard deviation, and (2) the participant's opinions that led to the large standard deviation. After the discussion, participants were provided with the opportunity to adjust their results if they found that their opinions had changed (due to added information or new research provided).

The results of the focus group suggested that all benefits could be "*likely"* or "*fully applied"* to Thunder Bay except one. The one exception (*Road Pavement Life – Tree shading extends the life of road pavement and decreases resurfacing costs*), was rated as "possibly applied" for Thunder Bay, because of the limited exposure of Thunder Bay's roads to UV light in comparison to California, as discussed earlier. The exercise did not indentify any benefits in the category "*Can't be Applied"*. The focus group was important to demonstrate that based on the experience of a group of qualified urban forest academics and practitioners, that the tree benefits discussed from the literature were all relevant in Thunder Bay to some extent. This list of benefits was subsequently used in the link table, discussed in Section 3.1.2.

A second focus group was used to identify and rank the sustainability goals of Thunder Bay that would ultimately be used in the link table discussed below. To identify the core goals and direction of the City that pertain to sustainability, a literature review of the City's major guiding documents was completed. Various documents were used, such as the City of Thunder Bay Official Plan (Thunder Bay 2005), the Earthwise Community Environmental Action Plan (2008), the Mayor's Strategic Plan (2007), and a subsection of the Ontario Professional Planners Institute, A Call to Action (2009). Although other plans exist within the community, these four were chosen primarily because of the broad range of people and comprehensive set of goals they represented, including their foci on subjects like education, the environment and public health.

The documents were reviewed by the author and the sustainability goals that had potential to be supported by an urban forest benefit were selected and listed in a framework presented in tabular form. In other words, if a particular goal could be partially or fully accomplished by the goods and services of an urban forest, it was included in the framework (e.g., a municipal goal to improve air quality). Each goal summarized in the framework was categorized into one of five categories based on the Roseland and Connelly's (2005) community capital approach. Each category represented a particular "asset" within the community. The five categories consisted of (1) natural capital, (2) physical capital, (3) economic capital, (4) human capital, and (5) social capital. Each sustainability goal also contained details pertaining to its goal category, goal description, documents cited, and other supplementary explanatory notes (see Appendix III) (see Section 5.1 for more details).

A focus group ranking exercise was then carried out to establish a level of priority with regards to the sustainability goals identified in the framework. The participants chosen for the focus group had experience in large-scale decision making within the community, in positions such as city managers, community decision makers (e.gs., health unit), the Mayor's assistant, and urban planners. A total of 18 potential eligible participants were approached to participate in the second focus group, of which eight participants chose to attend. See Table 3.1 for a description of the types of participants who attend the second focus group.

The process to determine a sustainability goal's importance is a challenging task for a number of reasons. First, the goals themselves can be considered equally important, as they have been selected and outlined in the City's guiding documents and have had significant review and support by groups like City Council and the Health Unit. Second, the ranking of the goals themselves can be subjective and prone to bias depending on the decision makers and their own preconceptions. For example, a participant could be particularly interested or experienced in stormwater and therefore could be more inclined to give priority to stormwater-related sustainability goals. These two challenges were recognized at the onset of planning for the focus group meetings and were addressed in a two ways. To address the first challenge – all goals being equally important – participants were encouraged to use their experience and broad understanding of community needs to choose the most pressing issues facing the city. It was reiterated to them that their decision to rank these goals would only inform the UFBM and had no bearing or impact on actual real-world actions or plans. The second objective concerning the bias was addressed by selecting a diverse array of participants who were experienced in broad-based, overview decisions, like planners, council members, and division managers. Selection of these types of participants, provided for a healthy and diverse perspective and priority of community values and goals.

The second focus group was held at the City of Thunder Bay Community Services Board Room on August 11, 2010. After an introduction to the research and exercise, participants were provided with a chart on paper, which displayed the framework of sustainability goals (described above). The participants were asked to rank the goals in terms of priority from one to five, five being the highest in priority. See Appendix III for the framework and additional key information provided. Upon completion of the individual exercise, which took about 60 minutes, the group's answers were tallied into an Excel spreadsheet. Within the meeting, the results were then presented to the group (via digital projection), which contained the average scores and standard deviations. Five sustainability goals were focused on for the post-discussion because they had large standard deviations, an indication that the group had varying opinions about the goal. Discussion was prompted to review these goals and the potential causes of the large standard deviation. In most cases, information was brought to the group's attention that prompted some participants to revise their rating of a goal. For example, a specific goal focused on improving the appearance of the Water Street Terminal (Thunder Bay 2007) was reviewed. At the onset of the focus group only a few decision makers had known that a capital project had just recently been performed to update the appearance of the terminal. As a result of the group discussion, some participants who had marked this goal high priority changed it to a low priority because of the updated information that affirmed the project had been completed.

The exercise provided a ranking of all sustainability goals as seen in Appendix IV. Some of the most important goals focused around food production, open space development, intensification, active transportation, crime and energy. The top thirty goals were then used in the link table, discussed in next section.

3.1.2 Linkages Between Urban Forest Benefits and Sustainability Goals

There are multiple connections between the benefits of an urban forest and sustainability goals of a community. Some municipalities have recognized this and have begun using green infrastructure to help attain several program goals to reduce issues like the urban heat island effect and stormwater damage. Although using trees to mitigate a few urban challenges can be very effective, there are also various other social and biophysical services that could be used to help achieve a community's sustainability goals. Presently, there has been little work done that thoroughly reviews all the benefits and the sustainability goals of a community and provides a method for understanding the connection between them. The link table was developed in this project to do exactly that –to demonstrate the value and connection between urban forest benefits and a community's sustainability goals. In doing so, the link table helps to demonstrate which benefit-goal connections (also called management tasks) are the most valuable to implement into the GIS component of the UFBM.

The link table was composed of three main elements. The first main element was the results of the calibrated benefits developed by the first focus group, and were listed along the horizontal axis (Figure 3.1). These included benefits such as increased tourism, decreased noise, and cleaner air. The second main element was the top thirty-ranked sustainability goals determined from the second focus group, and were listed on the vertical axis. These included goals such as reducing crime, protecting water habitats, and decreasing the total energy used by the municipality. Thirty of a total of sixty goals were used in the link table, which through subsequent steps explained in the third main element below, would be reduced to six link table goals (that contained the strongest scores). In between these two axes was the third main element, the black, gray, and white cells that contained a score denoting the strength of connection between that particular benefit and sustainability goal. The strength of the connection was determined by the author through an analysis of the literature, followed by a validation process by members of both focus groups. Conditional formatting was used in Microsoft Excel to help demonstrate the connections visually (Table 3.2 displays the colour and definition). Only cells that demonstrated a connection (i.e. with a score of 3 to 5) were considered important for the link table process and all other cells that did not have a connection (i.e. with a score of 2 or 1) were blacked out. As a result, the cells that remain visible on the link table were those that demonstrated some level of connection between benefit and goal. A connection score, which demonstrates the strength of connection between benefit and goal, is determined from the body of literature that pertains to

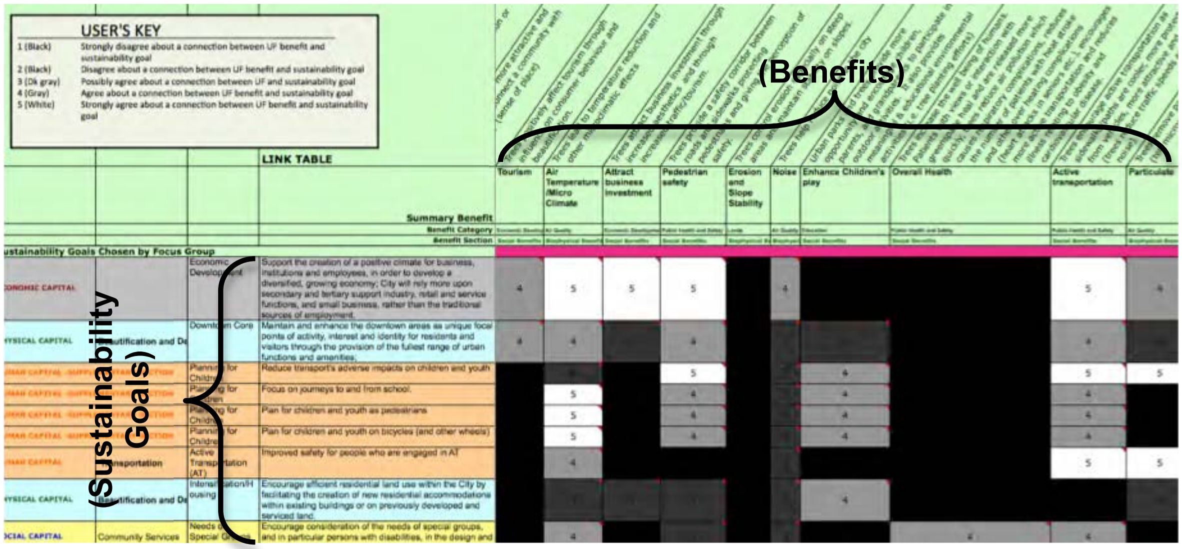

Figure 3.1. A screenshot of the link table displaying the urban forest benefits (see column heading) and the sustainability goals (see row heading). The black, gray, and white cells display a score that demonstrate how well a particular benefit connects to a goal. Conditional formatting was used in Microsoft Excel® to colour-code the cells.

arboriculture and urban forestry, but also stems from public health, planning, and engineering peer-reviewed literature. The connection score is determined by a combination of two things. First, if one or more sources of peer-review literature inferred a possible connection, then the linkage would receive a score of at least three. Second, the researcher, with focus group participants as validation, would determine the connection score based on the overall strength presented in the literature. If there were two or more publications that supported a connection, the connection score would be a four or higher. If there were multiple sources from the literature inferring a strong connection, then the score would be a five. The justification of each connection was provided in each cell's comment using Microsoft

Excel® and a validation process performed by previous focus group members provided further confirmation.

Table 3.2 The connection score, colour and definition used for each cell (connection) in the link table.

Connection Score	Colour	Definition
1	Black	The literature clearly does not support a connection between UF benefit and sustainability goal
2	Black	The literature does not support a connection between UF benefit and sustainability goal
3	Dark Gray	The literature possibly supports a connection between UF and sustainability goal
4	Light Gray	The literature supports a connection between UF benefit and sustainability goal
5	White	The literature strongly supports a connection between UF benefit and sustainability goal

The entire link table spreadsheet, with justification notes, was developed throughout the fall of 2010 and contained approximately 60 benefits and 30 sustainability goals. It was provided to the focus group participants for review (see Figure 3.2 for an example of a justification comment). This review process took the form of a Delphi method, which involved email-mediated discussions for two rounds with previous focus group's participants (see Table 3.1). During the first round, the participants were given the link table spreadsheets and were asked to review the table and selected tasks as well as provide their input and consent to the use of scores listed in the link table. Their decisions and comments were summarized by the author and redistributed to the group (all comments were kept anonymous) in the second round so that participants could review the choices and make final alterations. Outcomes of these rounds are discussed below.

The Delphi technique is a systematic collection of informed judgments from a group of experts (Reid 1988). It allows experts in the field to answer a questionnaire in an anonymous format in two rounds or more and was the method of choice for two reasons. First, it allowed all participants to be included in the decision-making process without having to reschedule a focus group meeting and risk the potential absence of some participants. Second it allowed for a quick and succinct means to receive input that did not require group collaboration. The participants selected for the review method were chosen from the two earlier focus groups. Those selected were required to have a good understanding of urban greening, community development, as well as Thunder Bay's goals. A total of eight participants were involved in the process and were associated with the City of Thunder Bay Parks Department, City of Thunder Bay Planning Division, Earthwise, and Lakehead University, among others (see Table 3.1).

Prior to the link table being sent out electronically to the participants, it was summarized using basic Microsoft Excel arithmetic to produce an average score of each goal, the frequency of benefits contributing to that score, and a final standardize score (see Appendix V) to view the entire link table. The final standardize score was calculated using the weighted linear combination method, a multi-attribute procedure based on the concept of a weighted average (Chang 2010). It is a common way of computing an index value and involves evaluation at three levels: criterion weights, data standardization, and data aggregation. First, the relative importance for each criterion was evaluated against the other. Three

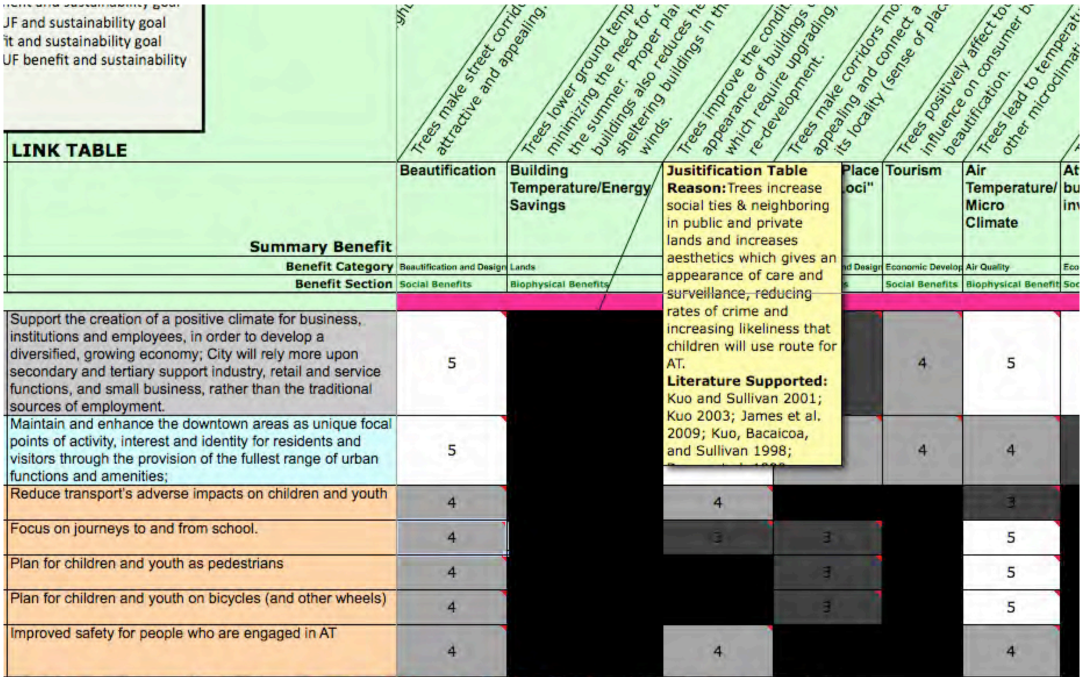

Figure 3.2. A screenshot of the link table displaying the comments section that provides justification for the score received and the supporting literature for each linkage.

criterion were used for this process: average score, frequency of benefits contributing to a goal, and the sustainability ranking based on the score resulting from focus group two (See Table 3.3 for a description of each criterion). The average score and frequency criterion were given a weight of one. The sustainability ranking was given a weight of 0.10 because it did not influence the strength of the connection, but was an indication of priority based on the second focus group. For instance a high priority goal would score slightly higher than a low priority goal if all other variables remained constant.

Table 3.3. The criterion used in the weighted linear combination method and their associated weights.

Criterion	Description	Weight	Reason for Weight
Average Score	The mean average of all the benefit-goal scores corresponding to a particular sustainability goal.	1	The average score helped determine the strength of the benefit-goal connection.
Frequency	The number of times a benefit connected with a particular sustainability goal	1	The frequency or number of benefit-goal connections helped determine the strength of final score
Sustainability Ranking	This ranking resulted from focus group two (FG2): prioritizing sustainability goals	0.10	Although FG2 determined the top 30 goals for the link table, it was important to allow the results from FG2 to help determine the final selection of tasks used for the UFBM. It was given a small weight of 0.10

Second, the data for each of the variables were standardized using a linear transformation into a scale of 0.0 to 1.0. The following formula was used for standardizing:

Equation 3.1

$$S_i = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}}$$

where S_i is the standardized value for the original value X_i, X_{min} is the lowest original value, and X_{max} is the highest original value. Third, the index value was calculated by summing the weighted criterion values and dividing the sum by the total of the weights (Chang 2010):

Equation 3.2

$$I = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i}$$

where *I* is the index value, n is the number of variables, w_i is the weight for criterion *i,* and x_i is the standardized value for criterion *i*. The results can be viewed in Appendix V – The link table. The final standardized score were ranked for each goal and the highest goals for each category were identified. These goals, also referred to as management tasks, will be further discussed in Section 3.2.1.

Upon completion of the link table, its calculations and summaries were emailed to the focus group participants as an Excel spreadsheet for their review and feedback. They were encouraged to provide adjustments to the link table if they deemed necessary and were also asked to provide comment on the final selection of management tasks that had scored the highest. See Appendix VI for the list of ranked goals per category. The participants provided comments but did not change any of the link table connections, and all participants agreed with the recommendations. Six management tasks were chosen through the link table process for use in the GIS component of the UFBM (Figure 3.4).

	Goal Category			Goal Description	Score
Recommended for UFBM	ECONOMIC CAPITAL		Economic Development	Support the creation of a positive climate for business, institutions and employees, in order to develop a diversified, growing economy; City will rely more upon secondary and tertiary support industry, retail and service functions, and small business, rather than the traditional sources of employment.	0.85
Recommended for UFBM	PHYSICAL CAPITAL	Beautification and Design	Downtown Core	Maintain and enhance the downtown areas as unique focal points of activity, interest and identity for residents and visitors through the provision of the fullest range of urban functions and amenities;	0.67
Recommended for UFBM	HUMAN CAPITAL -SUP. SECTION	Community Sustainability/Transportation	Planning for Children	Reduce transport's adverse impacts on children and youth	0.63
Recommended for UFBM	HUMAN CAPITAL -SUP. SECTION	Community Sustainability/Transportation	Planning for Children	Focus on journeys to and from school.	0.52
Recommended for UFBM	HUMAN CAPITAL -SUP. SECTION	Community Sustainability/Transportation	Planning for Children	Plan for children and youth on bicycles (and other wheels)	0.51
	HUMAN CAPITAL	Transportation	Active Transportation (AT)	Improved safety for people who are engaged in AT	0.52
Recommended for UFBM	NATURAL CAPITAL	Lands and Water	Water Quality	Policies will be developed to support the City's Pollution Prevention Control Plan and to protect the quality of water in the streams and rivers passing through the City and in Lake Superior.	0.57
Recommended for UFBM	SOCIAL CAPITAL	Community Services	Needs of Special Groups	Encourage consideration of the needs of special groups, and in particular persons with disabilities, in the design and construction of buildings and other facilities.	0.45
Non Selected - See description	CULTURAL CAPITAL		Heritage Resources	1) conserve the historic, archaeological, architectural and cultural heritage resources of	0.22
	CULTURAL CAPITAL			2) preserve and enhance structures, buildings or sites deemed to have significant historic, archaeological, architectural or cultural significance and, where practical, preserve significant public views and cultural heritage landscapes	0.22

Two overarching themes scored well in this category: Planning for Children and Active Transportation. Both themes are strongly interconnected and it is a recommended managment task to focus on Active Transportation for Children, focussing on journeys to and from school.

It is recommended that neither of the Cultural Management Tasks be chosen due to their low priority ranking, low averages, and low final score.

Figure 3.4. The top ranking goals (management tasks) identified in each goal category. Due to their similar theme, four Human Capital goals were selected and merged into one goal that focused on children's journeys to and from school. There was no cultural management task chosen for the model because of poor scores.

Through the link table process the focus group participants identified the following management tasks:

- creating positive climate for business
- downtown core beautification
- planning for children – focusing on journey's to and from school
- protect the quality of water entering streams and rivers
- encourage consideration of the needs of special groups

Using the knowledge from the literature and that of focus group participants, these six management tasks were isolated for Thunder Bay.

3.1.3 Standard Tasks

As discussed above, the link table is the process where the most pressing and valuable management tasks are determined (over the numerous others) that are then to be modeled using GIS. The link table provides a balanced selection of management tasks to fulfill the components of a typical sustainable system (e.gs., economic, social, environmental). Another method used in conjunction with the link table to select management tasks to be modeled with the UFBM is the standard task process. The use of both the link table and standard tasks processes to determine the management tasks for the GIS is referred to as the task generator (Figure 3.5).

A standard task is defined in this research as one or a set of commonly applied management activities performed by managers of an urban forest. In this study, standard tasks were chosen based on both the professional knowledge of the author, as well as considerations for what other municipalities have elected to do when making choices about strategic greening. The selection of standard tasks was established by the user and was derived in part by reviewing popular and successful criteria used by other municipalities to mitigate an urban challenge through strategic greening.

In reality, there are very few municipalities who manage their urban forests with the intentions of increasing benefits or mitigating a social or environmental problem (e.g., targeted planting to reduce air pollution), although this practice is now gaining more recognition. A standard task was also chosen based on urgency or operational need within the community. That is, if a goal had been identified through a municipal or council directive, it would be included as a standard task.

Such tasks could include current planting and maintenance strategies. An example is the planning for the emerald ash borer invasion (EAB) in Thunder Bay. Although it did not show up in the link table because of its non-sustainability focus, planning for the EAB invasion is a current management objective of the City's Park's Division (Vescio, pers. comm., 2010).

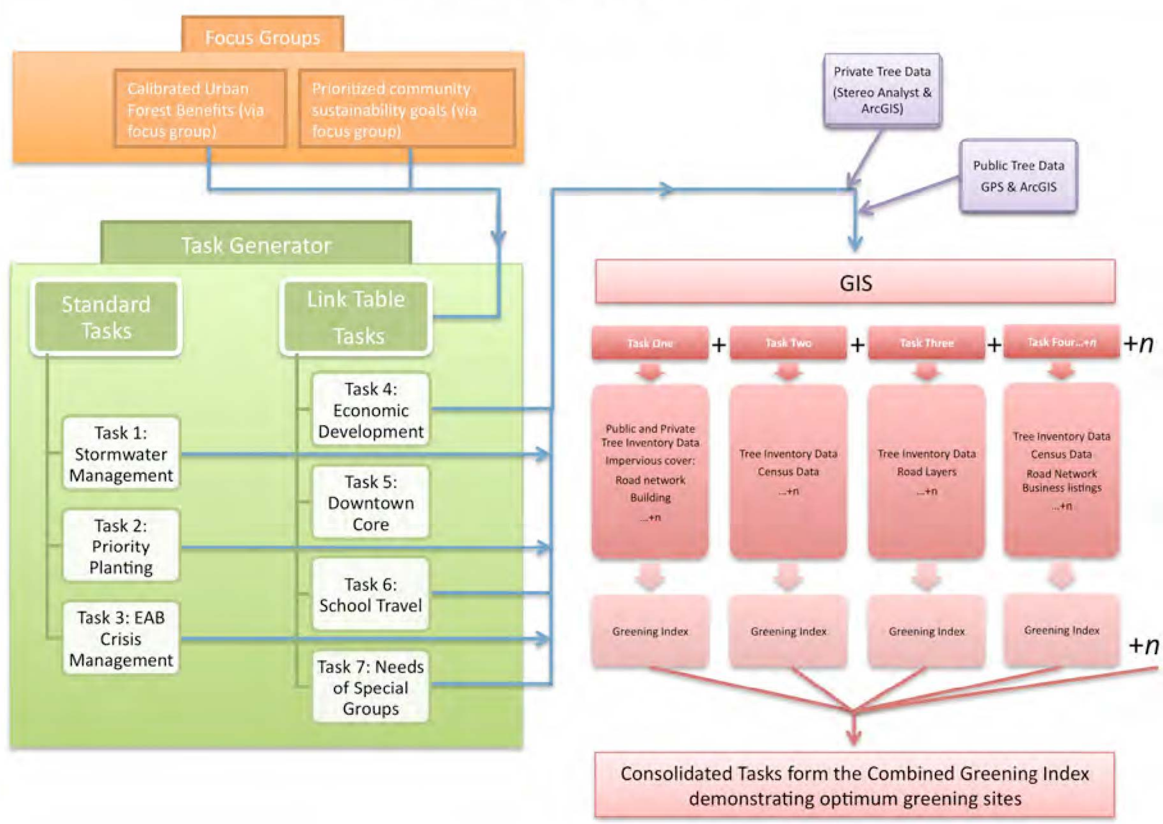

Figure 3.5. The conceptual model of the UFBM. The task generator includes both the standard tasks and those developed through the link table and focus group processes (as discussed in the text). A GIS model was developed for the seven listed tasks resulting in the identification of "hot spots" or priority locations for greening.

Three standard tasks were included in the UFBM: 1) stormwater management; 2) the Priority Planting Index (adapted from Nowak *et al.* 2002); and, 3) emerald ash borer (EAB) crisis management (see Figure 3.5). Stormwater management was chosen for two reasons. First, traditional stormwater infrastructure installation and maintenance is a costly endeavor for municipalities, and green infrastructure planted in the proper areas can provide significant mitigating effects and savings (Dywer *et al.* 1992). Larger urban centres like New York City and Philadelphia have recently been implementing green infrastructure to mitigate stormwater management damages and costs (Center for Watershed Protection 2009). Secondly, stormwater and water quality are of great importance in the Thunder Bay region, being that the city is at the headwaters of the Great Lakes, and recent studies have shown various problems in regards to water quality in the city (Stormwater Impacts Assessment 2011). This task is further discussed in Chapter 4: Standard Tasks.

The Priority Planting Index was developed by Nowak *et al.* (2002) and is now used by some municipalities to determine the most ideal planting sites. It uses three variables to determine a priority for planting: population density, tree stocking levels, and tree cover per capita. Areas with greater population density, low tree stocking, and lower tree canopy cover per capita were targeted as higher priority. This task is further discussed in Chapter 4: Standard Tasks.

The third included standard task – the emerald ash borer (EAB) management task – is in response to the EAB's anticipated arrival in Thunder Bay, according to professionals (Vescio, pers. comm., 2010). The EAB is projected to kill all ash trees in Thunder Bay, unless preventative measures, such as inoculation with TreeAzin ™ (BioForest Technologies Inc.), are performed. This inoculation process is costly and it is undetermined at present whether the City of Thunder Bay will embrace this method of pest management (Vescio, pers. comm., 2010). In the event the City uses the inoculation method it will only be administered to a proportion of trees due to costs. This task is designed to focus on areas of high ash concentration as a planning measure to perform infill planting in preparation for EAB. This task will be discussed further in Chapter 4: Standard Tasks.

3.1.4 Private Tree Inventory

To effectively guide decisions in urban forest planning one must first have a comprehensive understanding of the resources which need managing. In urban forest planning, one of the most fundamental and important elements is the tree inventory (Miller 1997). Tree inventories come in various forms depending on the desired needs and financial and time constraints. It is common for many municipalities to keep a relatively current inventory of the public trees they manage, and will generally have records of tree size, age, species-type, condition and location. Most inventories now contain spatial data derived from either GPS or GIS software that aid in various management operations and studies. Having a comprehensive inventory aids decision makers in allocating the proper resources for maintenance and removal (Miller 1997), studying changes to urban forest structure over time, and integrating the results into other models to increase the power and efficiency of these tools.

An updated inventory of publically-owned trees was acquired from the City of Thunder Bay for the UFBM. This inventory was current to 2010. Although many attributes were recorded in the inventory such as tree height, ages, species-type, stem diameter, and condition, only a few attributes were needed for the UFBM analyses (discussed in Chapter 5). However, while publicly-owned trees have long been a significant focus for urban forest planners, they comprise of only a portion of a city's entire urban forest (Clark *et al.* 1997). As Clark *et al.* (1997) suggests, between 60 and 90 percent of trees within a city are found on private property and thus are not part of a City's forestry department's inventory. Lacking data on privately-owned trees poses a significant challenge to urban forest planning within a community and also poses limitations to various management tasks identified within the UFBM. The UFBM was designed to include an exhaustive inventory of trees in a city, whether private and public, to make the best informed recommendations for a city as a whole. Although the model could be run with public-data only, it would produce inaccurate results. Therefore, a private tree inventory was carried out for the City of Thunder Bay to make the UFBM as realistic a model as possible.

Inventory Methods

The objective of the private tree inventory was to collect private tree data in order to create a comprehensive inventory of urban trees across the city. These private trees include those in the front, back and side yards of individual properties as well as forest stands (a collection of trees located in a relatively unmaintained environment). This type of coverage enables a higher number of tasks within the UFBM to be analyzed and thus increases the accuracy and effectiveness of the model. The following section describes the methodology through which the inventory objective was achieved.

The private tree inventory was carried out via remote sensing using a combination of both ERDAS' Stereo Analyst and ESRI's ArcGIS. Stereo Analyst is an extension for ArcGIS that allows stereo visualization within the ArcGIS display environment and thus improves the interpretation of the image.

Aerial interpretation of forest characteristics differs when one is looking at urban forests versus natural and commercial forests in rural areas. In commercial forestry, trees typically portray predictable and similar physical characteristics within their species-type. However trees in urban areas (when inventoried aerially) can take on various forms and characteristics even within one species-type, due to inconsistencies in growing space, soil type, care and maintenance (Xiao 2004). These inconsistencies make it difficult for analysts to accurately classify them. High-resolution imagery, therefore, is desirable for remotely obtained, urban tree inventories.

Two sets of high-resolution aerial imagery were acquired for the study area. The Ministry of Natural Resources provided 40 cm resolution near-infrared ADS40 imagery (leaf-off) and the City of Thunder Bay provided visible spectrum SID 20cm QUAD (leaf-on). Both sets of imagery were flown in 2008 and provided a strong aerial image bank needed for the inventory. A remote sensing analyst was hired for 16 weeks to collect the following attributes using Stereo Analyst: location; height; visible canopy width; species; and tree type (conifer or deciduous). After four weeks of data collection, the attributes being inventoried were scaled back to: location; visible canopy width class; and tree type (conifer or deciduous) due to projected time and financial constraints of doing a full set of attributes as noted above, and because there were more privately-owned trees than anticipated. The tree inventory began at Lakehead University, which allowed the analyst to critique and refine her proficiency by field verification of her estimates outside the lab on campus. Once the analyst became proficient with interpretation, she proceeded to inventory from Oliver Road to Thunder Bay South in 1km square units, and then to the rest of Thunder Bay using both sets of imagery noted above. Both sets of imagery had their advantages, and therefore frequent crosschecking was performed to ensure accuracy. For example, the leaf-off (40cm) imagery was best to identify conifers and some hardwoods (branching pattern), however it also contained larger tree shadows, making tree identification more difficult because of the time of season when the image was collected. The leaf-on imagery (20cm), taken in the fall, displayed the changing colour of hardwoods and tamarack and improved overall reliability of tree identification.

The scanning method, as discussed by Nowak *et al.* (1996), was used to measure the position of each tree along with the tree canopy width class and tree-type. The scanning method is the one of the most precise and detailed methods of analyzing urban tree cover because it measures tree cover throughout the entire study area without using sampling procedures (Nowak *et al.* 1996). As with all types of inventory methods, however, the accuracy is dependant upon the ability of the photo analyst to accurately identify tree cover (over other cover, i.e., grass or driveways) and categorize it into the proper tree canopy width class.

During the digitizing of the private tree inventory, the public tree dataset was displayed on the screen as a means to distinguish the public from private trees. A point was added to a shapefile representing the location of a given tree. The complete tree inventory, including both publically and privately owned trees, is displayed in Figure 3.6.

Using the measurement tool in ArcGIS, the tree canopy width was measured and categorized into one of five classes (Figure 3.7 and Table 3.4). The tree type (conifer/deciduous) was identified by visual inspection. Although there are various inventory methods discussed by Nowak *et al.* (1996) that are more time and cost efficient, this scanning method provides the most precise and detailed results for the cost. More recent advances in Geographic Information Science have produced tools like Geographic Object-Based Image Analysis (GEOBIA), which can help to produce very precise inventories, but are still very costly to perform and require data such as LIDAR (Light Detection And Ranging) imagery.

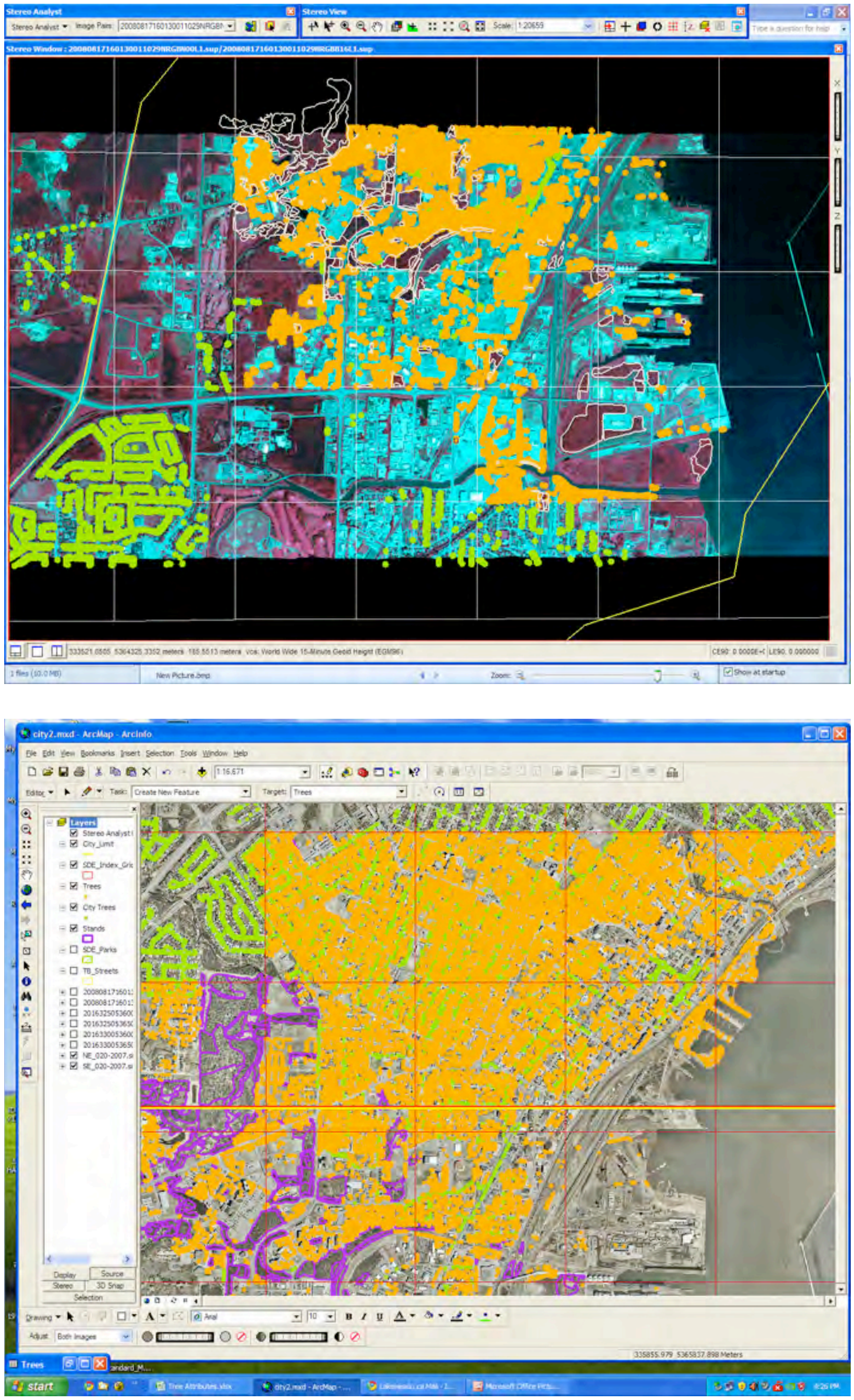

Figure 3.6. A screenshot of both ADS40 (top) and SID20 QUAD (bottom) imagery with the public tree data (green) and private tree data (orange) displayed on the screen. The forest stands (purple) are also delineated on the right hand screen. Software Stereo Analyst (ERDAS) is being used on the left hand screen and ArcMap (ESRI) on the right.

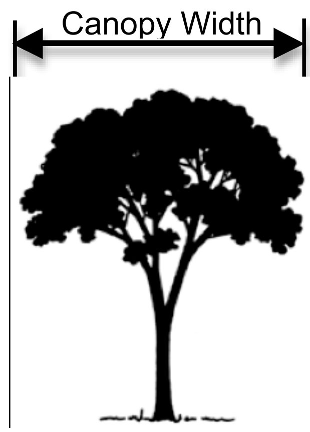

Figure 3.7. Determining the canopy width measurement.

Table 3.4 The visible canopy width measurements inventoried by remote sensing were grouped into five canopy classes.

Class	Crown Width (cm)
1	1-400
2	401-800
3	801-1200
4	1201-1600
5	1601+

In addition, the forest stands within the City were also mapped. Forest stands were defined as a group of trees uniquely distinguishable from adjoining areas. Trees were classified as a forest stand by the remote sensing analyst if they were located in a natural, relatively unmaintained environment. Forest stands within the city boundary included forested areas at George Burke Park and smaller areas as seen in Figure 3.8. Only the extent (border) of each stand was measured, and did not include any other attributes such as species composition, height, or crown closure. In contrast to stands, trees that were geographically close to each other in areas managed by humans (i.e. the grass around its base is maintained) were considered an urban tree and each tree was digitized as an individual tree. Due to financial constraints the inventory covered only about 65 percent of the city study area (Figure 3.9). With a limited private inventory, the extent of some management tasks as a result were restricted to this boundary (e.g., the stormwater task).

Figure 3.8. A screen capture displaying the delineation of a forest stand (light green) and individual trees (dark green).

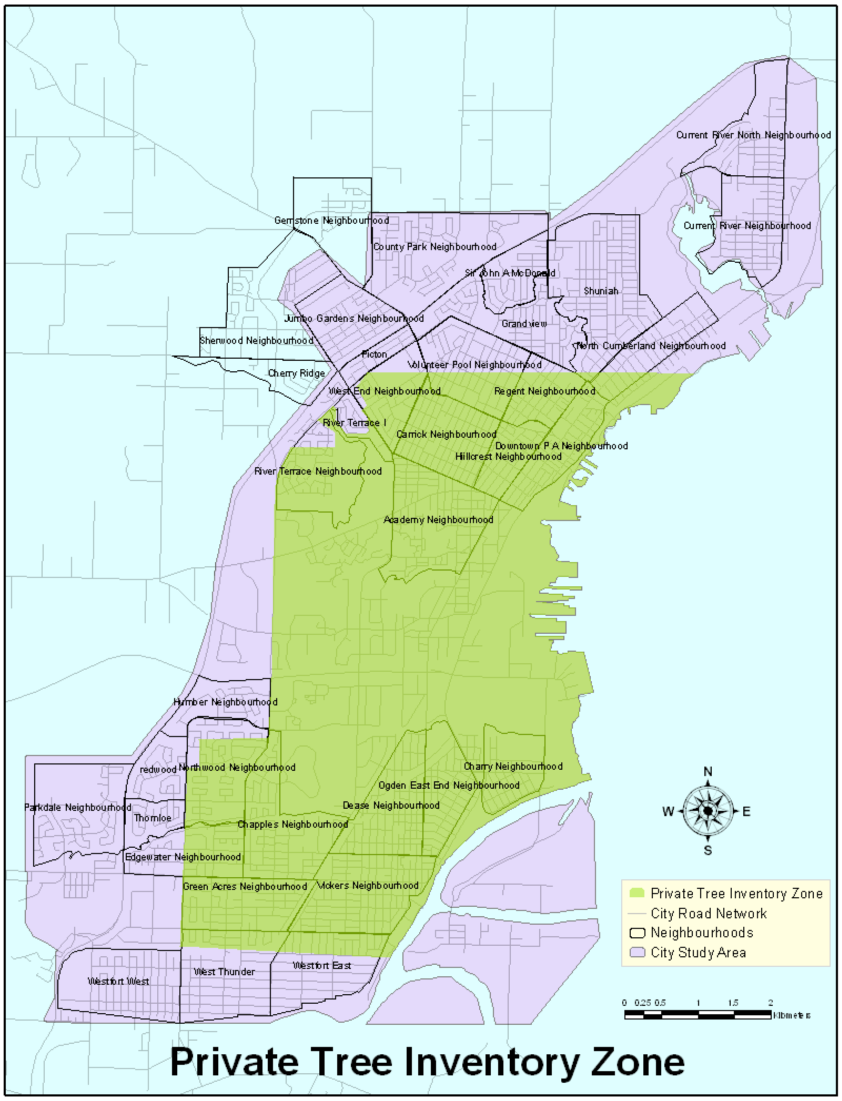

Figure 3.9. A map displaying the extent of the private tree inventory that falls within the city study area of Thunder Bay, Ontario.

3.2 Model Structure

3.2.1 Overview of GIS-Based Decision Support

A GIS model was developed for each of the seven standard and link table tasks that resulted in the identification of "hot spots" or priority locations for greening. Each task was modeled individually using ESRI's ArcGIS producing an independent set of recommended planting locations. These seven maps were then combined to form a final comprehensive map demonstrating optimum locations for greening (planting, maintenance, and protection). The analysis required for each task was determined by the type of task and the available data. Since both the standard and link table tasks incorporated a broad array of social, economic and environmental issues (e.gs., planning for children's journeys to and from school or for special needs groups), a host of associated data such as census data, business locations, impervious cover, etcetera were potentially required. For example, the objective for the stormwater standard task (see Chapter 4) was to identify areas for increased canopy cover that would mitigate stormwater problems (e.gs., flooding, surface pollutant runoff). An analysis of this kind requires a variety of data such as public and private tree cover, impervious cover, and aerial imagery. From these inputs, analysis is performed to determine problematic stormwater areas, and ultimately to demonstrate areas for which would benefit with additional tree cover. A general methodology for each task is found in Table 3.5. Most tasks required relatively small amounts of data inputs or analysis, the notable exception being the stormwater task. An additional description and methodology accompanies each task in their given sections below.

Within the GIS component of the model a vector grid was created at a block scale (a resolution of 100, 100m x 100m grid cell, or 1 hectare) using Hawth's Tools extension. This vector grid was used to define a standard management size and location that would be applied to each selected management task. The extent is

Table 3.5. A general GIS methodology used to determine hot spots for each task.

Step	Description
1. Identify the task	Identified by the task generator (Figure 3.5)
2. Explore the variables that could be used to determine and fulfill the task.	Explore the possible variables and types of data inputs required for the task (e.gs., population density, business locations).
3. Select the variables and prepare the data.	From the list of all possible variables that influence the task, select the variables based on the available data.
4. Choose methods and tools	Choose the methods and tools to perform the necessary measures to identify greening locations based on the selected variables.
5. Display the data on the map or perform analysis (if required)	Using GIS, the data for each criterion are represented on the map (e.gs., business and school locations). Depending on the type of data and the criterion, analysis may also be needed using ArcGIS tools.
6. This step is reserved for the final compilation of all tasks together to identify smart greening locations.	Using the weighted linear combination method to assign weights to each task (according to Focus Group Two) to identify areas where green infrastructure will simultaneously attain multiple benefits within a community.

meant to be at a coarse or neighbourhood scale, which ultimately determines the size of management area in the final hot spot map. For the case study application of this research to the City of Thunder Bay, a grid of one hectare was created to ensure the management areas were large enough to present a broad overview of the City while providing tangible, easily identifiable management blocks for planning. Too small of a management area could create an overwhelming amount of detail on a planning level and could limit for example, foresters and technicians on the ground in their ability to find adequate planting spots. A resolution of 10m (10m x 10m grid cell) would result in numerous management areas, small enough to conceivably be consumed with house rooftops and driveways, which clearly would allow little potential to plant. However, it should be noted that with the presence of a plantable-spots inventory, or a Geographic Object-Based Image Analysis (GEOBIA) a smaller cell size could be used. Advances in Geographic Information Science have rendered tools like GEOBIA, automated methods to classify remote sensing imagery into very detailed and meaningful data. In conjunction with technologies like LIDAR, cities can interpret and classify geographically based image-objects with high precision. This kind of technology was used for Locke's *et. al* (2010) study for New York City and allowed for a better intelligence and interpretation of ground objects like trees and plantable areas. This technology is costly, and therefore a city's existing plantable spot inventory could provide similar intelligence at less expense by indicating the exact spatial location where trees could be planted. In turn it also eliminates the areas where trees cannot be planted and allows for a greater level of precision in targeting true potential sites. Although a small cell size would not always be desirable (see above for justification) a plantable-spots inventory could increase the precision by reducing the size of the management areas in the model.

Without the use of a plantable spots survey or GEOBIA, a block scale (around one hectare) provides a good balance between management planning and finding realistic greening sites on the ground. A balance between these two grid sizes can be adjusted depending on the scenario and level of detail desired, however a coarse-scale between 0.5 and 1.0 hectare is suggested.

3.2.2 Application of the UFBM to Thunder Bay

By way of the task generator, seven tasks were chosen for use in the UFBM to identify optimized greening areas for the City of Thunder Bay, consisting of both standard and link table tasks (see Figure 3.5 and Table 3.6). As discussed

Table 3.6. The tasks identified for use in the UFBM for Thunder Bay consisting of both standard and link table tasks.

Management Task	Type
Stormwater	Standard / Link Table
Priority Planting (Population/UTC)	Standard
Emerald Ash Borer Crisis Planning	Standard
Economic Development	Link Table
Downtown Core Economic Development	Link Table
Children’s Journeys to and from School	Link Table
Needs of Special Groups	Link Table

previously, the link table process identified management tasks that are relevant to Thunder Bay, focused on a comprehensive set of community sustainability goals already established or in progress. The standard tasks cater to the needs of the community but are chosen based on urgency, operational needs, or the task’s success in other municipalities. For instance, the emerald ash borer (EAB) is a great threat to Thunder Bay and requires immediate planning. This standard task was selected because of the urgency of the situation and the value it will provide to the community. A task like EAB crisis planning would not have been identified through the link table process. In another example, the recent successful implementation of trees to reduce stormwater damage by some cities has lead to its use in the UFBM. As demonstrated here, and in the appropriate link table and standard tasks sections above, the application of UFBM tasks are tailored to Thunder Bay to provide the most meaningful and applicable services without compromising or competing against existing management strategies.

3.2.3 Application of the UFBM to Other Jurisdictions

The UFBM was conceptualized to be adaptable to other jurisdictions. However, in its current customized format for Thunder Bay, it is not readily transportable. The application of the UFBM in another city would require an individual with considerable knowledgeable of urban forest benefit literature to carry out the focus groups and develop the link table (as discussed in Section 3.1 Model Development). Through these processes the individual, in close correspondence with the city forester, would be able to develop a set of standard tasks and link table tasks customized to the needs in the particular community. A methodological framework within GIS would then have to be developed for each of these newly defined management tasks. Then the GIS technician would acquire the required data and process the selected tasks that are part of a newly-formulated UFBM for a given jurisdiction. An overview process is provided in Table 3.7.

In order for the UFBM to be used in another jurisdiction, there are data sets that will be needed by the host city. The municipality must have access to a spatial tree inventory preferably for both public and privately owned trees. It also would be advantageous to have access to a wide-variety of GIS layers like neighbourhood zones, road classes, and impervious cover, among others, that will help during the various parts of the analysis. Many municipalities now contain a good portion of their city assets and infrastructure data as GIS spatial layers.

Table 3.7. An overview of the methods required of an individual researcher in order to apply the UFBM to another jurisdiction.

Step	Description
1. Researcher reviews and updates urban forest benefits framework	Researcher would add any new or site specific relevant literature to that within the UFBM.
2. Focus group one	To identify the urban forest benefits from the research that are not realized in the study jurisdiction. The identified benefits are removed from the framework.
3. Researcher to review guiding documents in order to provide a list of sustainability goals that could be enhanced by the urban forest	This would be completed via a literature review of the jurisdiction's current guiding documents.
4. Focus group two	Community leaders prioritize sustainability goals for the community.
5. Link Table developed	The benefits and goals combined into one table and the researcher assess the literature to define the strength of connection between benefit and goal. The Link Table is further reviewed by focus group members.
6. Standard tasks determined	The leader and decision makers involved in the process identify the standard tasks.
7. Methodology developed for other tasks	Researcher to develop a methodology for each individual management tasks, especially those not covered in Brad Doff's UFBM.
8. Tasks determined from Link Table and sent to GIS	GIS technician to explore and prepare the required data for each task, perform analysis and produce a map of targeted greening sites.

This chapter presented a set of methods and a framework that can be adapted for any given city. The task generation processes used in the UFBM is a unique contribution to the literature and allows the services provided by an urban forest to deliberately work toward attaining the goals of a community. The process of carrying out these methods fosters a closer working relationship between city agencies, community groups and other NGO's as they explore together how planting, protection and care of trees in targeted areas can optimize their benefits. Although the UFBM is relatively simple in comparison to tools and models available to planners, the UFBM makes new contributions to the field by linking the urban forest with sustainability. In the following chapters the various link table tasks and standard tasks will be discussed in further detail.

4.0 Standard Tasks of the UFBM

4.1 Introduction

A standard task is defined in this research as a commonly applied management activity performed by managers of an urban forest. These management activities often refer to the municipal greening strategies used to mitigate a particular urban challenge. In reality, there are very few municipalities who manage their urban forests with the intentions of increasing benefits or mitigating a social or environmental problem (e.g., targeted planting to increase active transportation or to decrease crime rates). However, this practice is now growing in popularity. More common at present, however, is the application of standard tasks aligned with one of the standard goals of urban forest management, such as planning for a particular urban forest disease epidemic.

In this study, standard tasks were chosen based on both the professional knowledge of the author, as well as considerations for what other municipalities have elected to do when making choices about strategic greening. A standard task was also chosen based on urgency or operational need within the City of Thunder Bay. In addition the selection of tasks was partially influenced by the focus groups of urban forestry and other professionals as discussed earlier (see section 3.1.1). Together, the standard tasks and the link table tasks are those management activities that comprise the conceptual model for the developed UFBM (see Figure 3.5 and section 3.1.3).

The first standard task chosen for the UFBM was focused on stormwater. The stormwater standard task is a combination of impervious cover and tree cover variables that help produce a priority greening index to reduce stormwater damage and cost. The second standard task focuses on increasing tree cover so as to benefit the greatest number of people. This method, called the Priority Planting Index, was developed by researchers at the US Forest Service Northeastern Research Station and ranks tree planting locations based on population density, tree stocking, and trees per capita (Nowak *et al.* 2002). The third standard task chosen for the UFBM is in response to an anticipated arrival of an invasive, non-native, and harmful insect called the Emerald Ash Borer (EAB). Currently the EAB is documented in Sault Ste. Marie and Minneapolis and will likely be in Thunder Bay within 5 to 10 years (Vescio, pers. comm., 2010). This task indentifies areas of high concentration of ash (*Fraxinus* spp.) to produce priority-planting scheme to increase infill planting in these areas that will potentially suffer significant loss of tree cover.

This chapter is structured into three sections, one for each of the three standard tasks listed above. Each section provides a detailed description of the methodology, input data requirements (Table 4.1), and simplifying assumptions for each standard task. The UFBM is largely a GIS-based tool so the methodology adopted outlines the various GIS operations and equations used to generate geospatial planting locations, something that other decision support tools are lacking (see discussion of i-Tree earlier in section 2.3).

Table 4.1 The input data requirements for each standard task.

	Standard Tasks Theme Requirements			
Theme Description (Type)	Stormwater	PPI	EAB	Attributes Needed
public tree's existing (point)	✓	✓	✓	varied
private tree's existing (point)	✓	✓	✓	varied
road network (polyline)	✓	✓	✓	n/a
ortho SID 20cm Quad Aerial Images	✓	✓		n/a
dissemination areas (via census)		✓		population data
buildings (polygon)	✓			area
driveways (polygon)	✓	✓		area
lanes (polygon)	✓	✓		area
parking (polygon)	✓	✓		area
travelled roads (polygon)	✓	✓		road class
sidewalks (polygon)	✓	✓		area
neighbourhoods (polygon)	✓		✓	name and area
city study area (polygon)	✓		✓	n/a

4.2 Standard Task One: Stormwater

Urbanization increases the land area that is covered with impervious material, and inevitably diminishes areas of natural vegetation. The development of streets, sidewalks, building rooftops, parking lots and the resultant loss of vegetative cover significantly increases the volume and velocity of stormwater runoff (Wissmar *et al.* 2004). Large tracts of impervious cover, combined with a network of drainage infrastructure designed to carry stormwater long distances, have created a host of water quality and maintenance issues for municipalities. With heightened levels of car oil, gas, antifreeze, bacteria, garbage, pesticides and metals in cities, surface pollutants can be disastrous to watersheds and compromise human health (Dwyer 1999; Goonetilleke 2005; Nowak 2006). The repercussions of increased water volume, velocity, and non-point surface pollution are felt by cities in a variety of ways: flooding damage, increased tax payers' dollars to treat water, costly stormwater management infrastructure, degraded water quality and impaired aquatic habitats (Xiao *et al.* 1998; Wissmar *et al.* 2004; Goonetilleke *et al. 2005)*

Communities can diminish the effect of these damages by maintaining or planting trees, increasing other natural land cover (e.gs., soil, vegetation), and by reducing impervious cover (Dwyer and Miller 1999). Trees have been known for decades for their ability to capture rainfall and reduce runoff (Figure 4.1), but until recently, their ability to assist in a broad spectrum of stormwater management tasks has been overlooked (Seitz and Escobedo 2008). Trees intercept rainwater on leaves, branches and trunks, as well as create favourable soil conditions that allow rainwater to permeate into and replenish the groundwater. When engineered properly, surface runoff can be directed toward trees where many pollutants are absorbed by a tree's roots (which, depending on the species, are capable of bio-accumulating, denaturing and compartmentalizing pollutants without affecting tree health). By slowing the rate and volume of water runoff, trees consequently reduce the amount of pollutants entering streams and rivers, increase the quality of aquatic habitats, and ultimately replace or minimize the need of expensive hard infrastructure to manage the runoff.

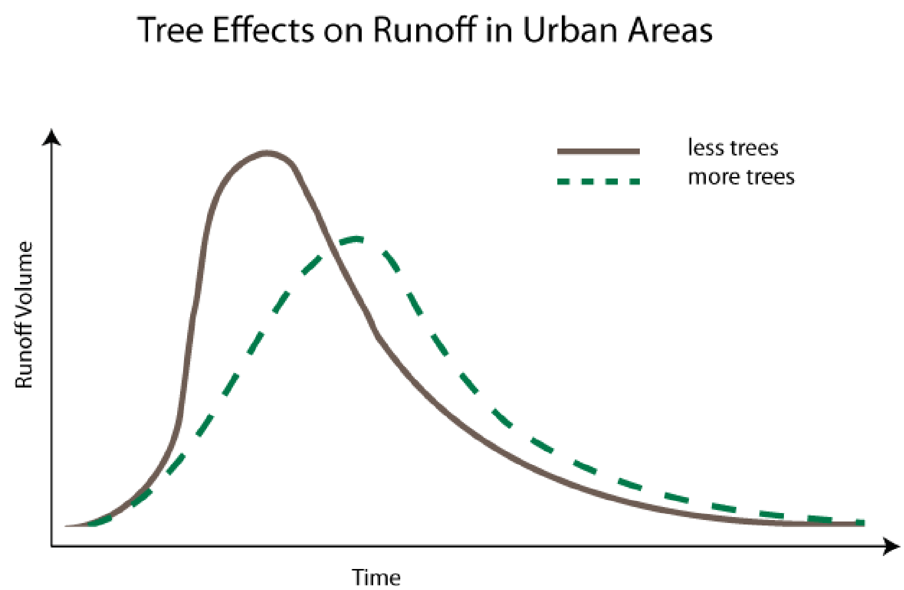

Figure 4.1. Conceptualization of the effects of trees on an urban hydrograph. An increased number of trees reduces the overall runoff, peak discharge and the steepness of the hydrograph's rising and falling limbs. Adapted from American Forests (2002).

The goals of stormwater best management practices (BMPs) are to reduce total runoff volume, reduce peak discharge, and remove pollutants (Day and Dickinson 2008). All three stormwater BMP goals can be accomplished by the use of green infrastructure. Properly located trees decrease peak discharge, that is, the target level that engineers use to decipher the type and amount of infrastructure required to manage stormwater. By doing so, green infrastructure does the same work as hard infrastructure like pipes, pumps, and storage chambers and can drastically reduce infrastructure, engineering and maintenance costs. By reducing total surface runoff, green infrastructure also decreases the risk of sewage overflow in cities with combined sewage overflow (CSO) systems. A CSO is a sewer that combines both stormwater and sanitary sewage in a single pipe system and can significantly impair water quality in rivers and lakes (Weyrauch *et al.* 2010; Gasperi *et al.* 2008).

Although it has been an aim of many municipalities to remove these combined systems, still about 772 communities in the US have active CSOs (United States 2008) and a total of 17 km of CSOs still remain in Thunder Bay (McConnell, pers. comm., 2011). This leads to more expensive, redundant treatment of fresh water and environmental costs associated with spills and clean up during and after rain events.

Over the past 40 years, many models have evolved to focus on urban hydrology and stormwater effects (Wang *et al.* 2008). The US EPA's Storm Water Management (SWMM) model (Huber *et al.* 1988), SWAT (Soil and Water Assessment Tool) model (Arnold *et al.* 1998) and TR-55 model (Natural Resource Conservation Services 1975) are effective at simulating and assessing the performance of a stormwater management system. Unfortunately, they are too highly parameterized for use in management applications, require significant and costly data inputs, and do not account for the urban forest (Wang *et al.* 2008). A recent release of the i-Tree Hydro model is the first of its kind to integrate trees into the urban stormwater modeling process, however like the above mentioned, it too is highly parameterized and therefore not readily applied for management applications with restricted budgets or access to data. The i-Tree Hydro model was created to simulate and study the effects of trees on urban runoff at the watershed scale. It uses complex algorithms to calculate stormwater interception, storage, infiltration, evaporation, and runoff and provides a measured benchmark in stormwater performance of an urban forest (Nowak 2006). Although these benchmark data would increase the precision of the UFBM by providing a more accurate estimate of the mitigating effects of Thunder Bay's trees, i-Tree Hydro falls short of providing the final step necessary to determine possible greening sites to mitigate stormwater effects that is included within the UFBM. The data required to run i-Tree Hydro were also not accessible in Thunder Bay. Due to these two disadvantages, sophisticated models like i-Tree Hydro were not used in the UFBM despite its strengths in other stormwater and urban forestry applications.

4.2.1 Task Objectives

The objective of task One was to produce a priority greening index to reduce stormwater damage and cost. The greening index reveals the management areas with the highest concentration of impervious cover and the lowest concentration of tree cover. The intended results lead to a priority planting scheme to reduce the peak, volume and rate of stormwater runoff. The objective was to use simple and readily available data to target these greening sites.

4.2.2 Modeling Approach for Task 1: Stormwater

Tree cover and impervious cover data are essential for decision makers in assessing areas of concern regarding stormwater, aquatic habitat quality and groundwater recharge (Greenfield *et al.* 2009). Hence the stormwater task focuses on the quantification of tree cover and impervious cover to derive information that is helpful for stormwater and urban forest managers. The data to assist in the quantification of impervious cover were provided by the City of Thunder Bay Planning Department and street tree data needed to estimate urban tree cover were provided by the City's Parks Department. However, these latter data were limited to public trees along roads and major parks and it was necessary to create an inventory of privately-owned trees (see discussion earlier in section 3.1.4). The private tree inventory was built in the summer of 2010 using remote sensing classification. The private tree data were combined with the public data to form a contiguous tree inventory throughout Thunder Bay[1]. These data are essential in determining a score that will help prioritize greening activities to mitigate stormwater effects. A complete list of data requirements for this task is found in Table 4.1.

The following section provides a detailed description of the methodology used in developing the stormwater task, including a discussion of GIS operations and equations used, data requirements, and simplifying assumptions. The discussion is organized into three sections based on the stages shown on Figure 4.2: (1) tree cover (Stages 1- 10); (2) impervious cover (Stages 12-23); and (3) the stormwater score (Stages 24-25). Associated metadata for stormwater score files can be found in Appendix VIII.

4.2.2.1. Tree Cover

The public tree inventory data obtained from the City of Thunder Bay were recently updated in December 2010. This public tree inventory consists of a point shapefile (compatible with a variety of GIS software, including ESRI's ArcGIS) and

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[1] The private tree inventory executed in the summer of 2010 was not fully completed due to financial constraints. The zone inventoried was approximately 65% of the greater study area as indicated in Figure 4.9

has the following attributes for each public tree location: tree coordinates, height, species, age, condition and diameter. However, only the location, height and spatial attributes were needed for the stormwater task model. The private tree inventory was built to mimic the format of the public inventory and is a point shapefile containing the following attributes: tree coordinates, tree canopy size class, and tree type (deciduous or conifer) (refer to Chapter 3 regarding sampling techniques used in private tree inventory). A third file contained polygon shapefiles of forested stands within the City, also remotely collected during the compilation of the private tree inventory. Forest stands (whether on private or public land) were defined as a group of trees uniquely distinguished from adjoining areas. Trees were delineated as a forest stand by the remote sensing analyst if the tree was found in a natural, unmaintained environment. Conversely, trees that were near each other in areas maintained by humans (i.e. the grass around its base is tended) would be considered a single urban tree and not in a forest stand (Figure 4.3).

In order to determine the overall tree canopy cover (as an estimate of the total leaf area), the first step was to combine both the public and private tree data. Prior to combining these two shapefiles (and their associated attribute tables), a conversion was necessary to ensure the attribute tables from both shapefiles would correspond. The public tree data, for example, contained an attribute that expressed tree size in terms of 'tree height class' in meters. Within the private tree data, the attribute that expressed tree size was 'crown width class' in meters. Because the tree size measurement desired for the model was 'crown width class', the public tree data required conversion. Although conversion algorithms have been

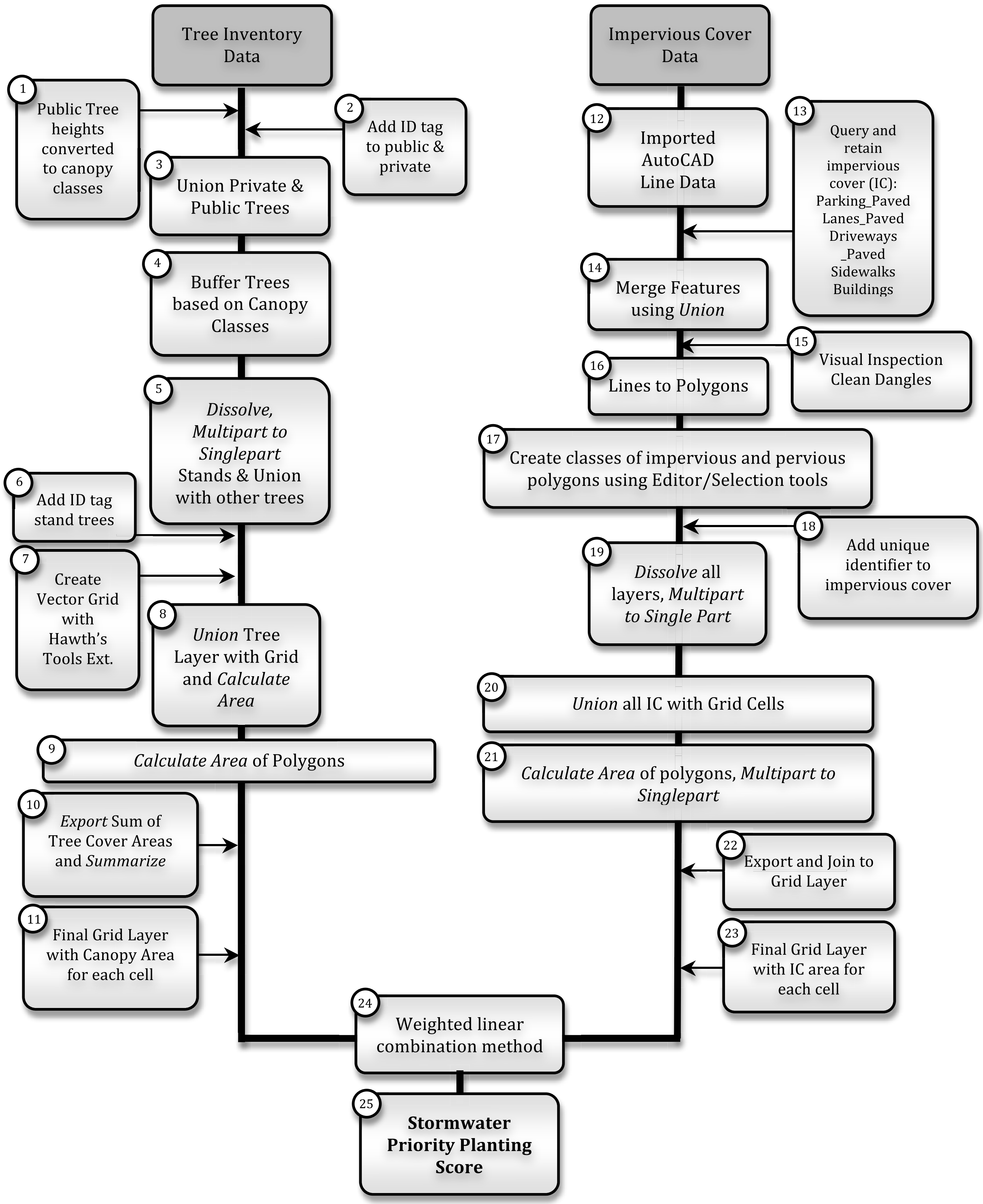

Figure 4.2. Conceptual diagram of GIS steps used in the stormwater task. It involves the analysis of tree inventory data and impervious cover data to generate a stormwater score.

Figure 4.3. A screenshot from ArcGIS displaying the delineation of a forest stand (light green) and individual trees (dark green).

developed for multiple instances in the commercial forestry sector (e.g., tree height, age and diameter variables can be used to estimate the amount of leaf area or tree volume), no algorithms exist for the conversion of height to crown width (or more desirably, leaf area) for urban trees. The closest available algorithm for urban trees developed by Nowak (1996) required the following variables: DBH (diameter at breast height), tree height, height to base of live crown, and crown width. Given the paucity of available tree inventory data needed for conversion within this model, an assumption was made that tree height correlated linearly with canopy width. This assumption was based on the data received during the first part of the private tree inventory when tree height, canopy width, and species attributes were inventoried. The data consisting of 398 trees demonstrated a linear relationship (Figure 4.4) between the height and crown width classes, using the four most predominant genera found in Thunder Bay – according to the public tree inventory (ash, *Fraxinus*; birch, *Betula*; linden, *Tilia*; maple, *Acer*). Therefore each height class (5 classes ranging between 1-23m) in the public dataset was converted linearly to crown width class (5 classes ranging between 1-18m) (Table 4.2). Short trees (between 1 to 5 m) were categorized to have small canopy width class (between 1 to 4 m) and so on until all the five classes were completed (Stage 1 in Figure 4.2). This assumption would not always be accurate, however, it provides a good estimate given the limited research and existing variables. For example, a tree with a height class of one (1-5m) would likely have a canopy diameter between 1-4m. Depending on the species, growing conditions, and tree shape, a tree in this height class could have a canopy width larger than 4m, although it would be unusual. As a whole, this assumption is useful by providing an estimate of tree canopy cover for all public trees within the city, given the lack of conversion algorithms. Before combining datasets, each attribute table was given an identifying tag to denote if it was a public or private tree. This step was included in the event a decision maker wanted to differentiate between the two types of trees after the analysis (Stage 2 in Figure 4.2).

Combining both shapefiles was completed using the ArcMap's *Union* function (Stage 3 in Figure 4.2). The redundant or unneeded attributes produced in the *Union* were discarded. The recently combined layer from Stage 3 was buffered using the *Buffer* tool to produce a realistic representation of canopy cover on the spatial layer

(Stage 4 in Figure 4.2) (see Figure 4.5). The distance each tree was buffered was based on the range median of the canopy width class it belonged to (Table 4.2).

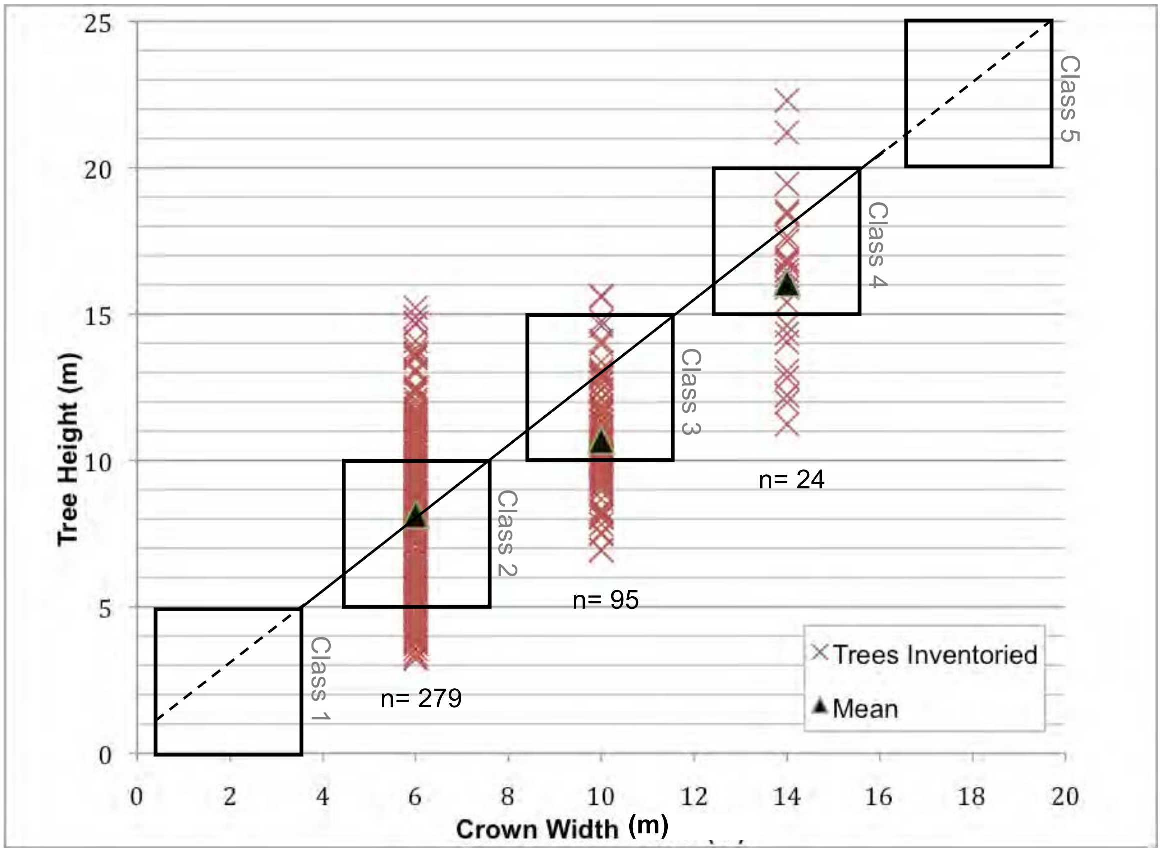

Figure 4.4. A linear relationship between tree height and crown width of the most common tree genus in Thunder Bay (ash, *Fraxinus*; birch, *Betula*; linden,*Tilia* ; maple, *Acer*). A total of 398 trees were inventoried by a remote sensing analyst in the summer of 2010 to calculate this relationship. The black boxes indicate the distribution of each class around the median for tree height and crown width. The mean tree height for each of the three crown width classes fell within the given proper tree height class distribution and thus demonstrates that a linear relationship could be used to estimate crown width using tree height.

Table 4.2. Canopy width classes and their median used for determining average canopy width.

Crown Width Class	Range (m)	Median (m)
1	0-4	2
2	4-8	6
3	8-12	10
4	12-16	14
5	16+	18

Figure 4.5. A screenshot from ArcGIS displaying the public (dark green) and private (light green) trees after the buffers had been applied, to produce a realistic representation of canopy cover based on each tree's crown width class.

The stand layer underwent a *Dissolve* and *MultiPart to Singlepart* function incase any overlap or multipart features existed (Stage 5 in Figure 4.2). Another specific ID tag was added to the attribute table in the event a user desired to distinguish between tree canopy or stand canopy in the results (Stage 6 in Figure

4.2). A vector grid was created at a resolution of 100m using Hawth's Tools extension (Stage 7 in Figure 4.2). Such a grid (the size determined by the user) was needed to serve as the management areas – to delineate the size and boundary of areas that the results would be presented in at the end of each task and the final layout, which would ultimately guide decision makers in their greening choices. For the present case study, a grid resolution of 100m (i.e., an area of 10,000m^2 or 1ha) was created to ensure the management areas were large enough to present a broad overview of the City and provide tangible, convenient and easily identifiable management areas for planning. Too small of a management area could create an overwhelming amount of detail on a planning level and could limit foresters and technicians on the ground in their ability to find adequate planting spots. If, for example, a grid resolution of 10m (i.e., an area of 100m^2 or 0.1ha) was used, many management areas would be small enough to conceivably be consumed with house rooftops and driveways, which clearly would allow little potential to plant. Increasing grid sizes to a neighbourhood scale provides more freedom for targeting greening sites. A balance between these two grid sizes (10m x 10m vs. 100m x 100m) can be adjusted depending on the scenario and level of detail desired, however a coarse-scale between 50m x 50m and 100m x 100m is suggested. It should be noted that with the presence of a plantable spots inventory, a smaller cell size would be achievable. A plantable spots inventory is an inventory normally undertaken by a municipality to determine the exact space where trees could be planted. A plantable spot is determined by a variety of factors such as available growing space, soil and lawn size and condition, above or below ground utilities or hard infrastructure (Kirnbauer *et al*. 2009). A plantable spots inventory removes the guesswork for planting and would also eliminate areas where trees couldn't be planted (e.g. a building rooftop). It would allow for a greater level of precision in targeting true potential sites. Although a small cell size wouldn't always be desirable (see above) a plantable spots inventory could increase the precision by reducing the management areas in the model.

Once the vector grid size had been created, another *Union* function was used to combine the tree cover data (public and private trees), stand data, and the grid layer (Stage 8 in Figure 4.2). The *Union* function computes an intersection of the various input features (tree cover and vector grid) and writes them to one feature class. This is important, as the final step will include a representation of each cell's corresponding area of tree cover. After the union, the area for all the polygons (grid, trees, and stands) was determined using the *Calculate Area* tool (Stage 9 in Figure 4.2). All fields with a buffer radius of >0 and features with a stand ID tag (which selects only the tree canopy polygons), were exported to a new layer. This layer's area of tree cover then was summarized using *Summarize* tool in the attribute table to determine how much tree cover area occupied each management area (Stage 10 in Figure 4.2). The DBF table created in the summary was then joined back to the original vector grid (stage 11 in Figure 4.2) to display the sum of tree cover in each grid cell. Tree cover can vary from 0 to 1.0 ha, with 1.0 ha representing complete canopy cover for a given cell or management area (See Figure 4.6)

Figure 4.6. A screenshot from ArcGIS displaying the sum of tree cover area per management area. Each grid cell, or management area, represents 1 hectare.

4.2.2.2. Impervious Cover Data

The second component of establishing a stormwater score is to determine the amount of impervious cover in the study area. The data received from the City of Thunder Bay pertaining to impervious cover were: building footprints, driveways, lanes, parking lots, sidewalks, and travelled roads. Many of theses layers, however, were a combination of paved and non-paved surfaces, originating from AutoCAD files. Therefore the GIS shapefiles (converted by the City of Thunder Bay from AutoCAD) were queried so as to extract the proper features for use in the model.

Shapefiles converted from AutoCad bring with them a variety of challenges. AutoCad data (lines or polygons) are drawn in an environment where symbology is the extent and boundary of the feature. In ArcGIS, the boundary remains the same regardless of the symbology used to display the feature. When a broken line, for example, in the AutoCAD display environment is brought into the GIS, it is normally converted as multiple polylines –with their own set of nodes and line properties (some newer versions of AutoCad can allow for more desirable conversions). As in this case, some municipalities have not converted over their CAD files to spatial files in a GIS environment. Consequently, a set of methods was developed to work with the converted AutoCAD data (Stage 12-17 in Figure 4.2).

The first stage was to query and retain all paved features from unpaved features (i.e., some parking lots, trails, were considered unpaved)(Stage 12 and 13 in Figure 4.2). For the purpose of this research all unpaved layers were considered pervious. In reality, some unpaved surfaces function like that of a paved surface, due to their compaction or fine granular size. However, without supplementary data, the assumption was made that all unpaved areas were pervious.

The converted AutoCAD shapefiles contained numerous line features representing sidewalks, roads, and driveways that when merged as “closed” polygons indicate areas of pervious and impervious cover. A two step process was used to convert these line features: (1) the line features were combined using the *Union* function; and (2) these unioned line features were converted to polygons, using the *Feature to Polygons* tool (Stage 14 and 16 in Figure 4.2). After using the *Feature to Polygons* tool, the x,y tolerance was set to 0.3 meter to ensure the polygons were closed. A brief visual inspection was necessary to ensure polygons were indeed closed and to ensure that a larger x,y tolerance was not required (Stage 15 in Figure 4.2).

The newly-created polygons needed to be classified as either an impervious or pervious surface. During Stage 16 in Figure 4.2, a majority of the polygons were properly converted into their respective classes (either a pervious or impervious), however some areas were encoded improperly (e.gs., large blocks, boulevards). Using ArcGIS' Selection and editing tools, most surfaces, especially the large polygons greater than $100m^2$ were properly classified using the City's 40 cm QUAD aerial imagery as a backdrop for verification (Stage 17 in Figure 4.2). Approximately 15 hours was required to classify these features in the stormwater area (3690 management areas) or on average about 15 seconds per management area. It must be noted that there were a significant amount of small areas of boulevards that were encoded improperly during the *Union* (back in stage 14 of Figure 4.2). For instance the driveway of a particular home between the sidewalk and road would be coded as pervious, while the front lawn between the sidewalk and the road was coded impervious. Also the shapefiles denoting impervious layers that were received from the City of Thunder Bay did not always match the existing road or impervious infrastructure (Figure 4.7). Given the time and financial constraints required to hire a technician to make all the edits, a give-and-take method was applied to these areas that had many small discrepancies in classification. The estimation practice permits a small error to pass if a neighbouring error counteracts it. Figure 4.8 demonstrates the various types of error associated with determining the overall error for a given

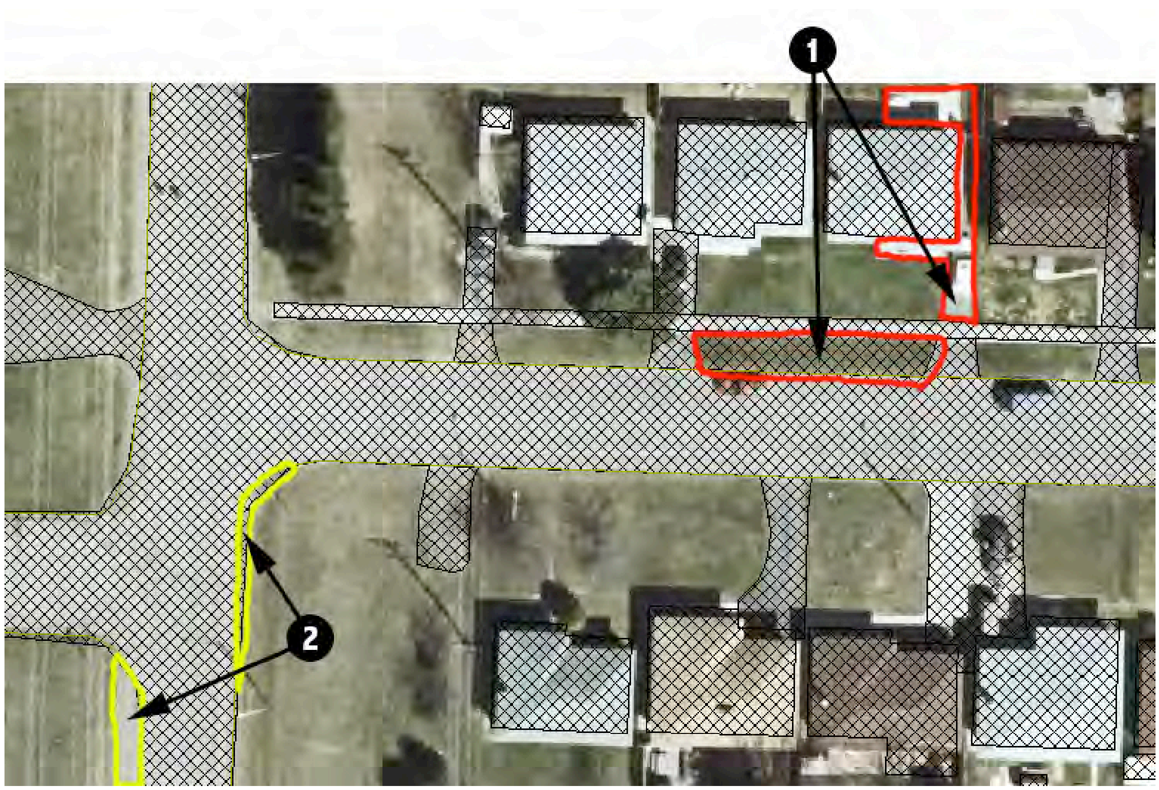

Figure 4.7. A screenshot from ArcGIS of impervious cover depicting two sources of coding inaccuracies: 1) the give and take method (see red outlines), where the front boulevard (classified as impervious on the map) is used as an estimate to counterbalance the driveway area (not classified as impervious on the map) and 2) the original data provided by the City is slightly imprecise with regards to various features (see yellow outlines). This type of error was generally not accounted for (see Figure 4.8 for further discussion).

management area. To determine the magnitude of error, one management area (i.e., a 100 m cell) was used for a trial. The impervious area was calculated for the cell and the various types of error were subtracted or added based on the following formula:

Equation 4.1

$$Error = \frac{A_o - A_p + A_i - B_p + B_i}{A_o}$$

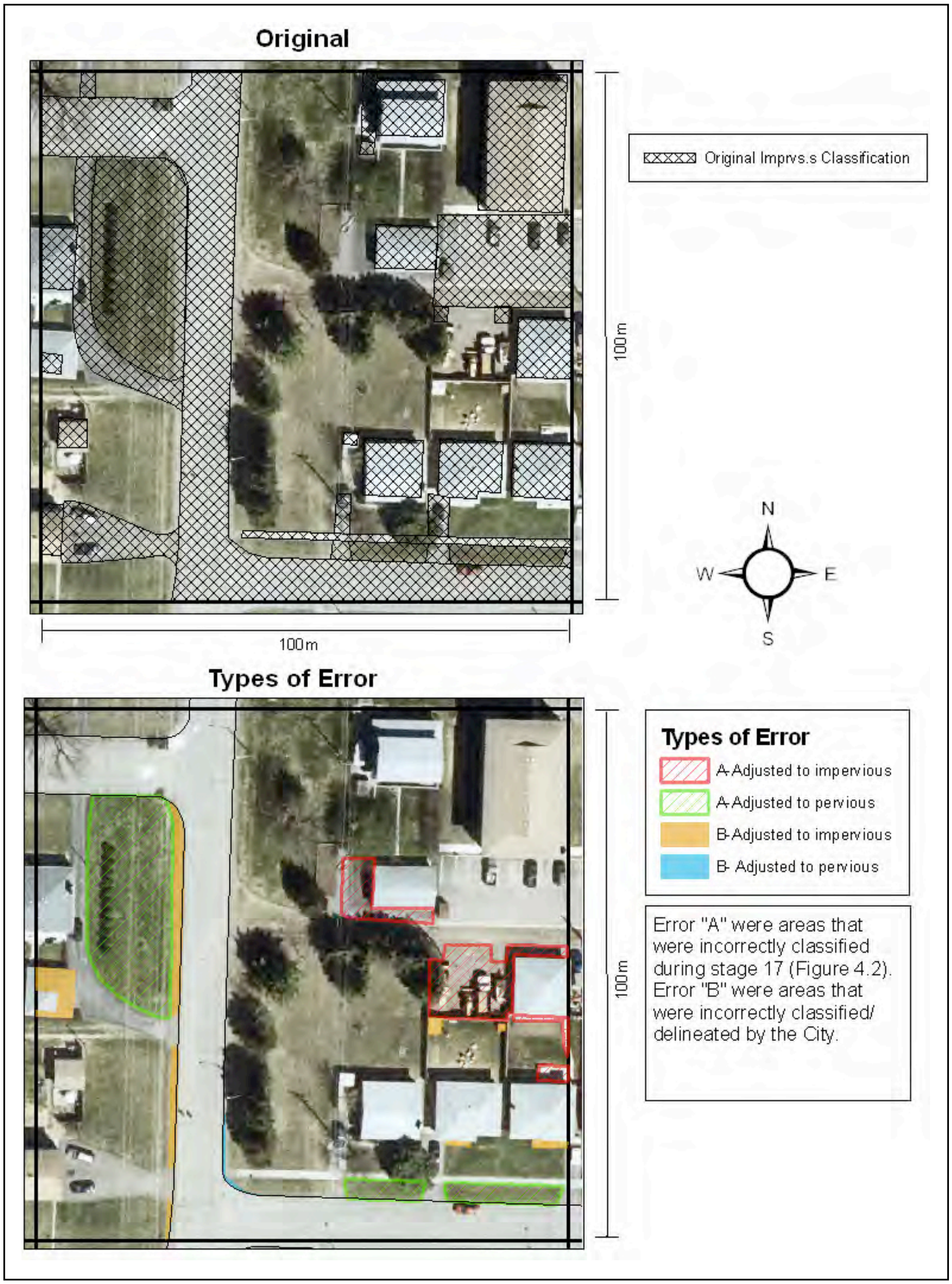

Figure 4.8. Types of error present during the analysis. Error "A" were areas that were incorrectly coded during the classification process (Stage 17 of Figure 4.2). Error "B" was incorrectly classified by the City (e.gs., roads that were digitized too large or too small, or new driveways or garages that were not updated in the City database). The give-and-take method was performed for this test management area and resulted in a 3.1% error.

where as A_o is original impervious cover in the cell (see top of Figure 4.8), A_p is the area that should not have been included as impervious cover during the classification process (Stage 17 of Figure 4.2)(see bottom of Figure 4.8), A_i is the area the should have been included as impervious cover during the classification process (Stage 17 of Figure 4.2), B_p is the area that was incorrectly classified by the city and should not have been included as impervious cover (i.e. the road was not as wide as indicated on the feature) and B_i is the area that was incorrectly classified by the city and should have been included as impervious cover. Figure 4.8 helps to demonstrate these various areas that were incorrectly classified.

An error of 3.1% was calculated for one test cell, and is a reflection of the level of inaccuracy in this process. The area that was classified into impervious and pervious cover was limited to within the stormwater study area only (See Figure 4.9).

In future studies, if a municipality had themselves created a polygon shapefile for impervious surfaces, Stages 12 through 17 (Figure 4.2) could be omitted thus increasing accuracy. In anticipation for a later step, a unique identifier was added to each impervious feature in the attribute table (Stage 18 in Figure 4.2). The impervious cover layer was *dissolved* and a *multipart to singlepart* function was also applied (Stage 19 in Figure 4.2). A 100m resolution vector grid identical to the layer used for the tree cover analysis, created with Hawth's Tool extension as discussed earlier (Stage 7 in Figure 4.2), was added to the map display. A unique identifier was also added to each feature (i.e., cell) on the grid. The grid and the

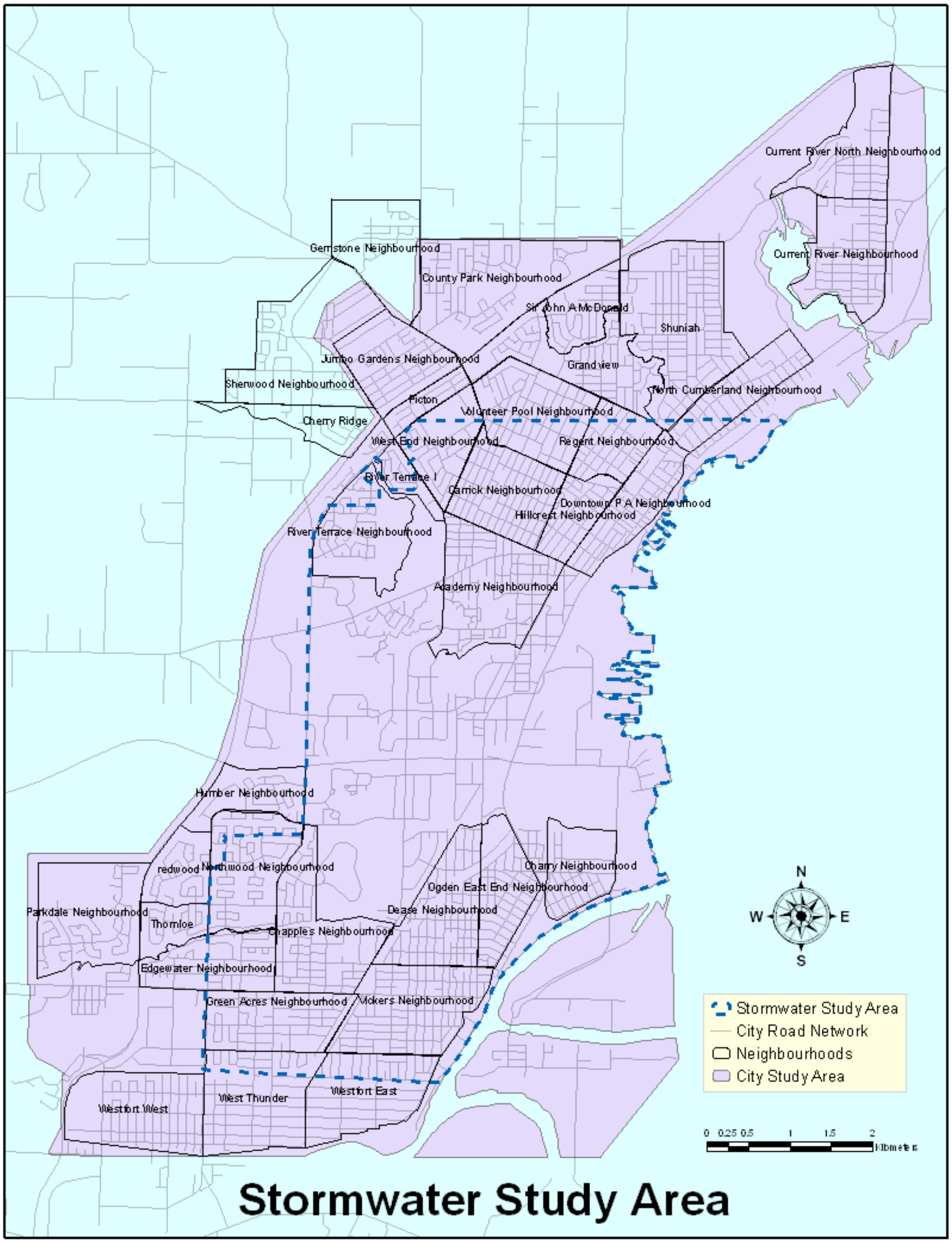

Figure 4.9. A map denoting the study area for the stormwater task. The regular City Study Area is also shown here which is used for other UFBM tasks.

impervious surface layer were then combined using the *Union* tool (Stage 20 in Figure 4.2). As discussed earlier, the *Union* function computes an intersection of the various input features (impervious cover and the vector grid) and writes them to one feature class (the grid cell). This is important, as the final step will include a representation of each cell's corresponding area of impervious cover. The area of all polygons was then calculated using the *Calculate Area* tool, and the *Multipart to Singlepart* function was once again applied (Stage 21 in Figure 4.2). Using the selection options, the impervious surfaces were selected and exported to a new layer. This layer was joined to the original grid and the area of impervious cover in each grid cell was summarized (Stages 22 and 23 in Figure 4.2) (Figure 4.10).

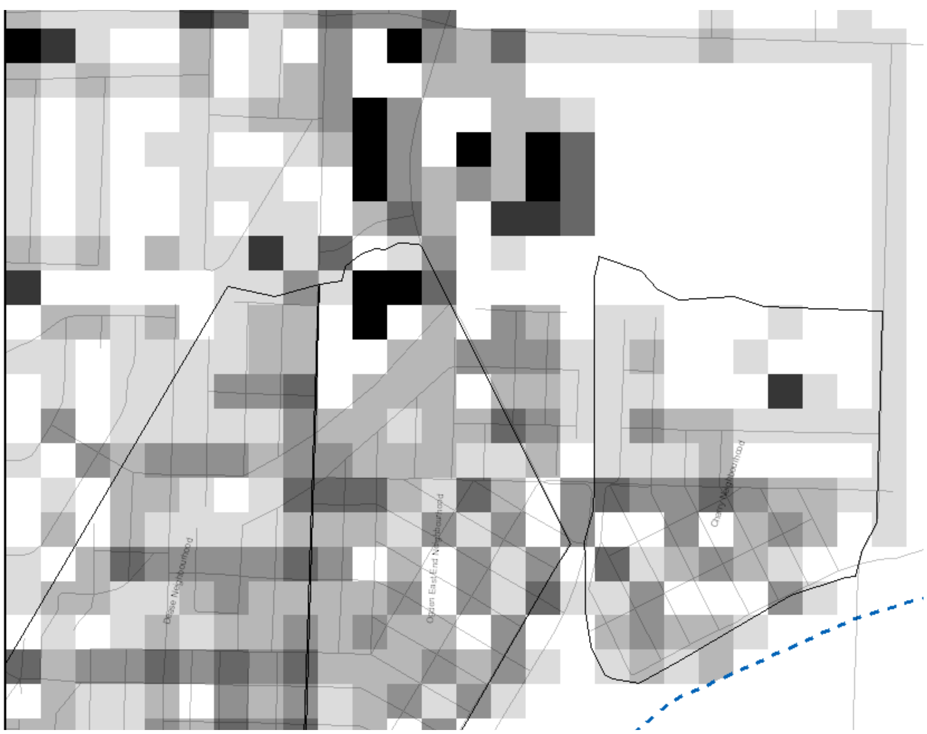

Figure 4.10. A screenshot from ArcGIS displaying the sum of impervious cover in each management area. Each grid cell represents 1 hectare. The darker shaded management areas have higher amounts of impervious surface.

4.2.2.3. Stormwater Score

With the completion of both tree cover and impervious cover grids, a weighted linear combination method was applied (Stage 24 in Figure 4.2) to the results of each section (tree cover and impervious cover) to calculate a final stormwater score. This method was used to standardize the impervious and tree cover scores and allow the user to weight these variables based on importance. The final score would indicate priority for greening (Stage 25 in Figure 4.2) (Figure 4.11).

The body of research indicates a varying level of benefits that trees provide with respect to stormwater management. Furthermore, the literature demonstrates the wide-ranging influence that impervious surfaces have on stormwater hydrology. The weighted linear combination method was used so as to account for these differing influences. Due to the variances in a trees' mitigation effect, the user is given the opportunity with this method to alter the weight a tree has in the providing an ameliorating effect. The interception of rainfall alone can range from 6 to 36 percent depending on the species, leaf type and amount, density, and climate (Xiao *et al.* 1998; Seitz and Escobedo 2008). Other studies demonstrate trees' ability to reduce total stormwater runoff from 7 to 12 percent (Wang *et al.* 2008). Other factors such as evapotranspiration, infiltration, and store rainfall, also affect stormwater hydrology.

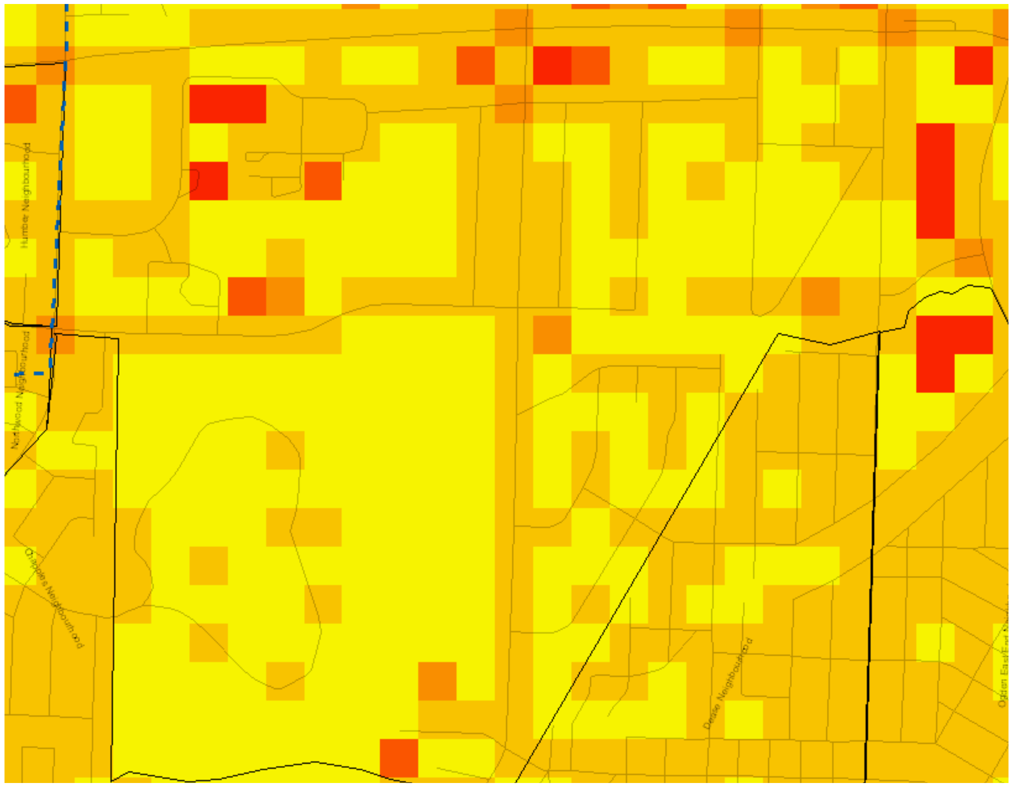

Figure 4.11. A screenshot from ArcGIS displaying the stormwater score. The combined score represents a 6 to 1 weighting of impervious cover and tree cover respectively. Values tending towards 1 (darker cells) indicate management areas that require focused greening to mitigate stormwater damages, while those tending towards 0 do not require greening. Each grid cell represents 1 hectare.

The weighted linear combination method is a common way of computing an index value for a vector-based model (Chang 2010). The method involves evaluation at three levels: criterion weights, data standardization, and data aggregation. First, the relative importance for each criterion was evaluated against the other. For example, based on the literature, impervious cover was considered to be approximately six times more important than tree cover in respect to the final stormwater score (Wissmar *et al.* 2004; Seitz and Escobedo 2008), so a 0.6 was recorded for impervious cover and 0.1 was recorded for tree cover. Second, the data for both impervious cover and canopy cover were standardized using a linear transformation into a scale of 0.0 to 1.0. The following formula was used for standardizing impervious cover:

Equation 4.2

$$S_i = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}}$$

where S_i is the standardized value for the original value X_i, X_{min} is the lowest original value, and X_{max} is the highest original value. Since tree cover was used to offset the impervious cover, its standardized value was subtracted from 1. Therefore the formula used for standardizing tree cover was:

Equation 4.3

$$1 - S_i = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}}$$

where S_i is the standardized value for the original value X_i, X_{min} is the lowest original value, and X_{max} is the highest original value. Third, the index value was calculated for each grid cell by summing the weighted criterion values and dividing the sum by the total of the weights (Chang 2010):

Equation 4.4

$$I = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i}$$

where *I* is the index value, n is the number of variables, w_i is the weight for criterion *i,* and x_i is the standardized value for criterion *i*.

4.2.3 Modeled Results for Task 1: Stormwater

The stormwater task has three major elements: tree cover, impervious cover, and a combined stormwater score. The following sections provide the results pertaining to each element.

4.2.3.1. Tree Cover

The main objective of the tree cover study was to arrive at an estimate of the distribution and extent of urban forest canopy cover within Thunder Bay. This estimate, in conjunction with the impervious cover, was used to determine the final stormwater score. The tree canopy analysis was carried out for the entire city, however, due to an incomplete private tree inventory, the study was limited to the areas that incorporated both public and private inventories (see Stormwater Study Area, Figure 4.9). The results were summarized in management areas of 1 ha in size, and various colour shades of green were used to represent the area of tree cover in each cell (Figure 4.12). Tree cover will be discussed in terms of percent cover to follow the industry standard when dealing with canopy cover analysis.

The entire stormwater study area (excluding Lake Superior) had an approximate mean canopy cover of 9.2 percent. The largest conglomerate of management areas with 100 percent canopy cover area were forested regions within the City limits (see George Burke Park and three management areas (A, B, C) found east of the Thunder Centre on Main Street (Figure 4.8). With the exception of these forested regions, Carrick, Academy, West End, and Volunteer Pool neighbourhoods had the greatest tree cover with 14.2, 13.4, 11.7, and 11.4 percent

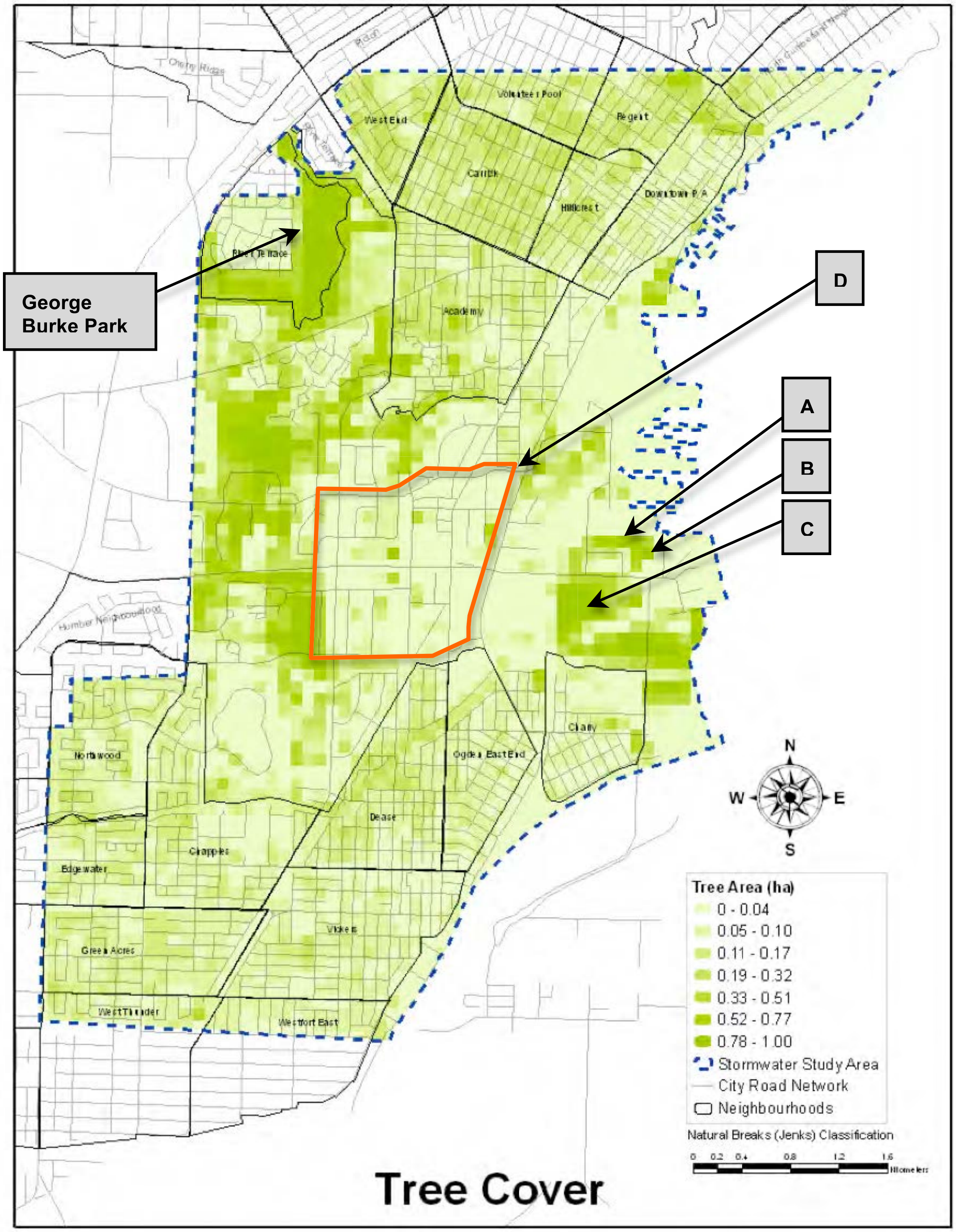

Figure 4.12. A map displaying the values of tree cover area for each management area for most of the City of Thunder Bay. Each grid cell represents 1 hectare. Labeled forested regions (A,B, C, and George Burke Park and zone around the Inter City Mall (D)), are discussed in the text.

canopy cover respectively (Figure 4.12). These higher-than-average canopy cover levels are likely due to the abundance of maturing public street trees (e.g., large Acer *saccharinum* and Fraxinus *pennsylvanica* L., along many of these streets) and numerous backyard trees in these areas. Table 4.3 presents the summaries of canopy cover, impervious cover and stormwater scores. Impervious cover and stormwater scores will be discussed in sections 4.3.2 and 4.3.3 below. In general, tree cover was highest in Thunder Bay north when compared to the inter-city area and Thunder Bay south. Although neighbourhoods such as Dease and Vickers in the south contained management areas with high tree cover (28%), their mean coverage across the neighbourhood was not as high as Carrick, Academy, West End, and Volunteer Pool neighbourhoods in the north. Neighbourhoods Dease and Vickers mean tree cover was 8.6 and 9.5 percent respectively. The least tree cover was found in inter-city area. Vast tracks of land, some 200-300 meters wide, stretching 700 meters long were found to have very little or no canopy cover, largely due to the substantial amount of buildings and parking lots within these industrial and commercial lands. An area of 211 ha surrounding the Inter-City Shopping Mall, bordered by Central Avenue (north), Fort William Rd (east), William Rd (south) and Balmoral Road (west) resulted in a mean tree cover of 3.1 percent (see area labeled D on Figure 4.12).

The summary of neighbourhood averages seen in Table 4.3, were calculated using the intersect selection method within ArcGIS. This selection method selects a cell (or feature) if the neighbourhood being summarized intersects any of the features (cells) (Figure 4.13). This technique was chosen to ensure that all areas

Table 4.3. A summary by neighbourhood of average percent tree cover, average percent impervious cover and average stormwater score. Impervious cover and average stormwater scores will be discussed in sections 4.3.3.2 and 4.3.3.3 respectively.

Neighbourhood	Neigh-bourhood Area (ha)	# of Grid Cells[2]	Avg. Tree Cover (%)	Avg. Impervious Cover (%)	Avg. Stormwater Score
Academy	171	206	13.4	13.8	0.24
Carrick	120	152	14.2	13.1	0.23
Chapples	148	239	5.5	12.8	0.24
Charry	79	105	6.6	8.5	0.2
Dease	129	158	8.6	15.8	0.26
Downtown PA	91	126	5.6	14.8	0.26
Edgewater[1]	102	82	6.5	14.4	0.25
Green Acres	118	145	7.4	14.1	0.25
Hillcrest	59	80	10.4	12.7	0.23
Intercity Mall (see "D" on Figure 4.12)	211	211	3.1	17.0	0.28
Northwood[1]	132	130	7.7	13.1	0.24
Ogden East End	91	122	5.7	16.6	0.27
Regent[1]	68	81	10.3	12.1	0.23
River Terrace[1]	120	143	33.3	4.1	0.13
Vickers	161	198	9.5	16.1	0.27
Volunteer Pool[1]	133	75	11.4	12.3	0.23
West End[1]	84	86	11.7	9.8	0.21
West Thunder[1]	155	62	6.8	12.2	0.24
Westfort East[1]	131	58	5.3	15.5	0.27
Total Average	**118**	**141**	**9.9**	**13.1**	**0.24**

[1] Only a portion of the neighbourhood was analyzed because part of the neighbourhood fell outside the stormwater management study area.
[2] This is a count of full and partial grid cells intersecting each defined neighbourhood.

within the neighbourhood were included, especially arterial roads that could be lined with trees and large tracts of impervious cover (i.e., road). The neighbourhood zones in most cases followed arterial roads and therefore the intersect method provided a means to include these sections where otherwise they would be omitted if using the *contain*, *have their centroid in,* or *completely within* selection methods.

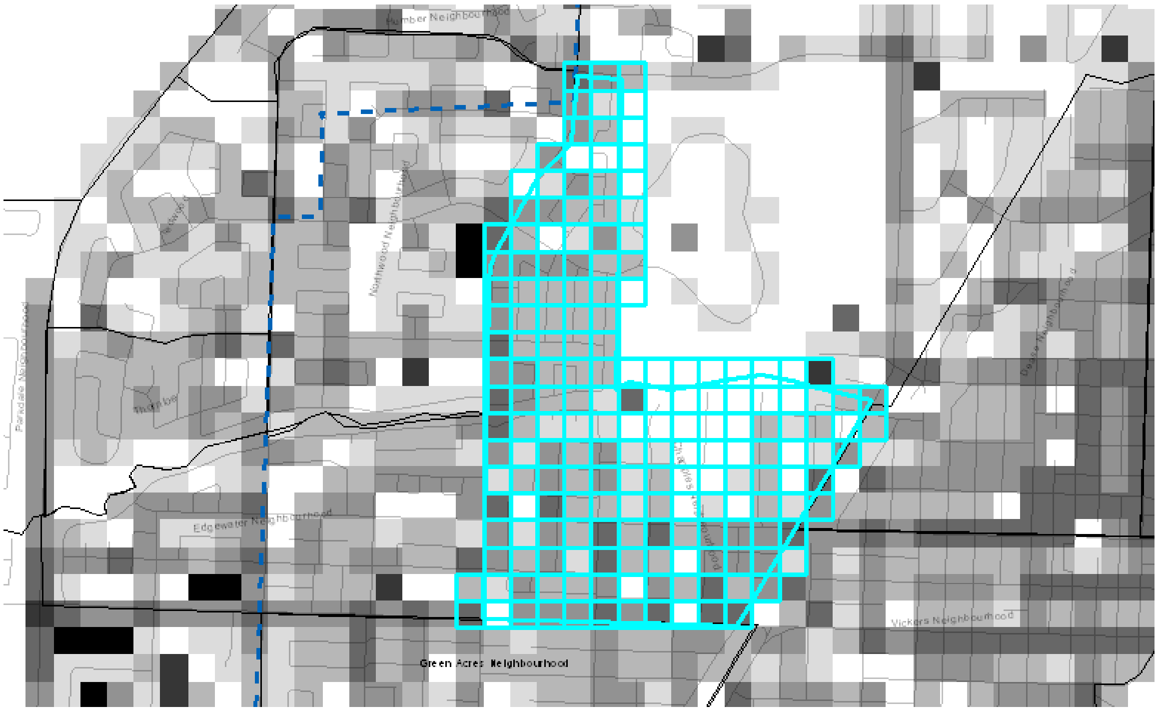

Figure 4.13. A screenshot from ArcGIS demonstrating how an intersect selection method within ArcGIS selects cells within a neighbourhood. The neighbourhood border and included cells (management areas) are highlighted.

4.2.3.2. Impervious Cover

The main objective of the impervious cover study was to arrive at an estimate of the distribution and extent of impervious cover within Thunder Bay. The results were summarized in management areas of 1 ha in size, and various colour shades of grey were used to represent the area of impervious cover in each cell (Figure 4.14). Management areas in Thunder Bay South adjacent to some major arterial roads were found to have high percentages of impervious cover, such as

Victoria Avenue and May Street corridors. Management areas with high percentages of impervious cover in Thunder Bay North were found to be adjacent to the Red River Road, Water Street, and Cumberland Street corridors (Figure 4.14).

In addition to the corridors that contained contiguous management areas of high impervious cover, 48 management areas throughout the city contained impervious cover greater than 0.5 ha. These management areas were primarily situated in the vicinity of the inter-city commercial and industrial core (31 management areas). Surprisingly, no management areas in the Thunder Bay north downtown core contained over 5000m^2 of impervious cover. Twenty-two management areas contained impervious cover greater than 0.9 ha. Of these 22 management areas, 15 were found in the inter-city region, three in Ogden East Neighbourhood, two at Lakehead University, and two in the Northwood Neighbourhood. The Intercity (see “D” on Figure 4.12), Ogden East End and Vickers Neighbourhoods had the highest average impervious cover at 17, 16.6 and 6.1 percent respectively. River Terrace, Charry, and the West End Neighbourhoods had the lowest average impervious cover at 4.1, 8.5, and 9.8 percent respectively (Table 4.2). In reference to the Thunder Bay land use designation map, one would note that many of the management areas with highest impervious cover were situated within a ‘commercial’ land use (Figure 4.15). These management areas will have a significant impact on the final stormwater score, recalling that impervious cover is weighted as 6 times to that of tree cover as discussed earlier.

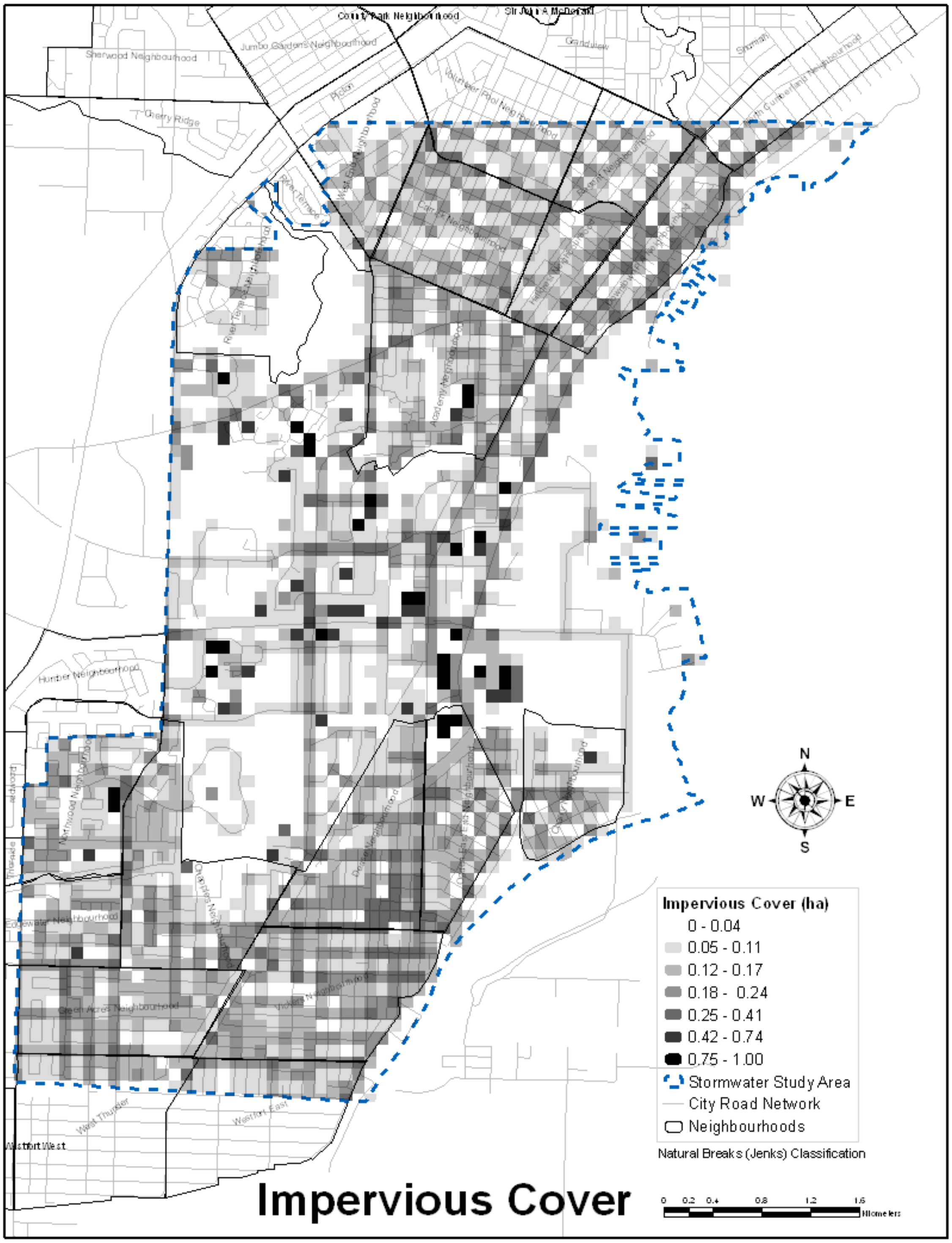

Figure 4.14. A map displaying the sum value of impervious cover for each management area for most of the City of Thunder Bay. Each grid cell represents 1 hectare. The darker shaded management areas have the higher amounts of impervious surface.

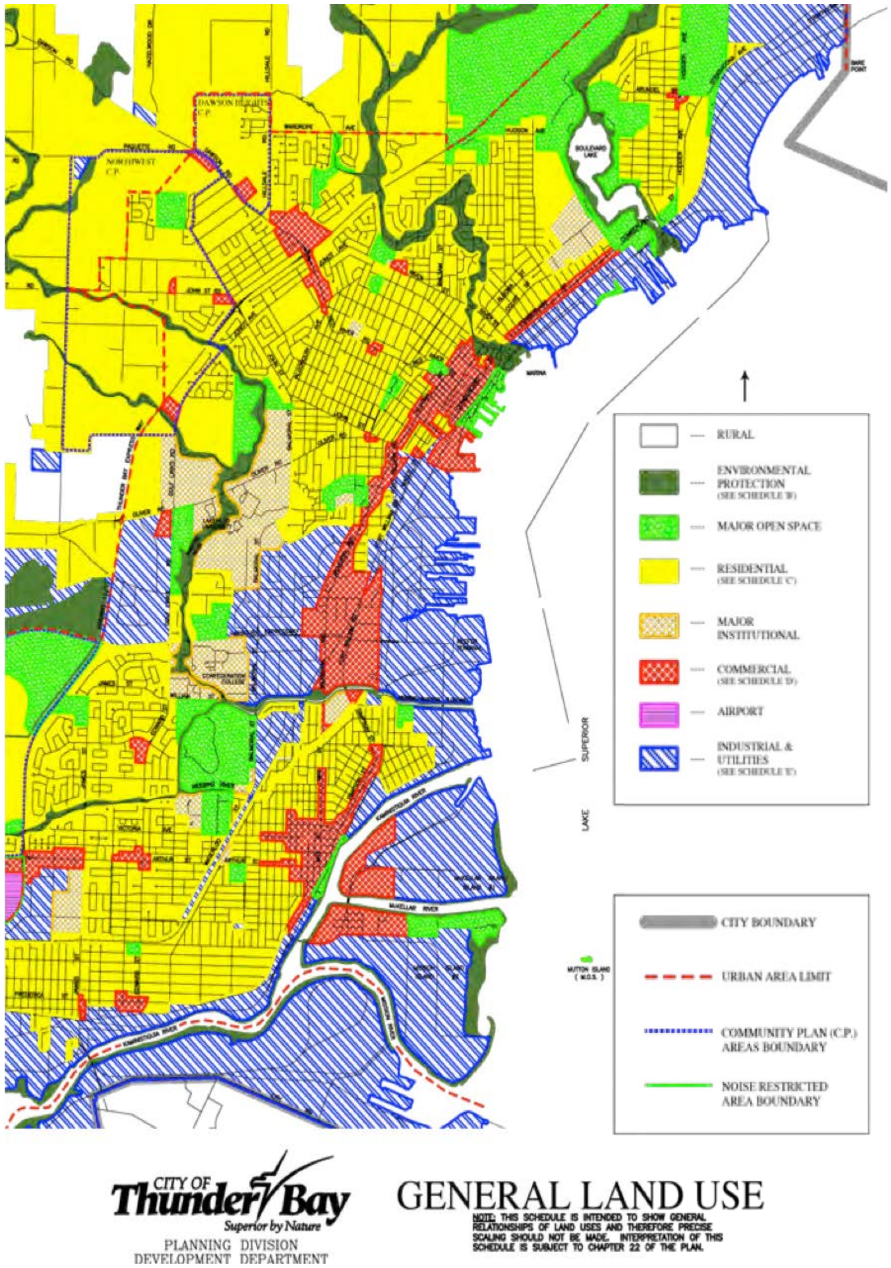

Figure 4.15. A land use map for the City of Thunder Bay. Adapted from the City of Thunder Bay Official Plan (Thunder Bay 2005).

4.2.3.3. Stormwater Score

The main objective of the stormwater score study was to arrive at an estimate of urban stormwater problem areas that could potentially be mitigated using green infrastructure. This was achieved by using both the impervious and tree cover results discussed above. The results were summarized in management areas of 1 ha in size and various colour shades (yellow to red) were used to denote a priority for greening (Figure 4.16).

The body of literature presents varying results about a tree's ability to mitigate stormwater and its associated hydrologic problems. For example, the literature indicates that a tree canopy can intercept between 6-36 percent of rainfall and thus decrease stormwater peak and flow (Seitz and Escobedo 2008; Xiao *et al.* 1998). The interception of stormwater by a tree, however, is dependant on the species, leaf type, leaf amount, density, and climate (Wang *et al.* 2008; Xiao *et al.* 1998). Changing these variables also influences a tree's performance with respect to other stormwater functions like storage, infiltration, evaporation, and runoff (Seitz and Escobedo 2008). Although i-Tree Hydro[R] now accounts for some of these variables (i.e., species, leaf type and amount, density, and climate), much of the data required is difficult or costly to access. Even when they are available, a model like this requires very detailed inputs to calculate an urban forest's performance in regard to stormwater. In support of the UFBM's objective to use simple and readily available inputs, the literature was therefore used to make an informed assumption about an urban forest's performance in regard to stormwater. This estimate was used to decipher the weight of the tree cover criterion for use in the weighted linear combination method to establish the stormwater score.

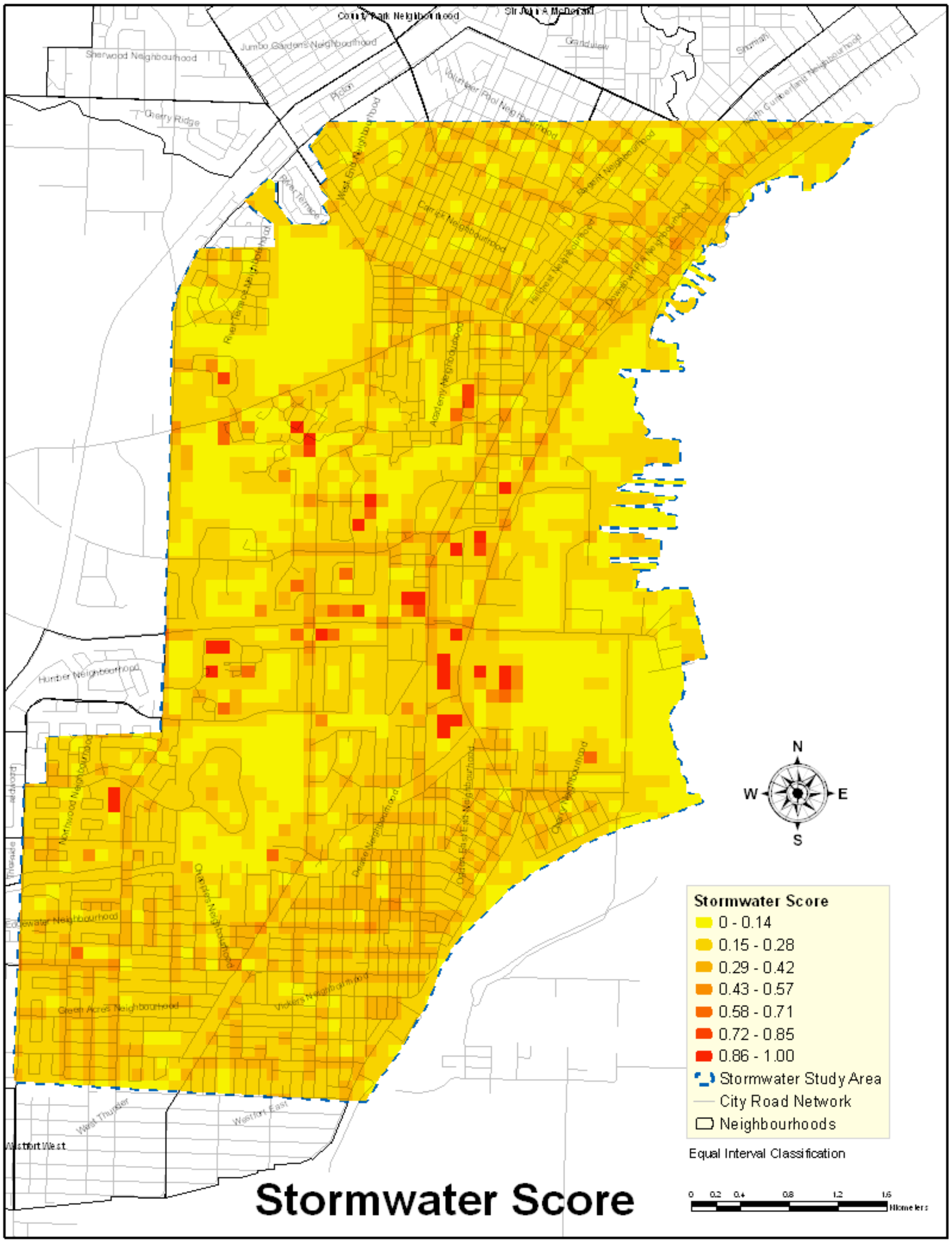

Figure 4.16. A map displaying the values of stormwater score for each management area for most of the City of Thunder Bay. Each grid cell represents 1 hectare. Management areas tending toward the colour red are a greater priority for greening.

As previously discussed, the weighted linear combination method is a common way of computing an index value for a vector-based model (Chang 2010) and involves evaluation at three levels: criterion weights, data standardization, and data aggregation. The relative importance for each criterion was evaluated against the other criterion. Based on the literature, tree cover was estimated to provide ameliorating services of approximately 16 percent, and was given a weight of 0.1. Conversely, the impervious cover was considered to be six times as important and was given a weight of 0.6.

The amalgamation of both tree cover and impervious cover layers using the weighted linear combination method produced a stormwater score for the city ranging between 0 and 1.0. The highest numbers indicated areas for priority greening. A management area with a score of 0 would typically have little to no impervious surface, and/or a large part of the management area with tree cover. A management area of 1.0 would be indicative of an area with large amounts of impervious surface and likely little to no tree cover.

The entire stormwater study area contained 22 management areas that were in the top 10^{th} percentile (a score of 0.9 and above). Of the 22 management areas, 15 were located in the inter-city region, three in the Ogden East End Neighbourhood, two on Lakehead University property, and two in the Northwood Neighbourhood. It is worth noting that none of the management areas in the top 10^{th} percentile were found in Thunder Bay North or north of Oliver Road. Within the top 25^{th} percentile were 31 management areas. The nine management areas found between 25^{th} and 10^{th} percentile (a score between .75 and 0.9) were primarily located in the inter-city region (five) with the exception of two more near Lakehead University and two in the Academy Neighbourhood. Neighbourhoods with the highest average stormwater score were Intercity (See "D" on Figure 4.12), Westfort East, and Vickers at 0.28, 0.27, and 0.27 respectively. River Terrace, Charry, and West End Neighbourhoods ranked the best with scores 0.13, 0.20, and 0.21 respectively.

4.2.4 Discussion and Recommendations for Planting Locations

In managing stormwater, impervious cover is the element that influences stormwater damage and costs the most (Wissmar, Timm, Logsdon 2004). For this reason, greening activities have been prioritized in areas that have a large percentage of impervious cover. It is recommended that if the City of Thunder Bay were to focus on stormwater as a sole task (not in conjunction with the other tasks) then it should target the most critical stormwater management areas (Figure 4.17).

Recent approaches to stormwater management have been largely focused on 'end-of-pipe' solutions, which are largely ineffective (Goonetilleke *et al.* 2005). A more comprehensive understanding of stormwater management is now focusing on the source controls because it is the most successful and least costly intervention. Properly placed green infrastructure is a valuable source control that manages rain on-site or close to where it falls. Tree cover has been shown to be most effective in reducing runoff for low intensity and short duration precipitation events. The largest pollution runoff is caused by short rain events and therefore trees should be seen as a tool that is more effective at managing water quality over storm flow (Xiao

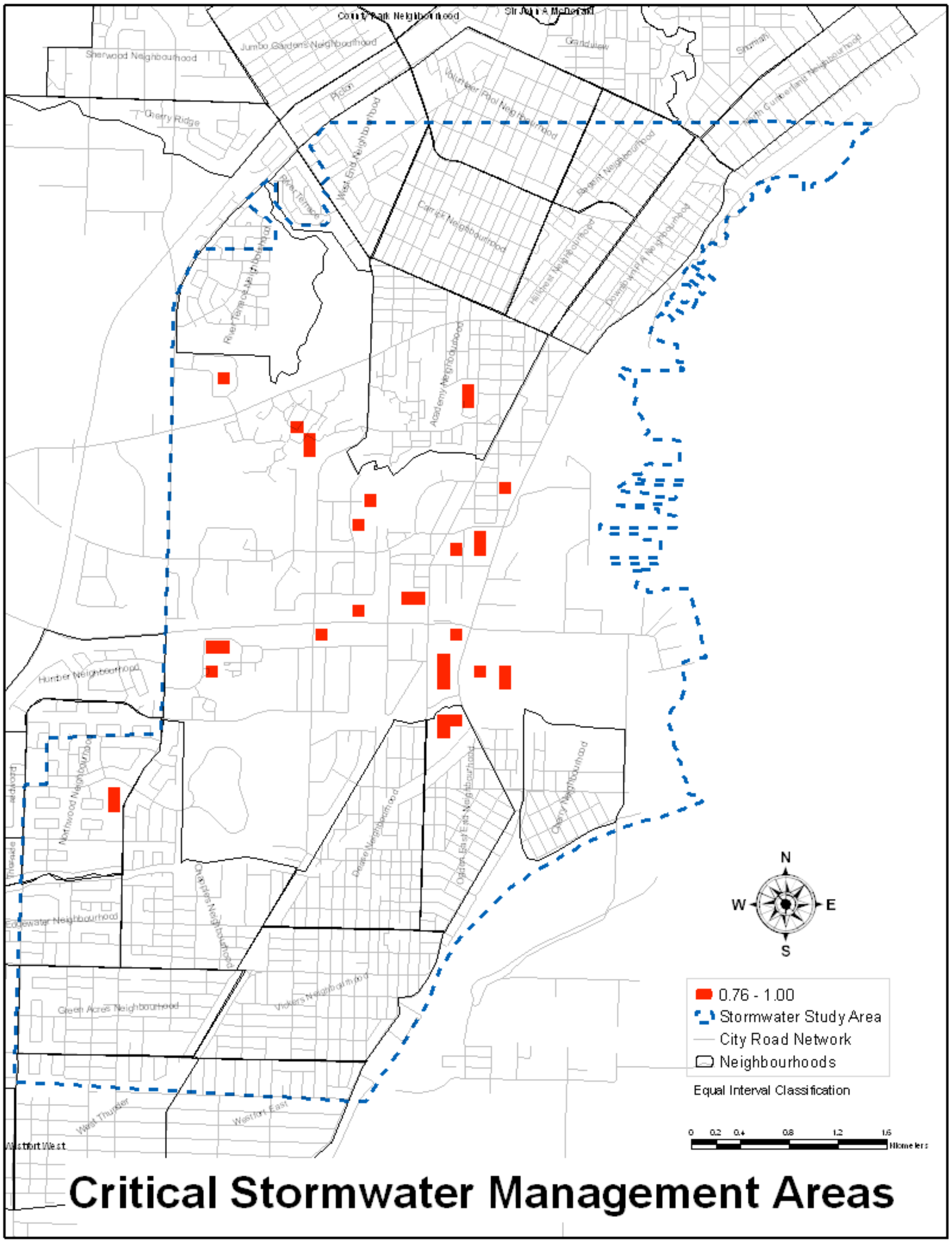

Figure 4.17. Twenty two stormwater management areas identified as critical priority with a score between 0.76 and 1.0.

et al. 1998). However, it is recommended that the City of Thunder Bay use and promote the use of green infrastructure in conjunction with other source controls, such as tree bioretention areas, vegetative filter strips, and soakaways in these critical areas so as to give more opportunity for trees to manage flooding. In the event stormwater was the sole task targeted in this model, the inter-city region should be given priority, based on the industrial and commercial land-use, and given that this region contains the six most urgent stormwater management areas. It would also help to mimic pre-development hydrologic conditions in these heavily industrialized areas.

Future research should integrate other spatial data such as point and non-point pollution and flooding densities, if available within a community to provide further direction with respect to greening. An increase in input data would provide more valuable decision-support for offsetting the damages caused by stormwater in a community.

4.3 Standard Task 2: Priority Planting Index

4.3.1 Task Objectives

The objective of task two was to reproduce the Priority Planting Index (PPI) in Thunder Bay. The PPI is an index developed by researchers at the US Forest Service Northeastern Research Station (Nowak *et al.* 2002) that ranks tree planting locations based on population densities, tree stocking, and trees per capita. The intended results lead to a priority-planting scheme to increase tree cover so as to benefit the greatest number of people. A variety of municipalities have used the PPI since its conception, providing recommendations for targeting planting locations in highly populated areas. Due to its wide acceptance and use by large and small municipalities alike, and its application in a variety of studies (Raciti *et al.* 2006; Morani *et al.* 2010), it was included in the UFBM as a standard task.

4.3.2 Modeling Approach

Three variables are used to calculate the PPI (population density, tree stocking, and trees per capita), following the approach of the USDA Forest Service (Nowak *et al.* 2002). A variety of data were needed to calculate these three variables. Data already processed and obtained for the stormwater task (tree canopy summaries, pervious cover summaries) were used, along with other new data types such as the 2001 Census of Population (Statistics Canada 2001). A complete list of data requirements is found in Table 4.1. The developed approach used to calculate the PPI is comprised of eighteen (18) key steps and is shown in Figure 4.18 and discussed beginning with section 4.3.2.1.

The values of the PPI range between 0 and 100, with higher values indicating a higher priority for planting in a particular area. Each input variable was standardized on a scale of 0 to 1, with 1 representing the management area with the highest priority for planting (i.e., areas with high population densities, low tree stocking levels, and few trees per capita). Individual scores were then combined with the following formula developed by the USDA (Nowak 2002):

Equation 4.5

$$I = (PD \times 40) + (TS \times 30) + (TPC \times 30)$$

Where I = priority planting index value, PD is *standardized* population density, TS is *standardized* tree stocking, and TPC is *standardized* tree cover per capita[2]. The numerical coefficients in the above equation indicate the relative weighting of the three variables to the overall PPI, noting the slight emphasis placed on the population density variable (40%). The population density variable is measured in order to determine which areas would benefit the most number of people. The tree stocking variable is a measure of available greenspace in order to determine if there is room to plant new trees. That is, if there is an area with high population density, tree stocking provides an indication if trees can be planted in the region. Standardized tree cover per capita is a measure of tree cover per person. It provides an indication of existing tree cover, and demonstrates if highly populated areas are currently well treed (not taking into account tree stocking).

The PPI was intended to determine the score per census tracts. However, to be consistent with the size and boundary of areas that the results would be presented in at the end of each task and the final layout within UFBM (see 4.2.2.1 in the stormwater task for further discussion about management areas), the data from the census tracts were further transferred down into 100m by 100m management areas (a grid resolution of 100m, an area of 10,000m^2 or 1ha). The methods required for this step will be further discussed in below.

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[2] The tree input variable were standardized in an identical approach to that discussed earlier for the stormwater management task – see equation 4.2 and 4.3.

The following section provides a detailed description of the methodology used in developing the PPI, including a discussion of GIS operations and equations used, data requirements, and simplifying assumptions. The discussion is organized into three sections based on the stages shown on Figure 4.18: (1) population density (Stages 1- 7); (2) tree stocking (Stages 8-12); and (3) tree cover per capita (Stages 13-16).

4.3.2.1. Population Density

To determine population density, the 2001 Canadian Census (Statistics Canada 2001) was obtained from an online source (Statistics Canada 2001) and imported into ArcGIS and converted into UTM (Stage 1 and 2 in Figure 4.18). The population attribute within the 2001 census data was the sole attribute required for this task. The area and resulting population density were calculated for each dissemination area (DA) using a simple equation (population divided by area) in ArcGIS' attribute table (Stage 3 and 4 in Figure 4.18) (Figure 4.19). As discussed above, the vector grid with a grid resolution of 100m was imported (originally created in the stormwater task via Hawth's Analysis Tools) into the project (Stage 5 in Figure 4.18) to present the final population densities within the standard 100 x 100m management areas. Overlay tools within ArcGIS present a typical problem in polygon-to-polygon translations. When merging or translating statistics represented in a polygon layer (the "summary" layer) to a polygon that has different border (the "zonal" layer), a variety of methods exist that provide different results (see Figure 4.20). For example, a standard intersect selection method such as "completely within" calculates the area of zonal polygons that are completely within the summary polygon. This methods also produces different results than, for example, the "touch the boundary" method.

The various standard selection methods were not ideal to calculate population density because of their imprecision. Alternatively, Hawth's Polygon to Polygon Analysis tool was used for its accuracy in statistical translation. This tool uses a weighted mean approach, which means it has the ability to derive a weighted mean statistic from each polygon in the summary layer that overlaps a zonal polygon. It then generates the weighted mean of the summary layer and writes it to a new field in the zonal layer (Stage 6 in Figure 4.18)(see Figure 4.21).

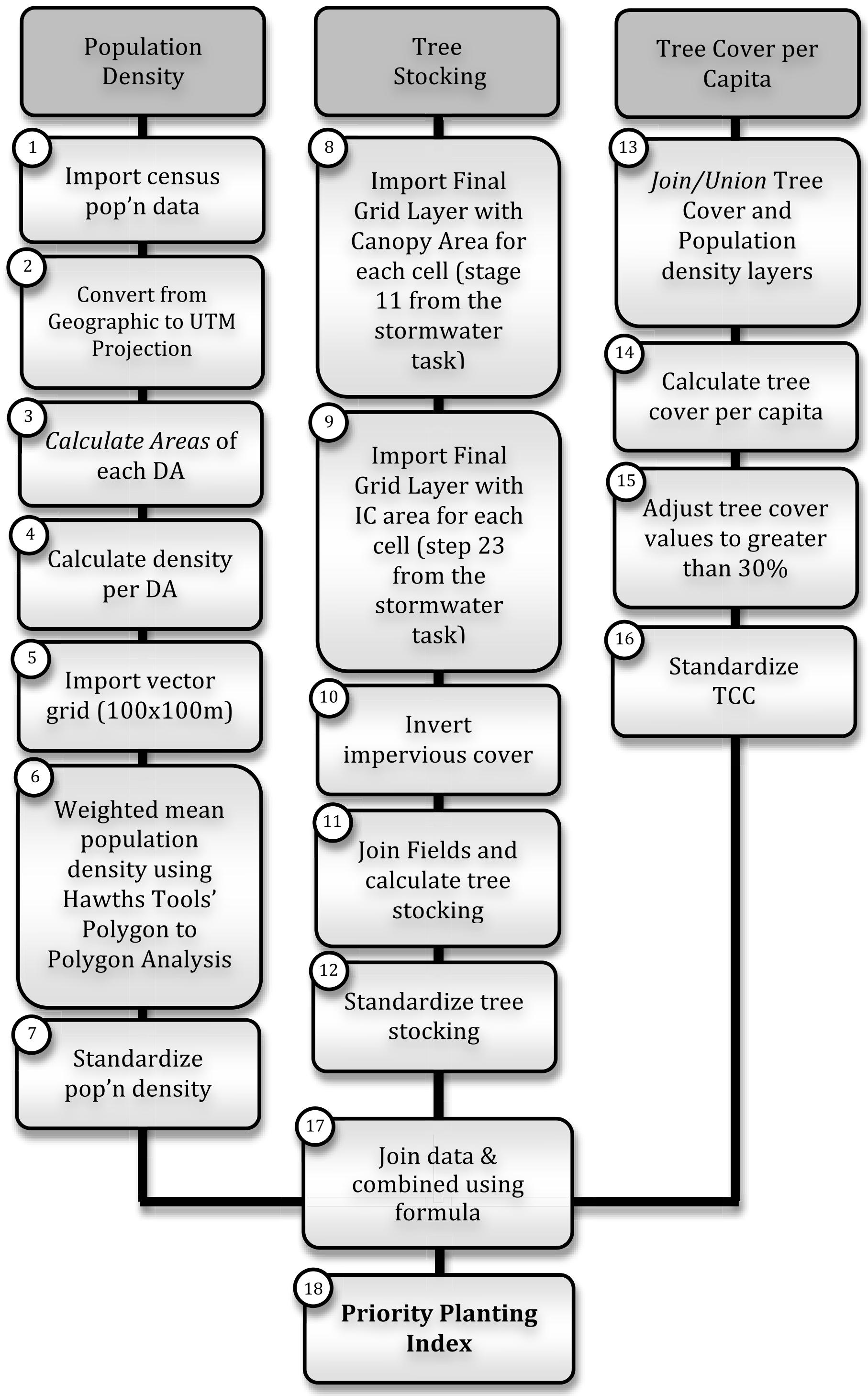


Figure 4.18. Conceptual diagram of the GIS steps used in the Priority Planting Index task, which involves the analysis of three variables: population density, tree stocking, and tree cover per capita. Numbered boxes are the specific stages in the developed methodology discussed in the text.

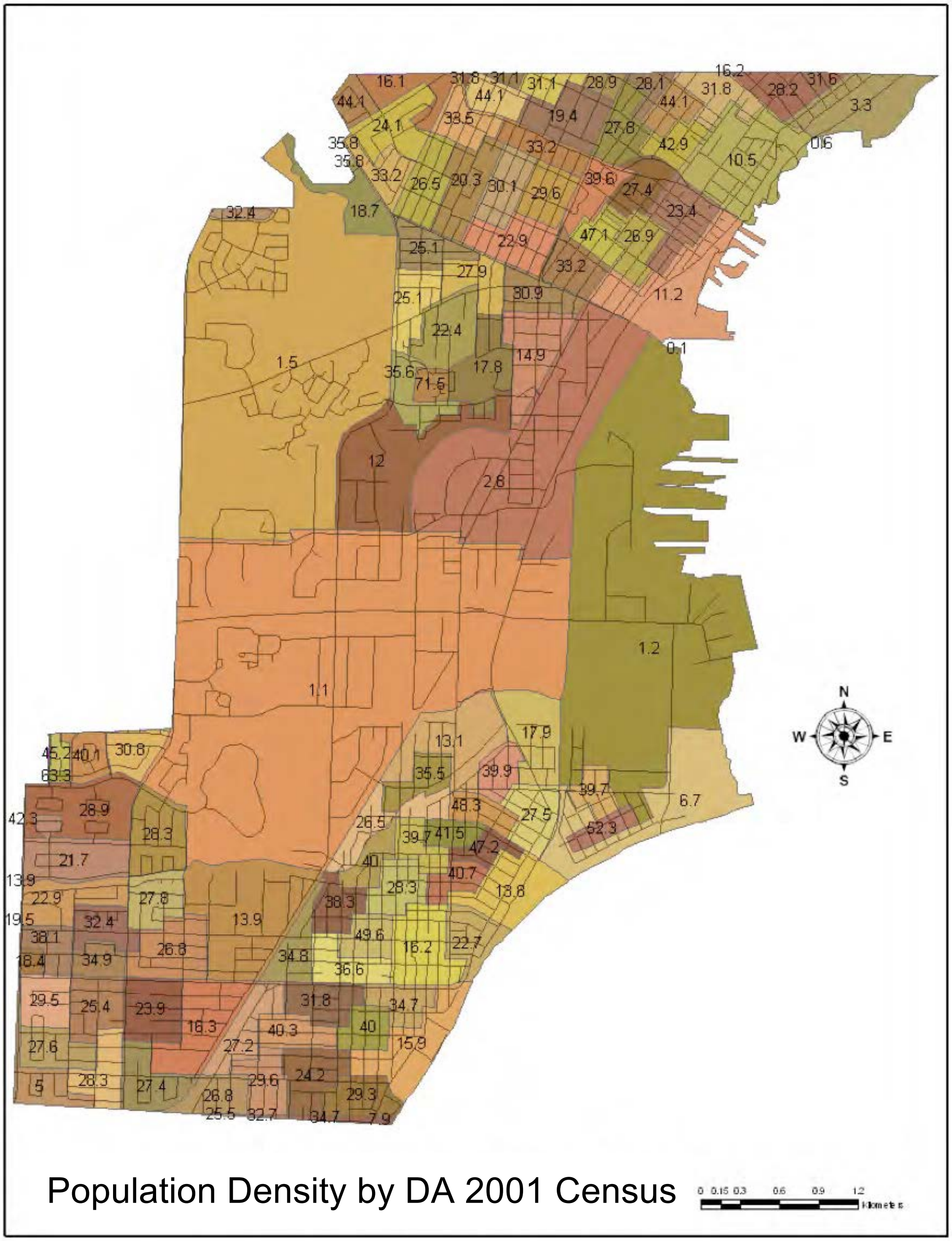


Figure 4.19. A map of the PPI study area displaying the population density summarized in dissemination areas. Density (per/ha) values are labeled to its corresponding dissemination area.

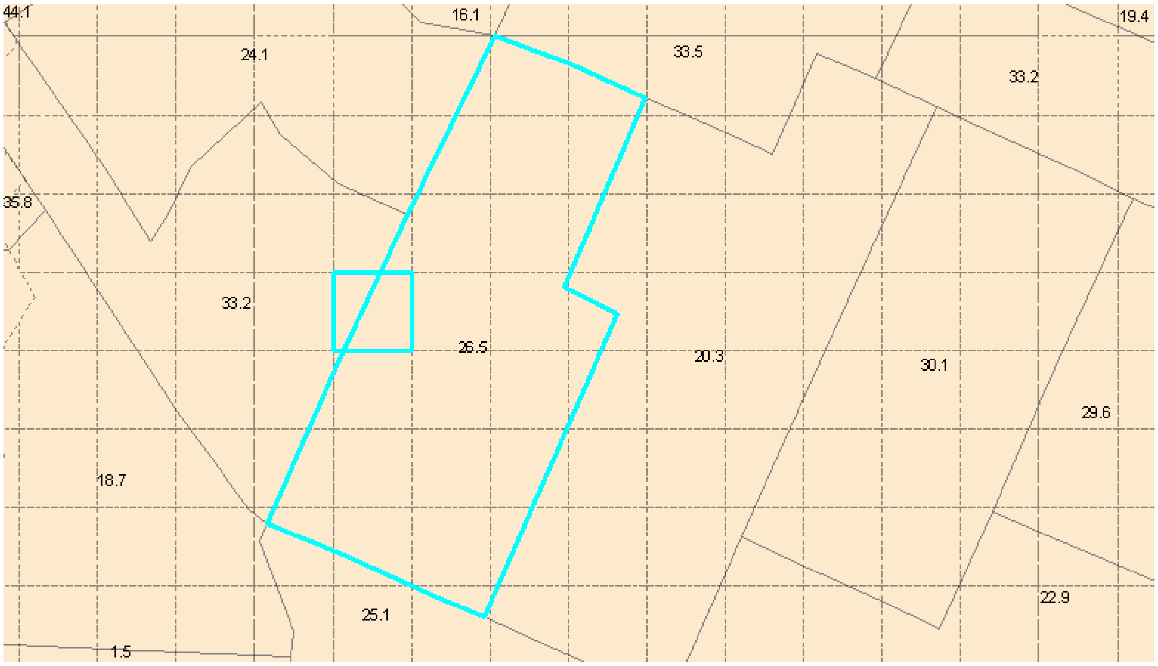


Figure 4.20. The summary layer (large blue polygon) is summarized into the zonal layer (small square polygons). Bordering polygons like the small square zonal polygon (highlighted) above demonstrates the problems associated with summarizing the summary layer into the zonal layer accurately. Some intersect methods (e.g., "have their centroid within") would give the zonal polygon a value of 26.5, while others (e.g., "completely contain") would not provide a value at all, because it is outside the zonal polygon. Other methods would allocate a value of 33.2 (adjacent summary polygon) to the zonal polygon. The various types of selection methods in ArcGIS were not adequate for accurately translating a statistic from one layer to another.

The weighted mean population density generated from Hawth's Tools is then standardized on a scale between 0 to 1, where the higher the density, the greater the priority for planting (Figure 4.22). The standardization followed Nowak's *et al.* (2002) PPI formula:

Equation 4.6

$$PD = \frac{(n - m)}{r}$$

Where, PD is the standardized value (0-1), n is the value of the population density

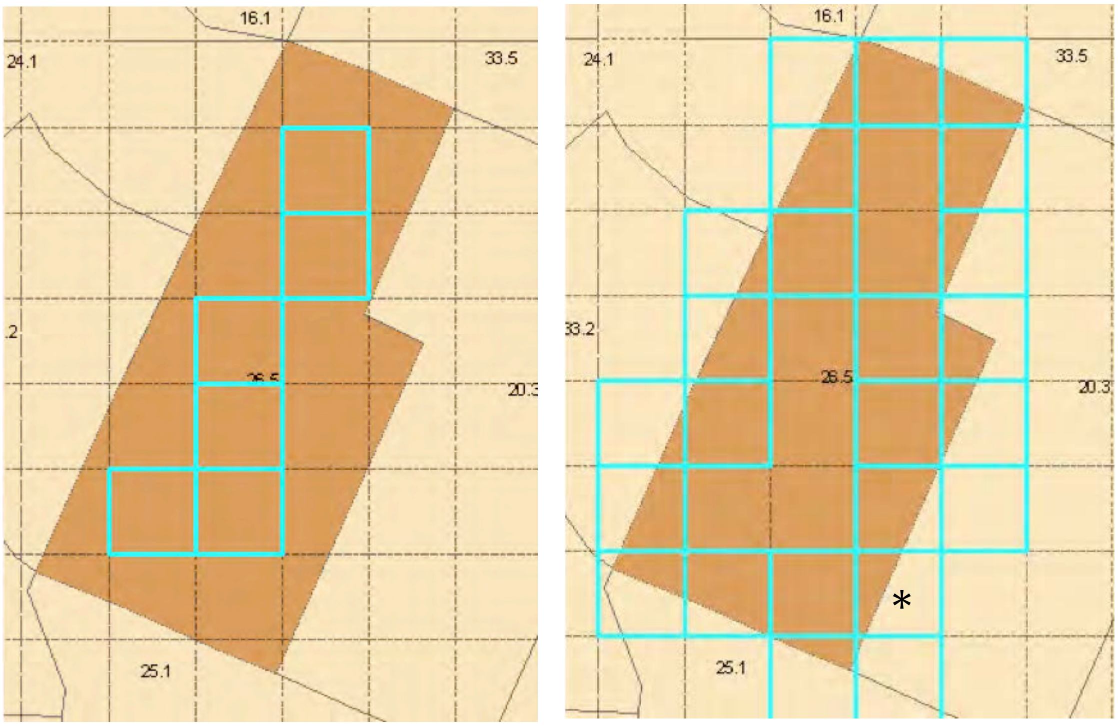


Figure 4.21. Polygon to Polygon Analysis tool performs a weighted mean calculation and assigns the zonal polygons (highlighted cells on left figure) 100 percent of the value of the summary polygon (dark brown polygon). In this scenario, the zonal polygons highlighted on the left figure would be assigned a density of 26.5 people/ha because they are entirely within the summary polygon boundary. The right figure demonstrates the zonal polygons (highlighted cells) that would undergo a weighted mean calculation that accounts for the proportion of area that the zonal polygon is overlaying on a summary polygon. For example, if 40 percent of the zonal polygon fell within the summary polygon of 26.5 people/ha, and the remaining 60 percent fell within a polygon of 20.3 people/ha, the zonal polygon would calculate (0.40*26.5) + (0.60*20.3) and would assign a weighted value of 22.8 people/ha to that zonal polygon (see example polygon with asterisk).

for the census block (per/ha), m is the minimum value of population density for all census blocks, and r is the range of population density values among all census blocks (i.e., maximum value – minimum value). Density in this study was calculated in units person per hectare.

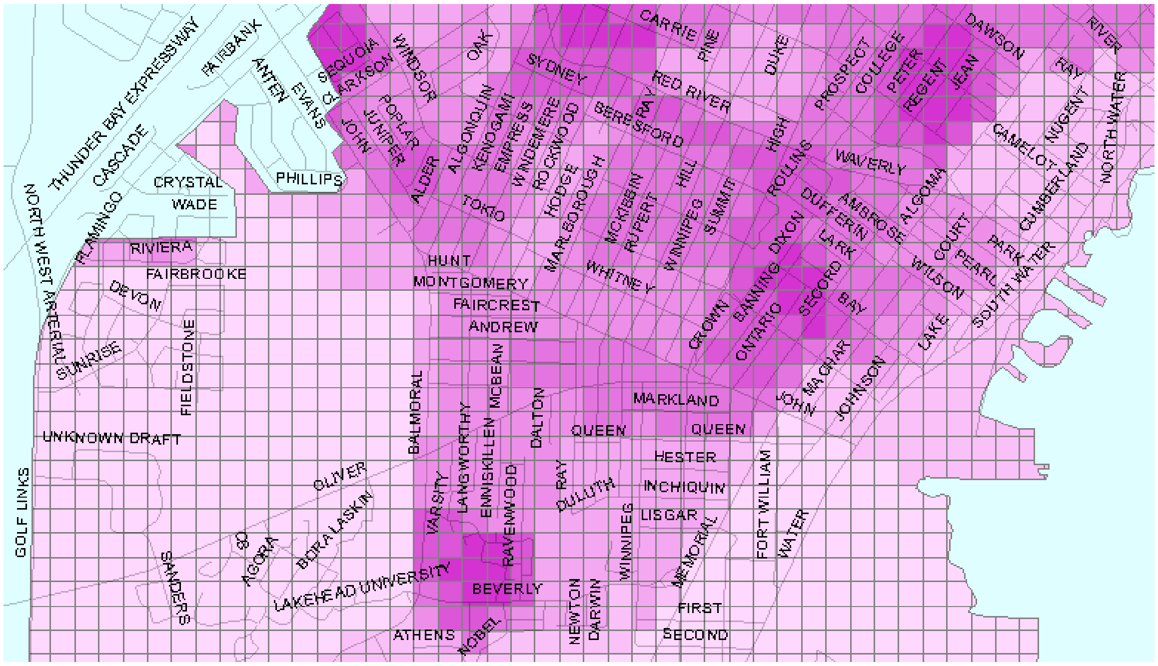


Figure 4.22. A screenshot from ArcGIS displaying the values of the population density variable summarized in each management area. Each grid cell represents 1 hectare. Dark purple indicates a high population density and a greater priority for planting.

4.3.2.2. Tree Stocking

Tree stocking is defined as the percentage of available planting space that is occupied by a tree and therefore varies from value of 0 to 100. Values of 100 would suggest that all available planting space has been utilized for trees. Within the PPI, the lower the tree stocking level, the greater the priority for planting. To determine the area of plantable space, the impervious cover and tree cover results from the stormwater task (Stages 11 and 23 in Figure 4.2) were imported (Stage 8 and 9 in Figure 4.18). The impervious cover was imported so the inverse could be taken from the results (i.e., the amount of pervious land cover) and then used a surrogate estimate for plantable space (Stage 10 in Figure 4.18). The amount of pervious land area provides an estimate of greenspace, which includes areas such as residential lawns, parks, and grassed boulevards (however, it only provides an estimate of greenspace because not all pervious surfaces can be considered plantable because of their proximity to utilities, sidewalks, and buildings). It does not include impervious cover elements such as building footprints, paved sidewalks/boulevards, paths, driveways and parking lots. As discussed in the stormwater task chapter, for the purpose of this research all unpaved layers were considered pervious. In reality, some unpaved surfaces function like that of a paved surface, due to their compaction or fine granular size (such as a gravel driveway). However, without supplementary data, the assumption was made that all unpaved areas were pervious. As discussed earlier in Section 4.2.2.2, an error of approximately three percent was calculated in the classification process of pervious and impervious cover for one test cell and is a reflection of the error existing in this classification process.

The pervious cover results were joined with the tree cover area results imported from the stormwater task so that the tree stocking variable could be calculated (Figure 4.23). The tree stocking and normalizing formula based on Nowak's *et al.* (2002) – see below – were used (Stage 11 and 12 in Figure 4.18):

Equation 4.7

$$TS = \frac{(100 - (\frac{T}{T+G}) \times 100)}{100}$$

where TS is the standardized value for tree stocking (0-1), T is percent tree cover, and G is percent grass cover.

The PPI study area was dependant on the public and private tree inventory (as discussed in chapter 3). Due to the financial constraints that limited the private tree inventory to about 65 percent of the City's area, the PPI study area, like that of the stormwater study area, were also limited to this same extent.

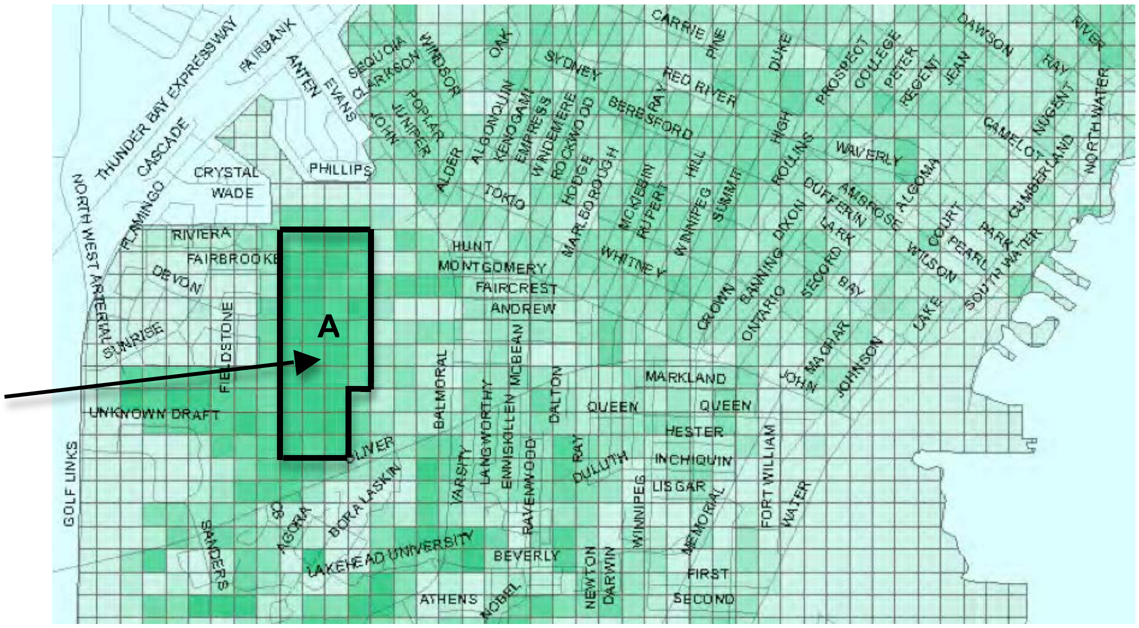


Figure 4.23. A screenshot from ArcGIS displaying the value of the tree stocking variable for management areas on the City's north side. Each grid cell represents 1 hectare. The lighter shades indicate management areas with lower levels of tree stocking, and therefore indicate a greater priority for planting. The arrowed polygon labeled (A) has adequate tree stocking (i.e., darker shades).

4.3.2.3. Tree Cover Per Capita

Tree cover per capita is determined by the amount of tree cover area divided by the population of a given area. Priority towards planting is assigned to those management areas having lower values of tree cover per capita. To determine tree cover per capita, both tree cover area and population density layers were joined using the *Union* tool in ArcGIS (Stage 13 in Figure 4.18). The tree cover per capita was calculated by grid cell (i.e., by management areas) in ArcGIS' attribute table using the following equation (Stage 14 in Figure 4.18):

Equation 4.8

$$\text{Tree Cover per Capita} = \frac{\text{Tree Cover (m}^2\text{)}}{\text{Population}}$$

At this point in the modeling process, the tree cover per capita would normally be standardized as was done in earlier tasks. However, the UFBM, which uses smaller areas (management areas of 100m resolution) compared to the areas used by Nowak *et al.* (2002) (normal census dissemination areas or census blocks), requires a process to adapt Nowak's *et al.* (2002) PPI method. When the polygon size gets reduced from a census block to 1 ha management area (like that used in the UFBM), the 1 ha areas are potentially consumed with entire forested regions that generally have very low populations. This leads to very high tree cover values per person (e.g., a management area in George Burk Park with 10 000 m^2 of tree cover and a density of 1.5 pers./ha resulted in a value of 6666 m^2/pers.), which skews the data significantly when attempting to standardize on a scale between 0 and 1. Nowak *et al.* (2002) would normally not get these kind of high tree cover per capita values because the census blocks (or DUs) used for urban settings were never consumed entirely with forest. For this reason, Nowak's *et al.* range for standardizing would be significantly smaller, and allow for a better final distribution of the data after the standardization step. Therefore to help correct this, a standard tree cover target was established at 30 percent cover, and all management areas with tree cover with 30 percent or more were given a maximum value of 30 (or 1 on the standardized scale) (Stage 15 in Figure 4.18). Many municipalities use tree cover targets between 25-40 percent (American Forest 2002; Librecz 2007), therefore 30 percent was deemed a suitable overall target for tree cover in Thunder Bay.

Standardized values for tree cover per capita were then calculated for the management areas using the formula presented in Nowak *et al.* (2002) (Stage 16 in Figure 4.18) (Figure 4.24):

Equation 4.9

$$V = 1 - \left(\frac{n - m}{r} \right)$$

where V is the standardized value, n is the value of tree cover per capita (m^2/person) for the management are of interest, m is the minimum value for all of tree cover per capita values, and r is the range of values among all tree cover per capita values (i.e., maximum value – minimum value).

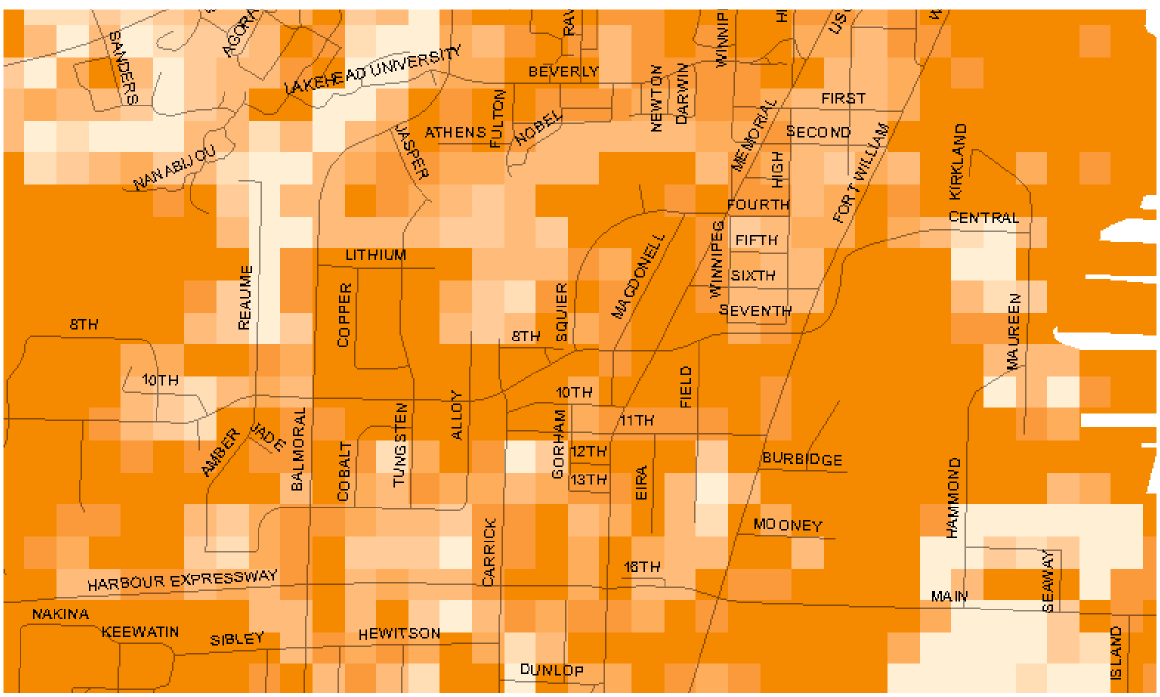


Figure 4.24. A screenshot from ArcGIS displaying the values of tree cover per capita variable for management areas in the intercity area of the City. Each grid cell represents 1 hectare. The darker shaded management areas have lower levels of tree cover per capita and hence, a greater priority for planting.

4.3.2.4. Priority Planting Index (PPI)

After each of the task variables has been standardized on a scale of 0 to 1, with 1 representing those management areas with the highest population density, lowest tree stocking density, and/or the lowest tree cover per capita, a final PPI score was determined by using the union or join tool in ArcGIS (Stage 17 in Figure 4.18). The following formula was used to produce an overall priority index value between 0 and 100 (Stage 17 in Figure 4.18):

Equation 4.10

$$I = (PD \times 40) + (TS \times 30) + (TPC \times 30)$$

Where I is the index value, PD is standardized population density, TS is standardized tree stocking, and TPC is standardized tree cover per capita. The next section provides a discussion of the results for each of the three variables contributing to the PPI as well as the combined index values.

4.3.3 Model Results

4.3.3.1. Population Density

The objective of the population density variable was to determine those higher density areas of the City that could be a priority for tree planting. Population density for the management areas (at a resolution of 1 ha) is depicted in Figure 4.25. Management areas in the Academy neighbourhood were found to have the highest densities with 71 persons/ha (four management areas in Figure 4.25), which has a concentration of multi-family dwelling units such as high rise apartments and townhouses. The least dense management areas were situated in the Intercity region which is primarily zoned as commercial (with densities less than 1 pers/ha) and light industry uses.

Neighbourhoods were also summarized according to population density (Table 4.4). The highest densities were in Hillcrest, Regent and Volunteer Pool neighbourhoods with an average of 32, 31.2, and 29.4 persons/ha respectively. The lowest densities were in the Intercity Mall area and in the River Terrace Neighbourhood with an average of 1.5 and 4.0 persons/ha respectively. According to Nowak *et al.* (2002), the higher the density, the greater the priority for planting.

The summary of neighbourhood averages seen in Table 4.4 were calculated using the intersect selection method within ArcGIS. This selection method selects the cells (management areas) if the neighbourhood polygon being summarized intersects any of the cells (management units) (see earlier Figure 4.13). This technique was chosen to ensure that all areas within the neighbourhood were included, especially arterial roads that could be lined with trees and large tracts of impervious cover (i.e., road). The neighbourhood zones in most cases followed arterial roads and therefore the intersect method provided a means to include these sections where otherwise they would be omitted if using the *contain*, *have their centroid in,* or *completely within* ArcGIS selection methods.

4.3.3.1. Tree Stocking

The main objective of the tree stocking variable was to estimate the percentage of available greenspace (tree, grass, and soil cover areas, i.e., pervious surface area) that is occupied by tree canopies. The results for the tree stocking variable for management areas at a resolution of 1 ha are shown in Figure 4.26.

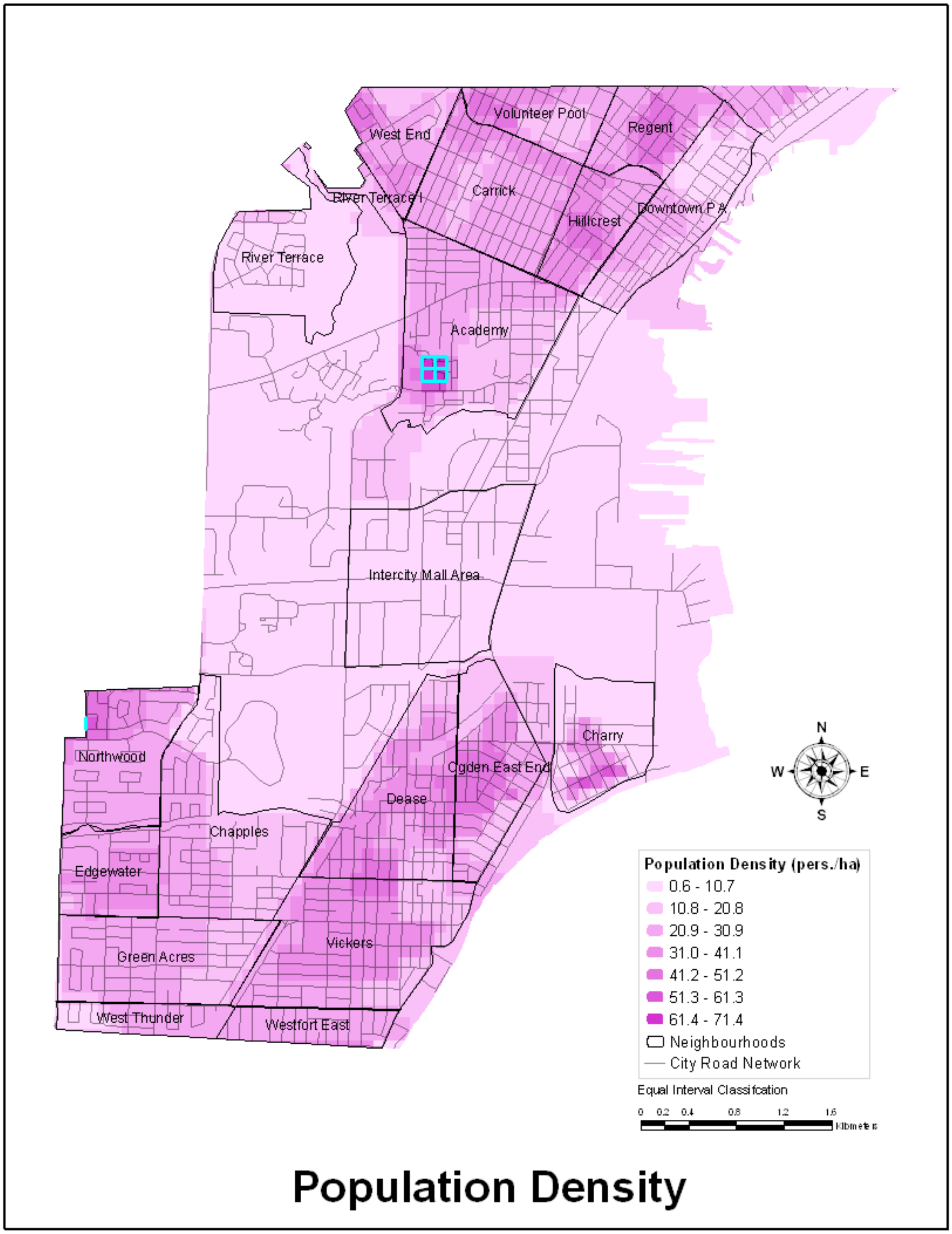


Figure 4.25. A map displaying the values of the population density variable for management areas for most of the City of Thunder Bay. Each grid cell represents 1 hectare. Dark purple indicates a high population density and a greater priority for planting. The highlighted cells (blue) indicate the management areas with the highest densities (approximately 71 persons/ha).

Table 4.4. Summary by neighbourhood of average population density (PD), average tree stocking (TS), average tree cover per capita (TCC) and average Priority Planting Index (PPI). Tree stocking, average tree cover per capita and Priority Planting Index results will be discussed in sections 4.3.3.2, 4.3.3.3 and 4.3.3.4 respectively.

Neighbourhood	Neigh-bourhood Area (ha)	# of Grid Cells[2]	PD (pers./ ha)	TS (%)	TCC (m^2/pers.)	Avg. PPI
Academy	171	206	22.0	15.7	72	45.9
Carrick	120	152	27.8	16.3	52	49.7
Chapples	148	239	17.6	6.5	58	40.9
Charry	79	105	12.1	7.1	179	36.8
Dease	129	158	29.1	10.1	33	48.7
Downtown PA	91	126	16.6	6.4	37	40.5
Edgewater[1]	102	82	27.9	7.5	24	47.4
Green Acres	118	145	22.9	8.6	34	44.8
Hillcrest	59	80	32.0	11.8	32	51.1
Intercity Mall Area	211	211	1.5	3.8	228	29.3
Northwood[1]	132	130	29.3	9.4	37	48.6
Ogden East End	91	122	27.4	6.8	24	46.9
Regent [1]	68	81	31.2	11.7	34	50.4
River Terrace[1]	120	143	4.0	33.6	1333	28.6
Vickers	161	198	28.7	11.2	35	48.9
Volunteer Pool [1]	133	75	29.4	12.9	43	49.6
West End *	84	86	27.3	13.1	44	48.5
West Thunder[1]	155	62	20.9	7.8	49	43.3
Westfort East[1]	131	58	28.3	6.3	1122	47.0
Total Average	**118**	**141**	**22.9**	**10.8**	**183**	**44.5**
Total Entire Study Area	**3209**	**3427**	**14.4**	**9.7**	**212**	**37.2**

[1] Only a portion of the neighbourhood was analyzed because part of the neighbourhood fell outside the study area.
[2] This is a count of full and partial grid cells intersecting each defined neighbourhood.

Forested regions within the City scored high in tree stocking because these areas contain close to 100 percent canopy cover. A total of 41 management areas having tree stocking value greater than 85% are scattered around the study area, with some concentrations of these in and around the River Terrace and Academy

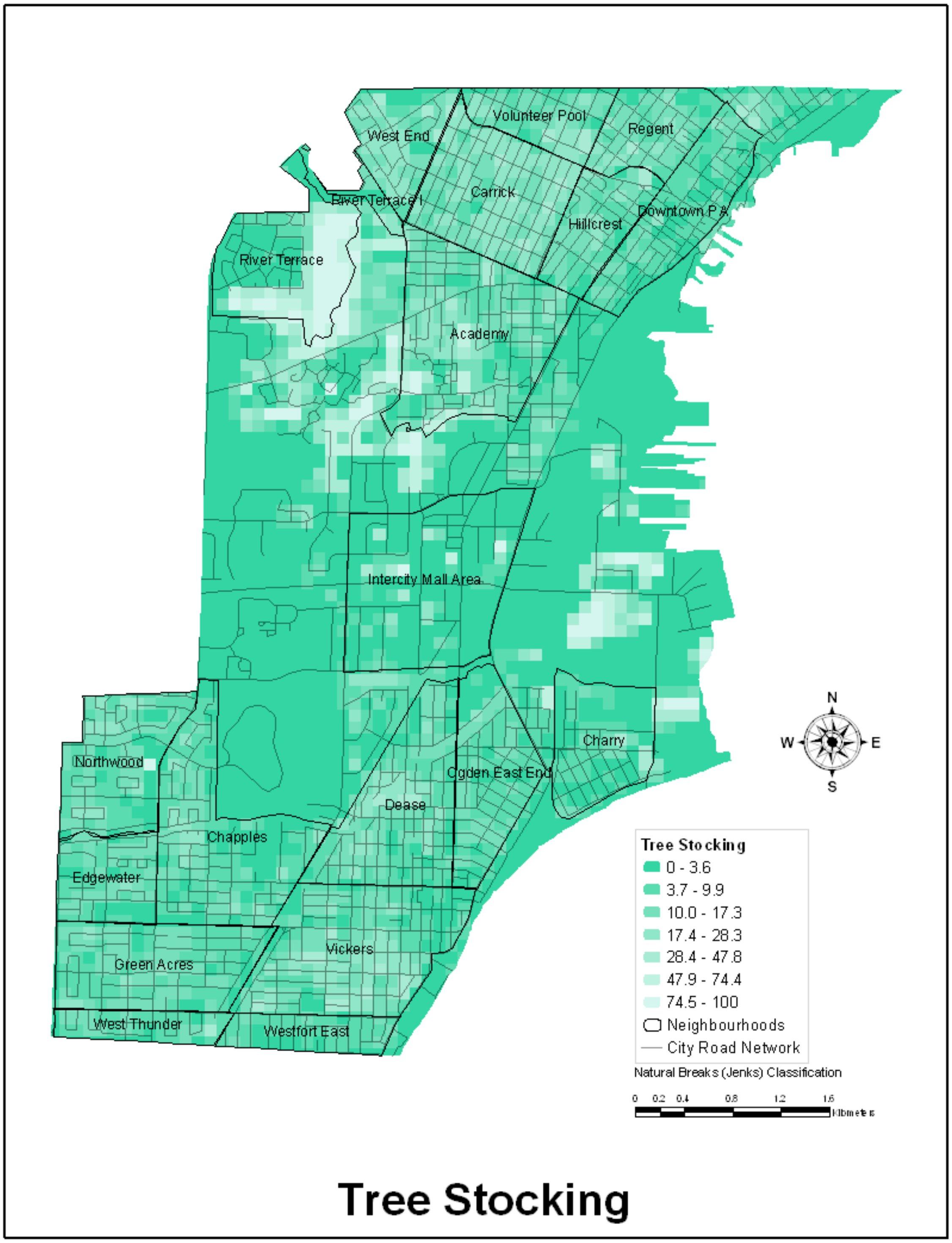


Figure 4.26. A map displaying the values of the tree stocking variable for each management area for most of the City of Thunder Bay. Each grid cell represents 1 hectare. The darker shaded management areas have lower tree stocking levels and hence, a greater priority for planting.

neighbourhoods and at Lakehead University. Some 880 management areas having low tree stocking values (<3.6%) were scattered across the city, however most were concentrated in the Intercity and industrial zones (Figure 4.26). A summary of tree stocking per neighbourhood (Table 4.4) demonstrates that the Intercity Mall Area, Westfort East, and Downtown Port Arthur had the lowest tree stocking levels at 3.8, 6.3, and 6.4 percent respectively. River Terrace, Carrick, and Academy neighbourhoods had the highest level of tree stocking with 33.6, 16.3, and 15.7 percent, respectively. A summary by neighbourhoods in this instance is misleading, where large tracts of unforested (low stocking) areas can be skewed by adjacent forested land (high stocking) within the same neighbourhood boundary. The boundary for River Terrace includes large tracts of forested land (nearly 50%), which increases its average stocking value when the neighbourhood is averaged as a whole. A closer look at the inhabited section of the neighbourhood demonstrates that in fact many areas with low tree stocking exist with most management areas in the western portions of the River Terrace neighbourhood with a tree stocking of <3.6% (Figure 4.26). Therefore, the neighbourhood summary results provide a general overview and indication of the average results, however it should be noted that the individual management areas are the intended focus for supporting decision makers in their greening activities.

4.3.3.2. Tree Cover per Capita

The objective of tree cover per capita variable was to determine those areas of the City with lesser amounts of tree canopy cover per capita (m^2/capita), that are a greater priority for planting. The results for the tree cover per capita variable were summarized in management areas at a resolution of 1 ha and are shown in Figure 4.27.

As discussed earlier, the management areas used in the UFBM are much smaller units than the census blocks used by Nowak *et al.* (2002). To reduce some of the skewing as a result, a 30 percent canopy target was established. Even with the established 30 percent target, many management areas with high tree cover (up to 30%), and low population densities created many low results as pertaining to tree cover per capita (Table 4.4). The lowest results were from Ogden East End, Edgewater, and Westfort East neighbourhoods. These neighborhoods scored low because a majority of the management areas contained little to no tree cover, in conjunction with their being of moderate to high population density (which would result in a low score). These areas, none-the-less, are key focal points for tree planting if one considers just the tree cover per capita variable. Neighbourhoods with the highest values of tree cover per capita were River Terrace and Intercity Mall area with 1333 and 228 m^2 per capita, respectively. River Terrace resulted in a score of 1333 m^2 per capita because it contained almost equal the amount of management areas with little to no tree cover as it did fully forested regions. The forested regions generally had very little population densities (and resulted in a high score). In contrast, the equal amount of management units with little tree cover contained high populations and resulted in a low tree cover per capita score. The Intercity Mall area also contained a variety of forested areas that exhibited low population densities. This resulted in slightly higher results when compared to

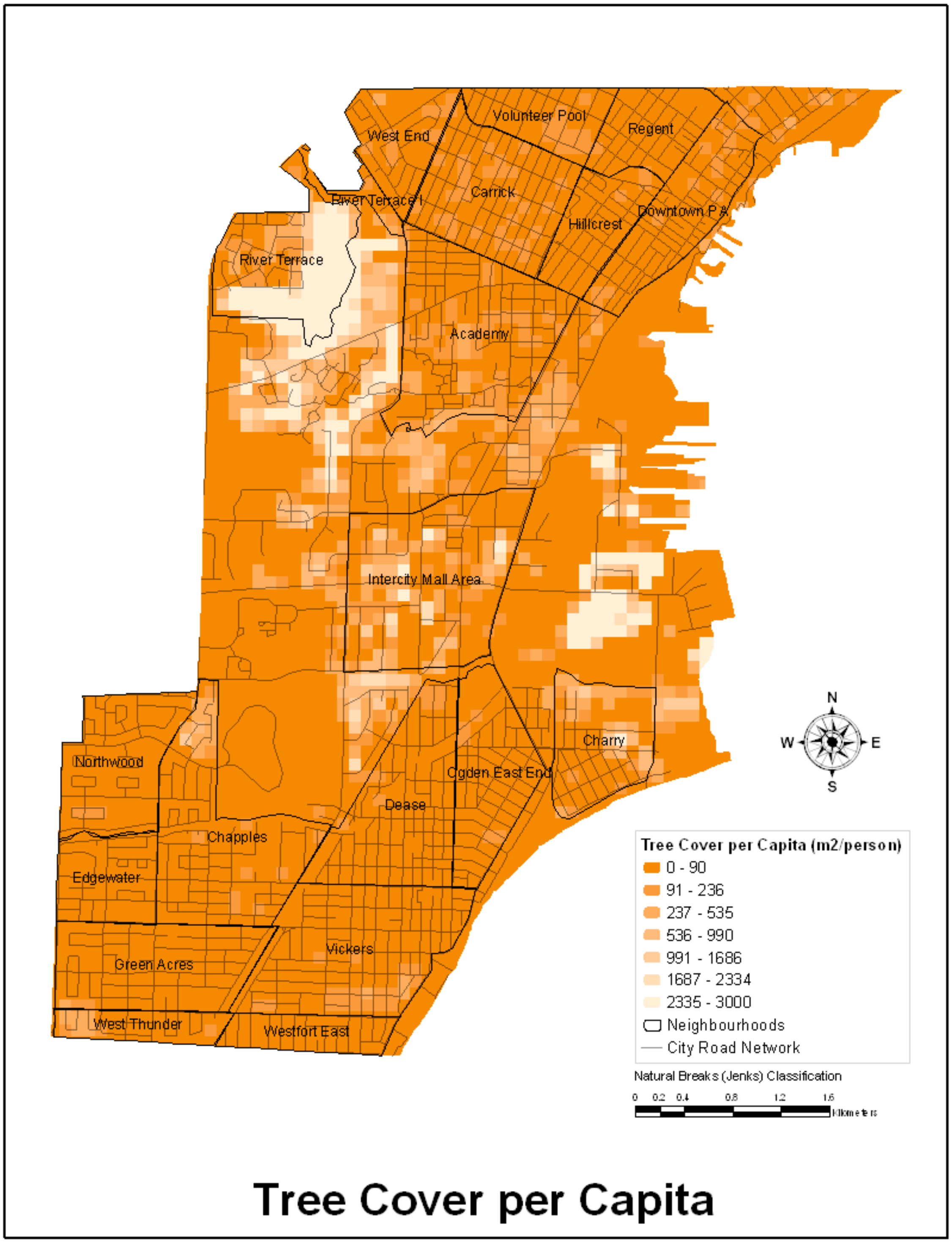


Figure 4.27. A map displaying the values of tree cover per capita variable for each management area for most of the City of Thunder Bay. Each grid cell represents 1 hectare. The darker shaded management areas have lower tree cover per capita levels and hence, a greater priority for planting.

more populated neighbourhoods like the Volunteer Pool and Academy neighbourhoods. It should be noted that the summaries of neighbourhoods are averages, and individual management areas should be focused on for greening. The implications of these results will be further discussed in Section 4.3.4.

4.3.3.3. Priority Planting Index

The Priority Planting Index (PPI) is the combination of the three previous variables (population density, lowest stocking density, and lowest tree cover per capita) using the formula developed by Nowak *et al.* (2002) (see equation 4.5). The results for the PPI for management areas at a resolution of 1 ha in size are shown in Figure 4.28 and denote the relative priority for greening.

The five management units with the highest index values across the study area were located in the Academy (4) and Northwood (1) neighbourhoods and ranged from 80 to 70 respectively in their index scores (see arrows “A” in Figure 4.28). The lowest index values were concentrated in the Intercity area and ranged in score between 10 to 12 (see “B” in Figure 4.28). Neighbourhoods were also summarized by average index values. The highest index value (highest priority to plant) is Hillcrest, Regent and Carrick neighbourhoods with index values of 51.1, 50.4, and 49.7, respectively. These neighbourhoods ranked highest due to their dense populations and available greenspace for planting in these areas. River Terrace, Intercity Mall Area, and Charry, ranked the lowest average index score at 28.6, 29.3 and 36.8, respectively. These neighbourhoods ranked lower because of low population densities, higher tree stocking densities, and higher tree cover per

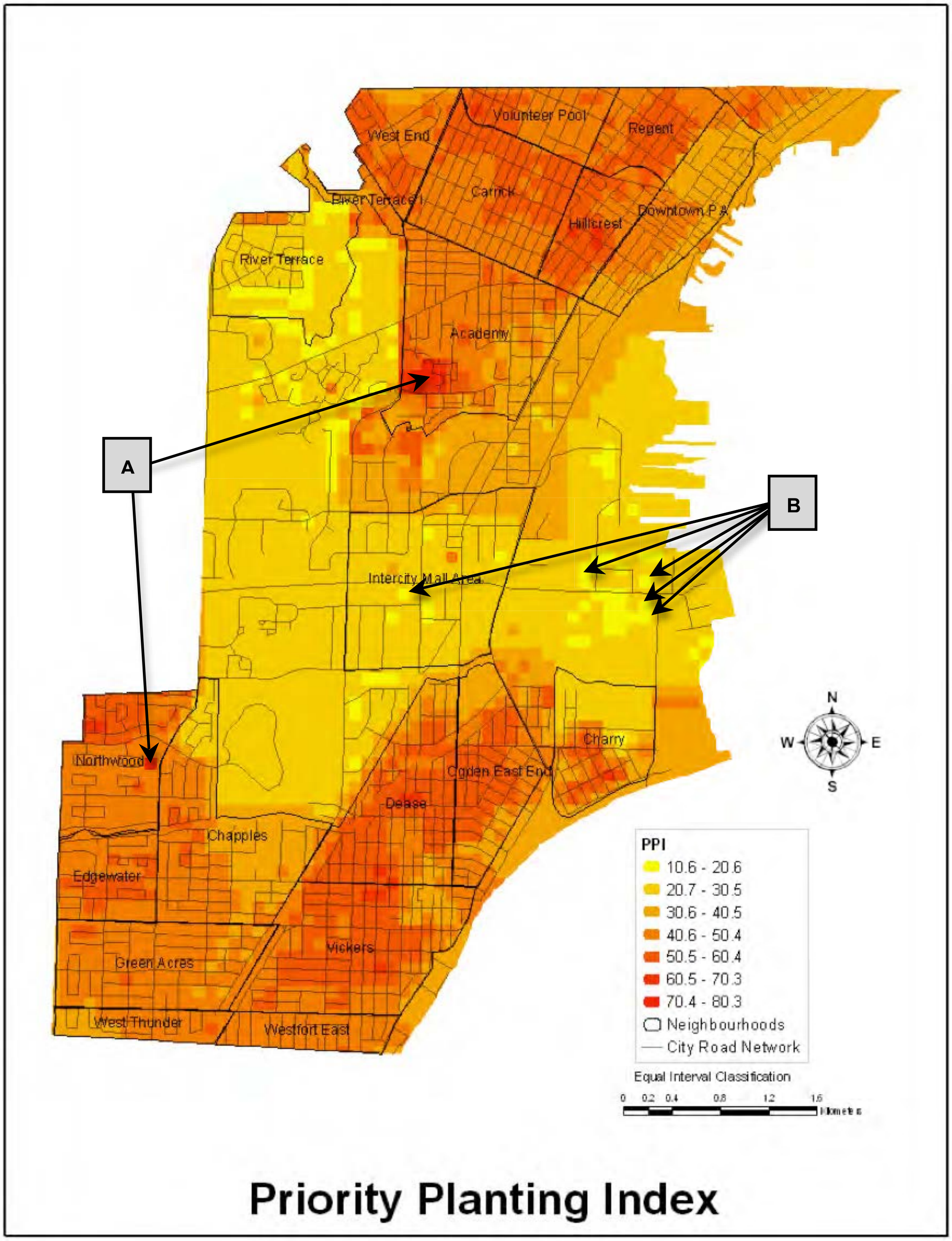


Figure 4.28. A map displaying the Priority Planting Index for management areas for most of the City of Thunder Bay. Each grid cell represents 1 hectare. The darker shaded management areas have lower PPI scores and hence, a greater priority for planting. Labeled forested regions (A,B) are discussed in the text.

capita values. River Terrace especially ranked low in part because its boundaries included large tracts of greenspace, which would significantly increase its overall tree stocking densities (33.6 percent), giving it the appearance that it does not require more trees. Similarly, Charry had a low population density (its border extends beyond the developed neighbourhood) which resulted in a low PPI.

4.3.4 Discussion and Recommendations for Planting Locations

The literature has demonstrated that trees are a significant benefit to people in cities. The PPI is one methodology embraced by many municipalities to help prioritize planting scheme to increase tree cover so as to benefit the greatest number of people. The results for portions of Thunder Bay considered in this model demonstrate that a focus of tree planting should occur in the most heavily populated areas that have available space for trees. It is recommended that if the City of Thunder Bay focuses on PPI as a sole task (not in conjunction with the other tasks) then it should target the most critical management areas. However, the PPI task within the UFBM is meant to be one of the many integral tasks that make up a comprehensive priority greening (planting, maintenance and protection) index for the City.

The wide range of results obtained for the *tree cover per capita* variable (as discussed previously) was mitigated by setting a tree cover target at 30 percent. Setting this type of target is helpful and recommended for a community undergoing the PPI study with smaller management areas (such as the 1 ha management areas used in the UFBM). Setting a tree cover target helped to mimic the original census tract extent/area used by Nowak *et al.* (2002), which generally has less overall tree cover and higher population densities in any one area. However, there is room to explore various other methods to best apply the PPI methods to smaller management areas. Possible modification of the formula (possibly weighting the *tree per capita* variable slightly less than the others) or other methods of translating statistics from polygon to polygon could provide other helpful alternatives.

4.4 Standard Task 3: Emerald Ash Borer Crisis Management

The Emerald Ash Borer (EAB) (*Agrilus planipennis*) is an invasive, non-native beetle that was first found in Windsor, Ontario in 2002. Since its introduction to North America, it has killed millions of ash (Fraxinus *spp.*) trees in Southern Ontario and the northern US states (CFIA 2011). It moves quickly by flying, however, its range is significantly amplified by artificial spread, that is, people moving infested ash materials (e.g. firewood) to new areas. The beetle has been identified as most destructive forest insect ever to invade North America (Ontario 2011). The beetle is approaching Thunder Bay, and its effects have been observed in Sault Ste. Marie (800km to the east) and Minneapolis (600 km to the south) and will likely be in Thunder Bay within 5-10 years (Vescio, pers. comm., 2010). The threat of extensive damage to Thunder Bay's ash tree population is real and significant according to the City's Forester (Vescio, pers. comm., 2010).

Thunder Bay has approximately 5500 street ash trees, comprising of approximately 25% of the total public tree inventory, and also has an abundance of privately owned ash trees (not inventoried in this project). The extent of damage to ash in Thunder Bay will not only include large costs incurred for removal and maintenance operations of the affected trees, but also the loss of the significant environmental services (and compensatory value) these trees provide.

One preventative measures now being used by homeowners and some municipalities to protect valued ash trees against the EAB is called TreeAzin ™. TreeAzin™ is a systemic insecticide and was developed by BioForest Technologies Inc. It can now be used to inoculate select ash trees to protect the tree from EAB for up to two years. This inoculation process is costly and it is undetermined at present whether the City of Thunder Bay will embrace this method of pest management. In the event the City uses the inoculation method it will only be administered to a proportion of trees due to high costs. This task within the UFBM was designed to focus on areas of high ash concentration as a planning measure to perform infill planting in preparation for the arrival of EAB.

4.4.1 Task Objectives

The objective of this third and final task was to produce a priority greening index to reduce the impact of ash-loss once EAB reaches Thunder Bay. The greening index uses an ash cover score to reveal the management areas with high concentrations of ash cover in m^2 per hectare. The intended results lead to a priority planting scheme to increase infill planting in these management areas. Because many municipalities today have been modifying their management plans and creating new strategies to address the EAB infestation, and due to the present and real threat to Thunder Bay, it was included as a standard task in the UFBM.

4.4.2 Modeling Approach

Tree cover, and more specifically, leaf area, is the benefit-generator of a tree. The more abundant a tree's leaf area and healthy a tree's canopy, the more the environmental services a tree produces for a community, such as air-filtration, cooling microclimates, beautifying a street, and dampening traffic noise. For this reason, this task focuses on the potential tree cover loss that could result within the first few years of an EAB infestation. The sudden loss or deterioration of ash tree cover has a significant impact on the community due to the loss of benefits they provide to the City. Hence, the EAB task focuses on the quantification of ash tree cover, whether from small or large trees. The data to assist in the quantification of ash tree cover were provided by the City of Thunder Bay Parks in the form of street tree data. These data were limited to public trees along roads and major parks. The private tree inventory used in the stormwater task was not used because it did not contain any attributes to discern species type (see discussion earlier in section 3.1.4). For this reason, the EAB task is solely focusing on public street trees, although its recommended planting locations (in the form of management areas) could also be used to encourage private tree planting. A complete list of input data requirements is found in Table 4.1.

The following section provides a detailed description of the methodology used in developing the EAB task, including a discussion of GIS operations, equations used, data requirements and simplifying assumptions.

4.4.2.1. Public Tree Cover

The public tree inventory data obtained from the City of Thunder Bay were recently updated in December 2010. This public tree inventory consists of a point shapefile (compatible with a variety of GIS software) and has the following attributes for each public tree location: tree coordinates, height, species, age, condition and diameter. However, only the species, height and spatial attributes were needed for this task. In order to determine the overall tree canopy cover (as an estimate of the total leaf area), the first step was to use the attribute for public tree height as a surrogate for tree canopy diameter. This assumption was based on the data received during the first part of the private tree inventory and was discussed earlier in the stormwater task (see section 4.2.2.1). Based on this assumption each height class (5 classes ranging between 1-23m) in the public dataset was converted linearly to crown width class (5 classes ranging between 1-18m) (Stage 1 in Figure 4.29) (Table 4.5). Similar to the stormwater task, the ash tree layer was buffered using the *Buffer* tool to produce a realistic representation of canopy cover on the spatial layer (Stage 2 in Figure 4.29). The distance each tree was buffered was based on the range median of the canopy width class it belonged to (Table 4.1). The tree buffer layer underwent a *Dissolve* and *MultiPart to Singlepart* function in case any overlap or multipart features existed (Stage 3 in Figure 4.29). As discussed above, the vector grid with a grid resolution of 100m was imported (originally created in the stormwater task via Hawth's Analysis Tools) into the project (Stage 4 in Figure 4.29) to represent the final ash tree cover statistics within the standard 100 x 100m management areas.

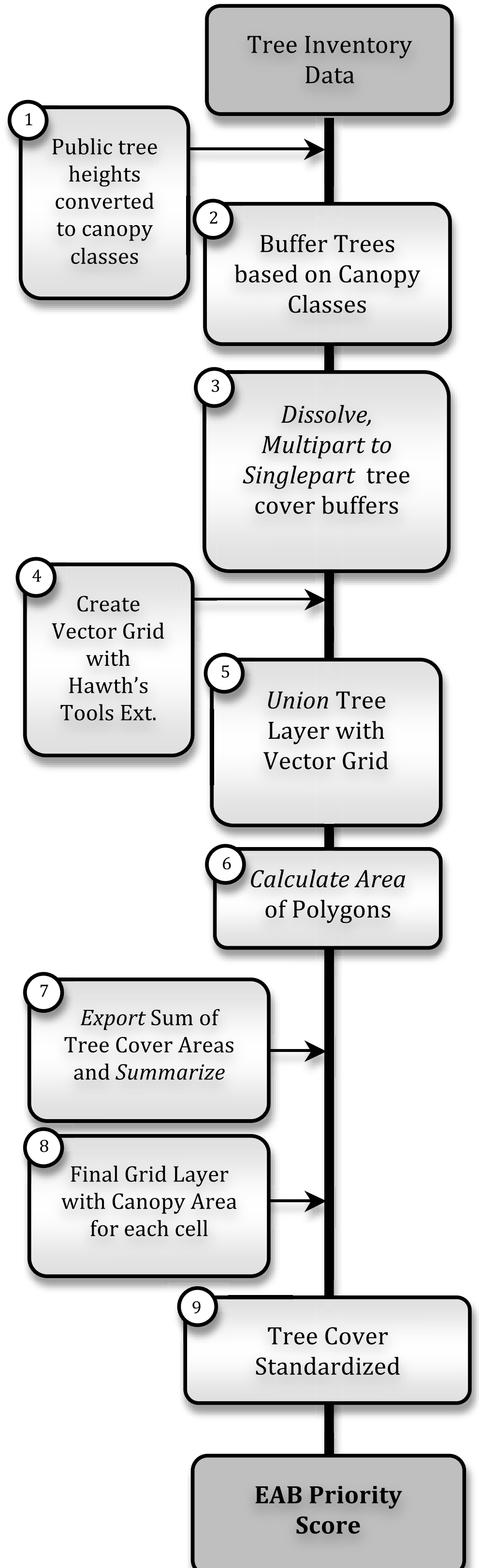


Figure 4.29. Conceptual diagram of GIS steps used in the EAB task. It involves the analysis of tree inventory data to generate an EAB priority score.

Table 4.5. Canopy width classes and their median used for determining average canopy width.

Crown Width Class	Range (m)	Median (m)
1	0-4	2
2	4-8	6
3	8-12	10
4	12-16	14
5	16+	18

Once the vector grid had been created, a *Union* function was used to combine the tree cover data and the grid layer (Stage 5 in Figure 4.29). The area for all the polygons (grid and trees) was determined using the *Calculate Area* tool (Stage 6 in Figure 4.29). All fields with a buffer radius of >0 and features (which selects only the tree canopy polygons), were exported to a new layer. This layer's area of tree cover then was summarized using *Summarize* tool in the attribute table to determine how much tree cover area occupied each management area (Stage 7 in Figure 4.29). The DBF table created in the summary was then joined back to the original vector grid (stage 8 in Figure 4.29) to display the sum of tree cover in each grid cell. As the final step the tree cover area was standardized on a scale between 0 to 1, with 1 representing the highest amount of ash tree cover (Stage 9 in Figure 4.29)(Figure 4.30). The tree area was standardized using the followed formula:

Equation 4.11

$$V = \frac{(n - m)}{r}$$

where, V is the standardized value of ash tree cover (0-1), n is the value of ash tree cover (ha), m is the minimum value of ash tree cover (ha), and r is the range of ash tree cover (ha) (maximum value – minimum value).

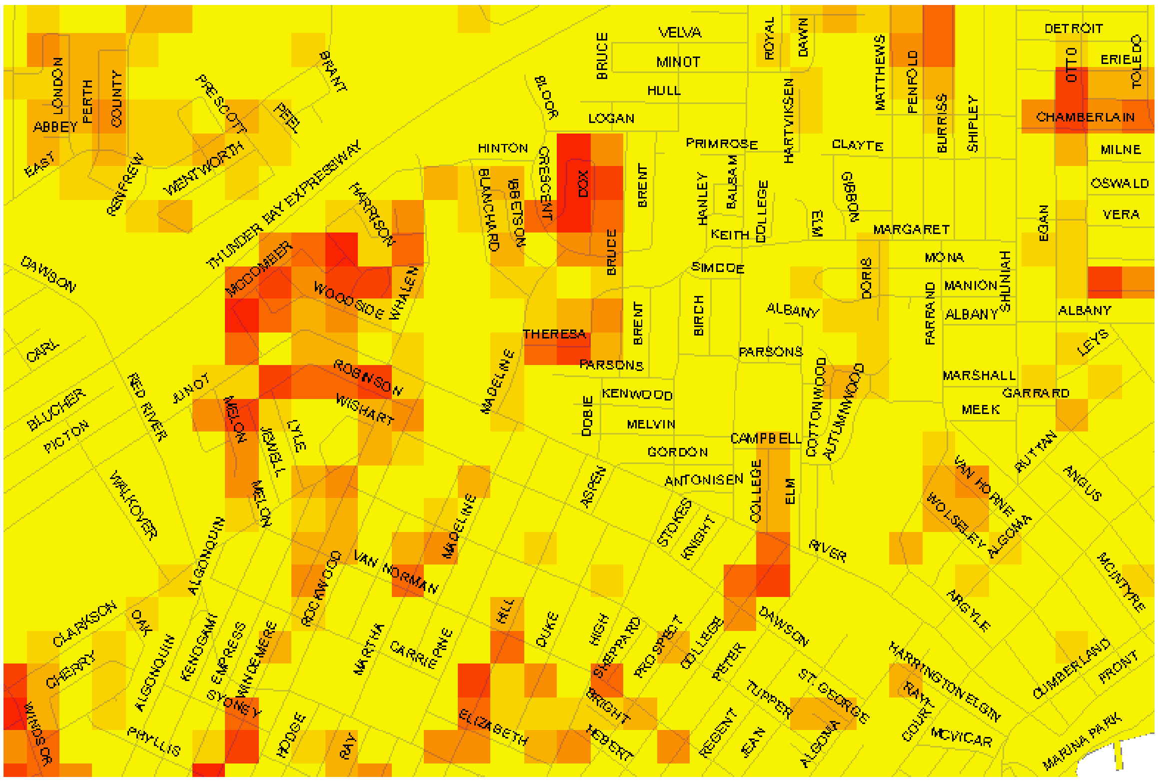


Figure 4.30. A screenshot from ArcGIS in the northern portion of the City of Thunder Bay displaying the ash tree cover management areas. Each grid cell represents an area of 1 hectare. The darker shaded management areas have higher ash tree cover and, hence a greater priority for planting and managing.

4.4.3 Model Results

The main objective of the EAB task was to estimate the extent of ash tree cover within the City of Thunder Bay. The results were summarized in management areas at a resolution of 1 ha in size and are shown in Figure 4.31. Various colour shades (yellow to red) were used to denote a priority for greening. The ash cover scores shown in Figure 4.31 is a standardized value of the cover of ash trees as a fraction of the management area.

The summary of neighbourhood averages seen in Table 4.6 were calculated using the intersect selection method within ArcGIS. This selection method selects the cells (management areas) if the neighbourhood polygon being summarized intersects any of the cells (management units) (see earlier Figure 4.13). Further details on this selection method were discussed earlier in the Priority Planting Index section 4.3.3.

The five management units with the highest ash cover scores were located in four different neighbourhoods. One management area in each of the Carrick, Hillcrest and Academy neighbourhoods and two in the Westfort West neighbourhood had ash cover ranging between 1524 – 1215 m^2, and represent areas for increased greening (see highlighted grid cells in Figure 4.31). The neighbourhoods with the highest priority to green were River Terrace I, Redwood, and West End, with an average of 215.1, 202.6, and 169.6 m^2 ash cover respectively. Intercity Mall Area, Green Acres, and North Cumberland were the lowest priority neighbourhoods with and average of 0, 3.6, and 5.6 m^2 ash cover respectively.

4.4.4 Discussion and Recommendations for Planting Locations

Many solutions to prevent and control EAB are presently being explored and implemented by municipalities, including the City of Thunder Bay. Nevertheless, these solutions may not prevent or control an infestation in Thunder Bay in the event EAB arrives in the region. For this reason, managing for EAB now with infill

Table 4.6. Summary by neighbourhood of average ash cover (m²).

Neighbourhood	Neighbourhood Area (ha)	# of Grid Cells[1]	Average Ash Cover (m^2)
Academy	170.8	206	75.9
Carrick	119.9	152	130.0
Chapples	148.3	239	7.8
Charry	79.4	105	10.0
County Park	217.4	264	49.5
Current River	119.6	151	63.9
Current River North	113.8	147	51.3
Dease	128.6	158	65.7
Downtown PA	90.8	126	24.0
Edgewater	101.9	132	13.6
Grandview	134.6	191	82.6
Green Acres	118.2	145	3.6
Hillcrest	59.2	80	106.2
Humber	72.8	99	60.7
Intercity Mall Area	179.8	211	0.0
Jumbo Gardens	105.9	136	51.3
North Cumberland	87.2	120	5.6
Northwood	131.8	162	76.6
Ogden East End	91.1	122	68.2
Parkdale	158.6	180	24.8
Picton	30.1	49	29.7
Redwood	61.4	84	202.6
Regent	68.3	94	67.4
River Terrace	120.2	152	69.1
River Terrace I	27.9	47	215.1
Sherwood	42.1	73	32.5
Shuniah	226.6	280	44.5
Sir John A McDonald	65.6	89	81.8
Thornloe	43.1	58	75.3
Vickers	161.4	198	5.9
Volunteer Pool	133.8	165	93.6
West End	83.6	113	169.6
West Thunder	155.3	187	30.2
Westfort East	131.2	157	14.1
Westfort West	148.6	178	34

[1] This is a count of full and partial grid cells intersecting each defined neighbourhood.

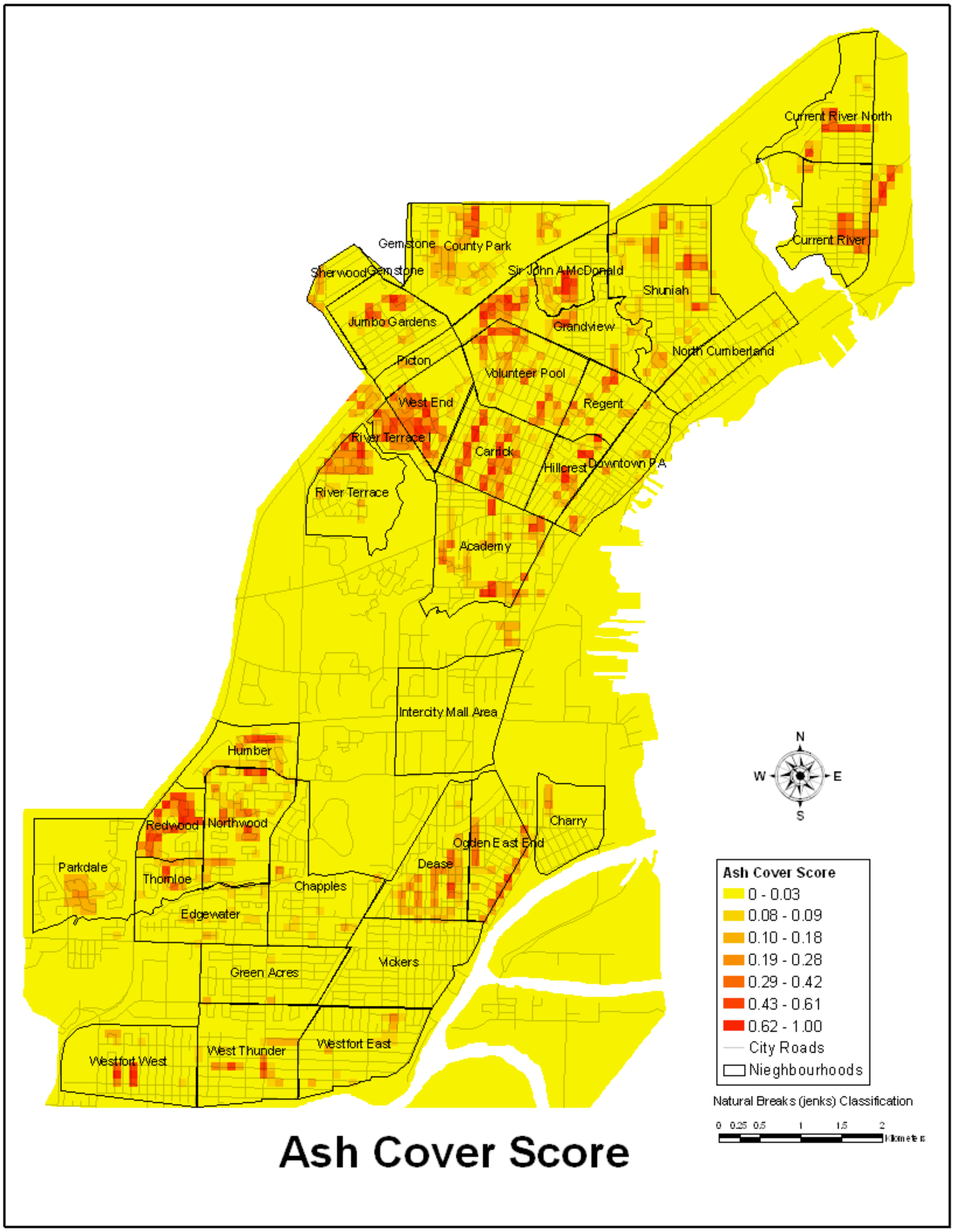


Figure 4.31. A map displaying the values of the standardized ash cover score. Each grid cell represents 1 hectare. The darker shaded management areas are a greater priority for greening. Highlighted cells (light blue) are five of the management areas with the highest ash cover score, as discussed in the text.

planting to guard the significant loss (25%) of public tree canopy cover, will help mitigate the deficit felt by the community.

This task within the UFBM prioritizes tree-planting activities in areas with levels of high ash tree cover. However, by identifying areas of possible significant damage, this task is also identifying the management areas that necessitate additional maintenance and protection to increase the leaf area for non-ash trees. As ash decline, these neighbourhoods will be more reliant on the other mature trees to provide the services the ash once did.

The results demonstrate that tree planting should occur in the most heavily ash populated areas (Figure 4.31). It is recommended that if the City of Thunder Bay focuses on EAB and ash cover as a sole task (not in conjunction with the other tasks) then it should target the most critical management areas identified in Figure 4.31. However, the ultimate UFBM is meant to integrate the 3 standard and 4 link table tasks so as to develop a more comprehensive priority greening (planting, maintenance and protection) index for the City that reflects a variety of goals.

4.5 Conclusion

These standard tasks provided a means to apply important municipal greening strategies from other jurisdictions, along with local priorities such as EAB management, to the UFBM. The results from the stormwater task demonstrated that greening activities should be prioritized in areas that have a large percentage of impervious cover and low existing tree cover. The critical areas were illustrated and were located primarily in the Intercity region. An approach to stormwater management of this kind would significantly increase tree cover where it is needed to reduce damages and costs caused by stormwater. The Priority Planting Index demonstrated where to increase tree cover to benefit the largest number of people in Thunder Bay. It designated the better part of residential areas of both Thunder Bay north and south as the focal point, leaving out much of the intercity region. And third, the EAB task facilitated an urgent issue to be included into the model by prioritizing tree-planting activities in areas which could be devoid of trees in a few years. The high level of ash cover in the City, which is a target for the EAB, was well distributed across the city, although higher concentrations existed in the north. Planting and maintaining existing trees in these areas is priority to sustaining a strong flow of urban forest benefits in these neighbourhoods.

The results from these standard tasks provided a strong and comprehensive set of results that will be especially useful when combined with the link table tasks discussed in the next chapter.

5.0 Link Table Tasks of the UFBM

5.1 Introduction

The link table within the UFBM is a comprehensive process that includes the use of focus groups to measure the level of connection, however small or large, between an urban forest benefit and a particular sustainability goal (e.g., a goal of increasing active transportation in a community is influenced by the ability of trees to beautify the neighourhood, to absorb noise, to slow traffic, and to protect pedestrians.). If a particular connection is strong (i.e., a particular sustainability goal of a community can be in part or in whole accomplished through the function of an urban forest), then a link table process creates 'tasks' that will be used in the UFBM to direct greening initiatives. The tasks derived from the link table process are focused primarily on the most urgent sustainability aims of a community. The link table process provides a balanced approach to sustainability goals, by choosing an array of tasks that focus on one or more of the various elements that make up a healthy community. These elements include a community's economic capital, physical capital, human capital, natural capital and social capital (see section 1.3 Model Development for further discussion). These four link table tasks address all of the above elements except for natural capital, which was fulfilled through both the stormwater and EAB standard tasks discussed in chapter four. Of the numerous potential tasks that were generated, the prototype UFBM includes <u>four</u> link table tasks that address a variety of sustainability goals. These link table tasks were selected to meet goals of the City of Thunder Bay and therefore represented a unique customization “prototype” UFBM to Thunder Bay.

The first link table task chosen for the economic capital category is called the *Economic Development Greening Index*. The economic category based on Roseland and Connelly (2005) focuses on a community’s material wealth and on ways to allocate resources to make more with less. The index focuses on supporting the creation of a positive climate for business, institutions and employees, in order to encourage a growing economy (Thunder Bay 2005). The sustainability goal behind this task was derived from the Thunder Bay 2005 Official Plan, which looked to develop and rely more upon secondary and tertiary support industry, retail and service functions, and small business, rather than the traditional sources of employment (Thunder Bay 2005). This task produces an index that ranks tree greening locations based on business density and existing tree cover. The intended results lead to a priority-greening scheme to increase tree cover so as to benefit the greatest number of businesses across the City of Thunder Bay.

The second link table task focuses on physical capital and was called the *Downtown Core Greening Index*. Physical capital is the stock of material resources such as buildings and other infrastructure to be used to produce a good and a flow of future income (Roseland and Connelly 2005). Improving physical capital includes focusing on the assets of a community, such as downtown infrastructure (Roseland and Connelly 2005). Although closely related to the *Economic Development Greening Index* discussed above, this task focuses on maintaining and enhancing the downtown areas as unique focal points of activity and interest for residents and visitors through the provision of strong business amenities (Thunder Bay 2005). It, too, stems from objectives found in the City of Thunder Bay's 2005 Official Plan. The objective of the D*owntown Core Greening Index* was to produce a priority-greening scheme to increase tree cover so as to compliment existing infrastructure and benefit the greatest number of people and businesses in Thunder Bay's two downtown cores.

The third link table task chosen for the prototype UFBM is called the *School Travel Greening Index* and focuses on the human capital category. Human capital, according to Roseland and Connelly (2005), focuses on health, education, skills, knowledge and leadership to increase things like literacy and family and community cohesion. The *School Travel Greening Index* produces a priority greening index to direct the benefits of an urban forest to children engaging in active, non-vehicular, transportation to and from school. The index ranks public tree greening locations (planting, maintenance and protection) based on proximity of roads to a school and existing tree cover. This goal stemmed from a set of guidelines created for municipalities by the Ontario Professional Planners Institute (OPPI 2009).

The last link table task used in the prototype UFBM is called the *Special Needs Greening Index* and fits within the social capital category. Social capital is a wide term and refers to the connections within and between social networks that contributes to strong community cohesion and social relations (Roseland and Connelly 2005). Social capital can result with society's investment in social development that ensures people have equitable access to basic determinants of health (e.gs., peace, safety, food, and shelther)(Roseland and Connelly 2005). The

Special Needs Greening Index aims to direct the benefits of an urban forest to the needs of special groups, in particular persons with disabilities. The index is primarily meant to increase the aesthetics, safety, and cleanliness of a neighbourhood in the vicinity of a "care residence" and to moderate extreme temperatures, traffic, and noise that can be hostile to people with special needs. This task also stemmed from goals found in the Thunder Bay 2005 Official Plan.

This chapter is comprised of four sections, each devoted to one of the link table tasks described above. Each section provides a description of the methodology, the input data requirements (Table 5.1), and simplifying assumptions for each task. The UFBM is largely a GIS-based tool so the methodology adopted outlines the various GIS operations and equations used to generate geospatial planting locations, something that other decision support tools are lacking.

Table 5.1. The input data requirements for each link table task.

	Link Table Tasks Theme Requirements				
Theme Description (Type)	Economic Development	Downtown Core Development	School Travel	Special Needs	Attributes Needed
public tree's existing (point)	✓		✓	✓	varied
private tree's existing (point)	✓				varied
road network (polyline)	✓	✓	✓	✓	n/a
ortho SID 20cm Quad aerial images	✓				n/a
business (point)					location
neighbourhoods (polygon)	✓		✓	✓	name and area
city study area (polygon)	✓	✓	✓	✓	n/a
central business districts (polygon)		✓			n/a
school locations (points)			✓		location

5.2 Link Table Task One: Economic Development Greening Index

Over the past few decades, a growing level of research has demonstrated the positive influence of greenery on human attitudes and function. However, due to the complex methods required to undertake such research, the empirical data required to demonstrate this to the public was lacking up until recently (Wolfe 2002; Joye *et al.* 2010). Hard, empirical data have since accrued and provide telling evidence that urban vegetation not only supports the well-being of people, but also helps stimulate and benefit urban business districts (Wolf 2004a; 2005; 2007a; Yanick *et al.* 2010). Trees can play an important 'healing' role by mitigating the effects of negative moods and stress, which are commonplace for shoppers and business people (Gullone 2000; Joye *et al.* 2010). These effects impact purchasing behaviour in a positive manner among consumers and increase the work ethic and productivity among business people. Wolf and others have concluded that greenery enhances the perceived aesthetic qualities of urban areas and the appeal of commercial/retail districts (McPherson *et al.* 2006; Velarde *et al.* 2007; Wolf 2007a, Joye *et al.* 2010). In short urban environments with greenspace elements, such as a mature streetscape canopy, were constantly preferred over non-greenspace environments by both shoppers and business people (Wolf 2005; Joye *et al.* 2010). Although there are a variety of factors that influence the success of an economic district, researchers have found that outdoor aesthetics are equally as important as indoor aesthetics to consumers (Wolf, pers. comm., 2010). Wolf (1999; 2005) reports that customers are willing to stay longer and pay more for a product and for parking in greened urban environments over non-green urban settings.

In Thunder Bay, as in other cities, locally-based small retailers continue to contend with the domination of the big box store retail format. It is thought that greenspace elements, such as trees, plants, and flowers located near small retailers, could stimulate additional business growth or success. Although high-end retail businesses are presumed to receive the greatest benefits, no research presently exists that specifies the types of business that benefits more or less from greenery (Wolf, pers. comm., 2011). Therefore, the Economic Development Greening Index focuses on (and does not discriminate between) all types of business and commercial types in Thunder Bay (e.gs., restaurants, stores, businesses, financial institutions).

5.2.1 Task Objectives

The objective of this link table task was to produce an Economic Development Greening Index that ranks tree greening locations based on business density and existing tree cover. The intended results lead to a priority-greening scheme to increase tree cover so as to benefit the greatest number of businesses across the City of Thunder Bay. It differs from the Downtown Core Greening Index (link table task 2) in that this task focuses on business development throughout the city and is not geographically limited to downtown areas.

5.2.2 Modeling Approach

Two variables are used to determine the Economic Development Greening Index: a tree cover score (private/public); and a business density score. To determine these variables, a variety of spatial data were needed. The data to assist in the quantification of tree cover were provided by the City of Thunder Bay Parks Department in the form of street tree data. These data, in addition to the private tree inventory discussed in the stormwater task, make up the dataset required for this task. Since both public and private tree cover data had already been processed for the stormwater task, that dataset was simply imported into this project. For this reason, the task's study area was limited to the same region used in the stormwater task and PPI tasks (see Figure 4.28). The City of Thunder Bay provided a list of businesses needed to determine the extent and distribution of businesses in and around Thunder Bay. A complete list of data requirements for this task is found in Table 5.1.

The following section provides a detailed description of the methodology used in developing the Economic Development Greening Index, including a discussion of GIS operations, equations used, data requirements and simplifying assumptions. The methodology to calculate the tree cover score was previously discussed in section 4.2.2.1 (i.e., in the stormwater section), hence most of the details on how the tree cover score is calculated is omitted here to avoid unnecessary repetition. The discussion of the Economic Development Greening Index is organized into three sections based on the stages shown on Figure 5.1: (1) business density score (Stages 1- 4); (2) tree cover (Stages 5); and (3) the Economic Development Greening Index (Stages 6-8).

5.2.2.1. Business Density Score

To determine the concentration (i.e., density) of businesses in Thunder Bay, the first stage was to import the business location shapefile (a point shapefile provided by the City of Thunder Bay with a point allocated to each business) and the vector grid created originally in the stormwater task (and used consequently for each task), into ArcGIS (Stages 1 and 2 in Figure 5.1). Hawth's Analysis *Count Points in Polygon Tool* was then used to determine the amount of businesses in each grid cell of 100m resolution (Stages 3 in Figure 5.1). This tool counts the number of points (businesses) that occur in each vector grid cell (or management area), and the value is written to the vector grid attribute table. To target areas of medium to high concentrations for the study, a criterion of 4 or more businesses per hectare was selected. This number was chosen so the task could focus on more concentrated business areas, ignoring areas of irregularly dispersed businesses. The business count generated from Hawth's Tools was then standardized on a scale between 0 to 1, with 1 representing the greatest concentration of businesses in a given management area (Stages 4 in Figure 5.1). The standardization formula used was:

Equation 5.1

$$S_i = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}}$$

where S_i is the standardized value for the original value X_i, X_{min} is the lowest original value, and X_{max} is the highest original value.

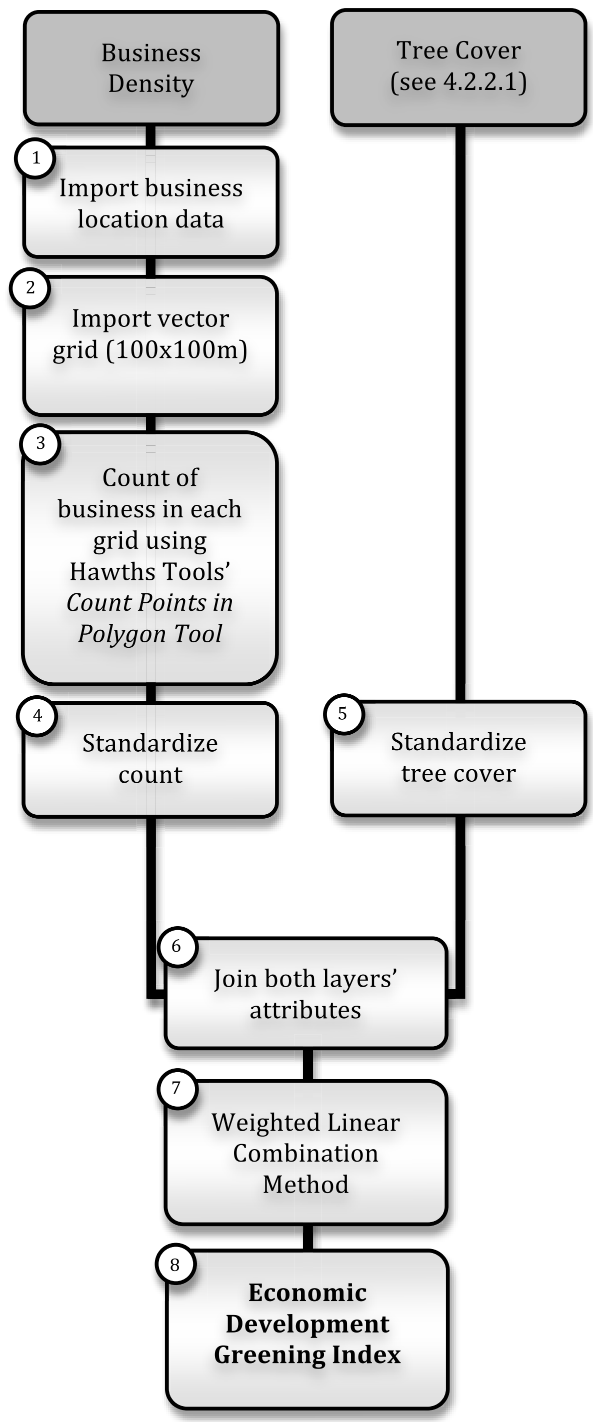


Figure 5.1. Conceptual diagram of GIS steps used in the Economic Development Greening Index. It involves the analysis of business density and tree cover variables to generate the final index.

5.2.2.2. Tree Cover Score

To determine the tree cover within each management area, the tree cover score was imported from the previous stormwater task (see 4.2.2.1). American Forests recommends on average between 15 percent tree cover in central business districts and 25 percent tree cover for residential areas (American Forests 2002). A mean target of 20 percent was established as a desired tree cover. Before standardizing the tree cover per cell, the maximum tree cover levels citywide were adjusted to 2000 m^2, or 20 percent. This readjusted the range based on the new desired target to provide more precise results. The tree cover was then standardized based on the 20% target, so any cells above 2000 m^2 were given a value of 0 (i.e., no need for planting)(Stages 5 in Figure 5.1). Values greater than 0 and tending towards 1 are those areas with tree cover less than 2000 m^2 and in need of planting.

5.2.2.3. Economic Development Greening Index

After both the business density and tree cover variables were standardized on a scale of 0 to 1 (Stages 4 and 5 in Figure 5.1), with 1 representing the management areas with the highest business density and lowest tree cover score, the individual scores were combined using the *join table* tool in ArcGIS (Stages 6 in Figure 5.1). A weighted linear combination method (Chang 2010) was then applied (Stages 7 in Figure 5.1) to calculate the Economic Development Greening Index (Stages 8 in Figure 5.1).

The weighted linear combination method is a common way of computing an index value for a vector-based model (Chang 2010). This method was discussed earlier in the stormwater task (see section 4.2.2.3) and allows for the weighting of the criterion depending on the users specification. This index is new and thus the variable weights cannot be established from other research, hence a series of scenarios (6) were done to demonstrate the effects of various weighted variables (Figure 5.2). The focus groups, used to select the link table tasks (see section 3.1.1), identified business density as the priority and principle variable. Therefore, the business density variable was given a weight of four times the importance of tree cover.

5.2.1 Model Results

The Economic Development Greening Index has two variables: business density score and tree cover score. The following section provides the results and summaries of the business density score and the final Economic Development Greening Index. The tree cover score discussed earlier (see section 4.2.2.3) will be omitted in this section, although its results, summarized by neighbourhoods, are presented in tabular format in Table 5.2.

5.2.1.1. Business Density Score

The main objective of the business density score was to arrive at an estimate of the distribution and extent of the businesses within Thunder Bay. The results for the business density variable for management areas at a resolution of 1 ha are shown in

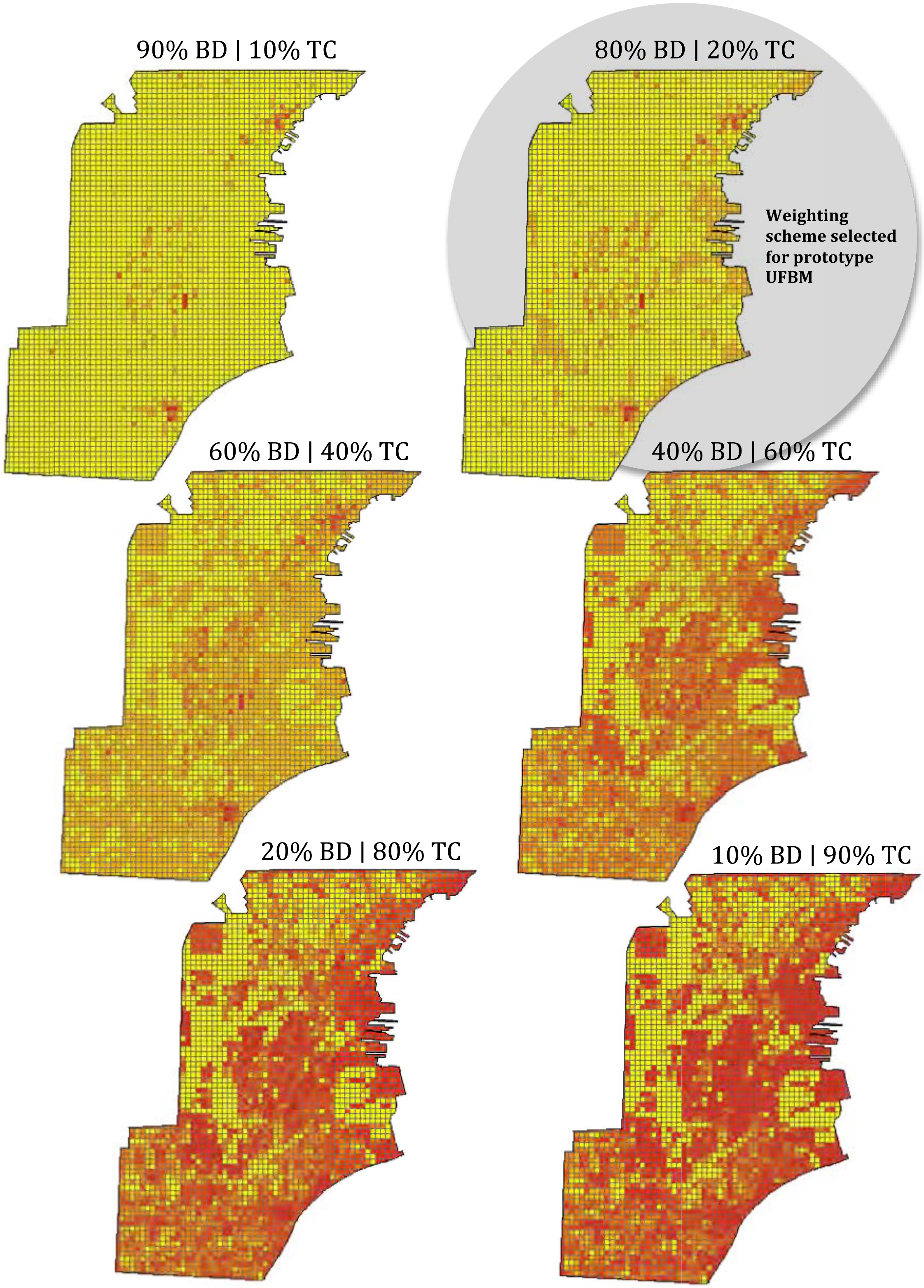


Figure 5.2. Maps of the Economic Development Greening Index values for portions of Thunder Bay, displaying the various weighting scenarios of the business density (BD) and tree cover (TC) variables. Values tending towards 1 (red) indicate management areas that require focused greening, while those tending towards 0 (yellow) do not require greening. Each grid cell represents 1 hectare.

Figure 5.3. The four most dense management areas ranging from 40-34 business per hectare were found at Intercity Mall (2) and Victoriaville Centre (2) (see Figure 5.3). The neighbourhoods with the greatest average densities were Downtown Port Arthur, Intercity Mall Area, Vickers, and Dease with an average 3.9, 2.3, 1.9, and 1.8 businesses per hectare respectively (Table 5.1). The neighbourhood with the lowest densities were River Terrace and West Thunder, both with 0 businesses per hectare.

Table 5.2. Summary by neighbourhood of average business density and average tree cover and the average Economic Development Greening Index. The greening index will be discussed in sections 5.3.3.2.

Neighbourhood	Neighbourhood Area (ha)	# of Grid Cells[2]	Business Density (avg # of businesses /ha)	Tree Cover (%)	Econ. Dev. Greening Index
Academy	171	206	0.33	13.4	0.09
Carrick	120	152	0.32	14.2	0.09
Chapples	148	239	0.23	5.5	0.10
Charry	79	105	0.05	6.6	0.09
Dease	129	158	1.78	8.6	0.13
Downtown PA	91	126	3.96	5.6	0.18
Edgewater[1]	102	82	0.06	6.5	0.10
Green Acres	118	145	0.26	7.4	0.10
Hillcrest	59	80	1.52	10.4	0.12
Intercity Mall Area	211	211	2.28	3.1	0.15
Northwood[1]	132	130	0.17	7.7	0.10
Ogden East End	91	122	1.31	5.7	0.12
Regent[1]	68	81	0.26	10.3	0.10
River Terrace[1]	120	143	0	33.3	0.07
Vickers	161	198	1.91	9.5	0.13
Volunteer Pool[1]	133	75	0.72	11.4	0.11
West End[1]	84	86	0.22	11.7	0.09
West Thunder[1]	155	62	0	6.8	0.09
Westfort East[1]	131	58	0.07	5.3	0.10
Total Average	**121.2**	**129.4**	**0.8**	**9.6**	**0.1**

[1] Only a portion of the neighbourhood was analyzed because part of the neighbourhood fell outside the study area.

[2] This is a count of full and partial grid cells intersecting each defined neighbourhood.

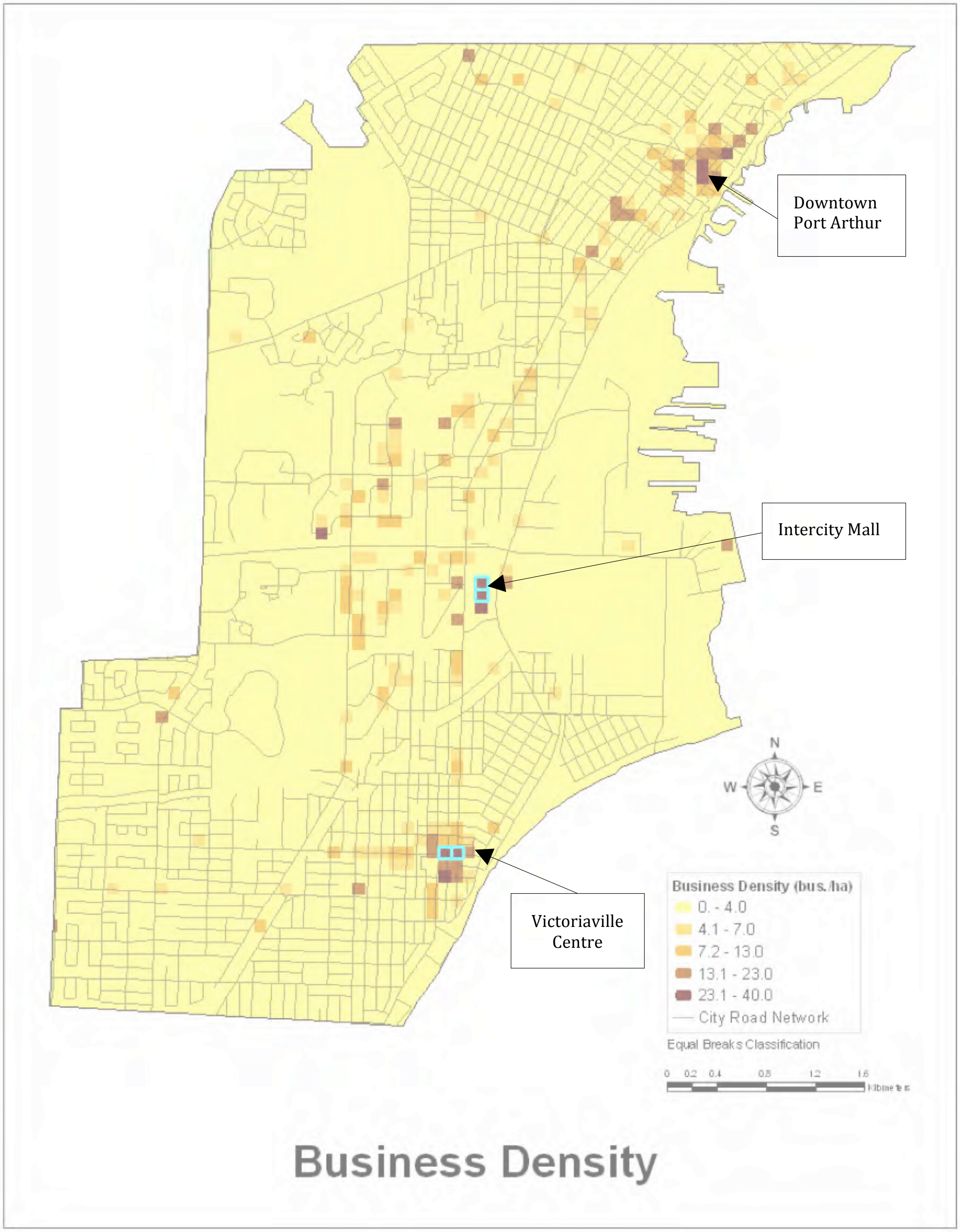


Figure 5.3. A map displaying the values of the business density variable summarized for management areas for most of the City of Thunder Bay. Each grid cell represents 1 hectare. The darker the shaded management areas the higher the business density and a greater priority for planting. The highlighted cells (blue) indicate the management areas with the highest densities (approximately 40 businesses/ha).

5.2.1.2. Economic Development Greening Index

The Economic Development Greening Index is the combination of the business density and tree cover scores. Tree cover scores were imported from the stormwater task and a full description of results is discussed in section 4.2. A weighting of 4 was given to business density and a 1 to the tree cover score. The results were summarized in management areas of 1 ha in size and various colour shades (yellow to red) were used to denote a priority for greening (Figure 5.4).

The four management areas with the highest index value across the study area were located at Intercity Mall and the Victoriaville Centre with a score range of 0.86 to 1 (see highlighted cells in Figure 5.4). Significant sections along Memorial Avenue, Algoma Street South and Central Avenue also demonstrated a need for priority greening. Neighbourhoods were also summarized by average index values. The highest average index value (highest priority to plant) is Downtown Port Arthur, Intercity Mall Area, and Vickers with index values of 0.18, 0.15, and 0.13 respectively. These neighbourhoods ranked highest due to the dense concentration of businesses and also influenced by the low tree cover in these areas. River Terrace, Carrick and West End neighbourhoods ranked the lowest average index score at 0.07, 0.09, and 0.09 respectively. These neighbourhoods were low ranking primarily because of their low business density score.

5.2.2 Discussion and Recommendations for Planting Locations

Research has demonstrated the positive impact trees have on consumer behavior and stimulating overall economic development. The Economic

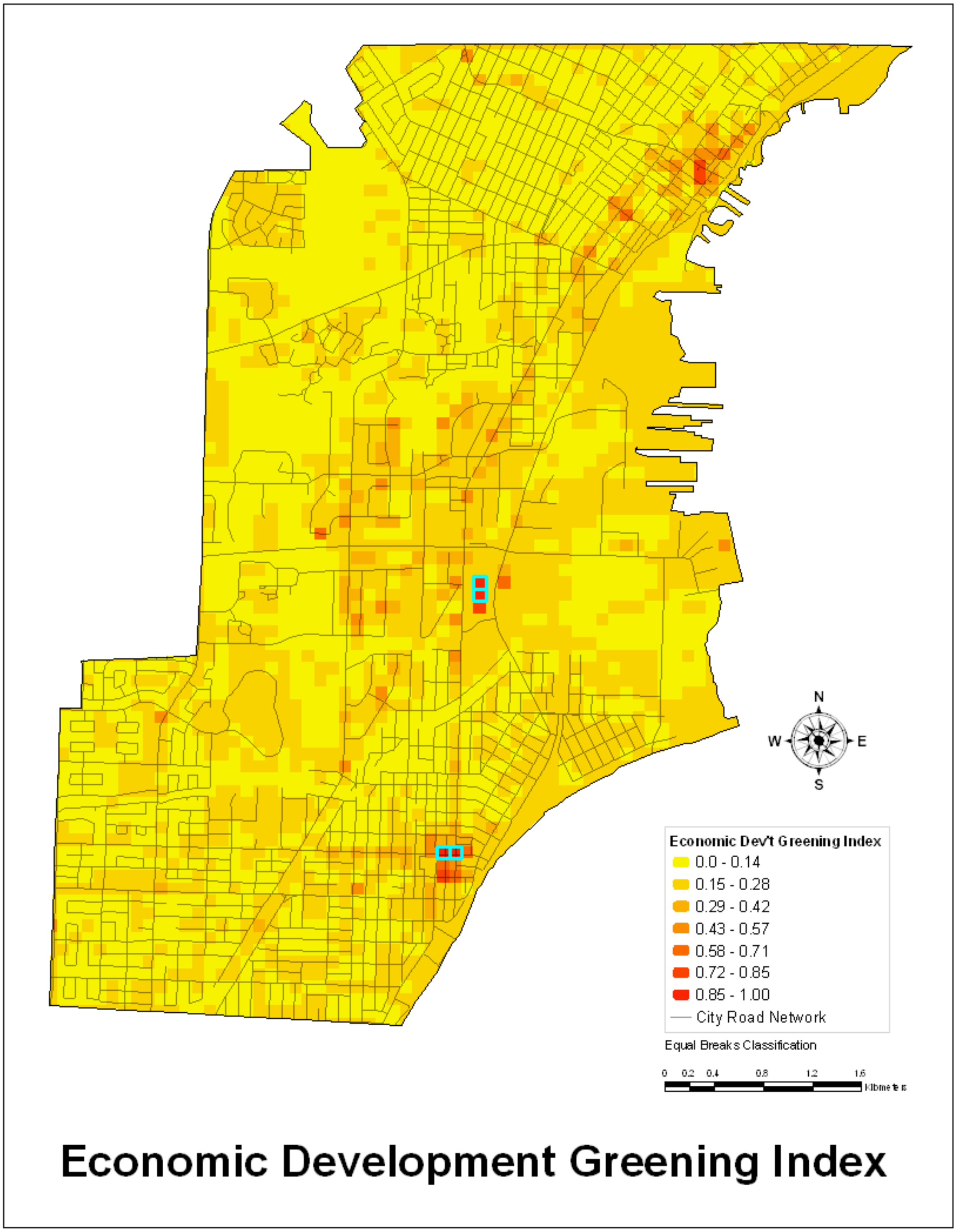


Figure 5.4. A map displaying the value of the Economic Development Greening Index score summarized for management areas for most of the City of Thunder Bay. Each grid cell represents 1 hectare. The darker shaded management areas have higher business densities and lower tree cover and hence, a greater priority for planting. The highlighted cells (blue) indicate the management areas with the highest index scores (as discussed in text).

Development Greening Index is a first attempt to help municipalities prioritize greening schemes so as to benefit the greatest number of businesses. The results demonstrated that tree planting, maintenance, and protection should occur in the most heavily concentrated business areas in Thunder Bay, that are devoid, or lacking in existing tree cover. Some of the focal points include the downtown cores, intercity area, along Memorial Avenue, Algoma Street and Central Avenue.

At this point, no research has studied the type of businesses that would benefit more from greening over others. If such studies existed, this level of detail could easily be applied to the UFBM to make this index more relevant by preventing areas from being unnecessarily greened (i.e., convenience stores may not benefit as much from green infrastructure as high-end retail shops and restaurants). Therefore, further research could allow this index to be further refined and become more effective. It is also noted that these recommended locations are governed by the 80 to 20% weighting of business density score versus tree cover score. Further testing of other weighting scenarios may have generated alternate locations.

5.3 Link Table Task Two: Downtown Core Greening Index

Trees play an important role in improving the aesthetics of a downtown neighbourhood. As discussed in the previous section, the presence of trees in business areas can stimulate value, the perception of value, and provide a welcoming facade to attract customers and tourists (Wolf 2006). In Thunder Bay, the downtown cores are arguably more important than other areas of the City to stimulate the growth and health of the business sector. This is because healthy, vibrant downtown cores are significant assets and are essential for the life of a community (McPherson and Murray 2002; Thunder Bay 2005). Like many North American cities, the 1970's saw the gradual decline of downtown core areas. Unique to Thunder Bay was the merger of two former cities of Port Arthur and Fort William in 1970 that meant two downtowns suffered during this period. The economic activity that once thrived in the cores was directed to a new focal point in the Intercity area and was meant to bring the two cities together in both the physical and economic sense (Randall and Lorch 2007; EarthWise Thunder Bay 2008). The merger of these cities also instigated new levels of urban sprawl and was another contributor to the population loss in the cores.

This task's focus is solely on benefiting the downtown cores to increase the aesthetics and function of these areas with the hope that, as the literature indicates, business and population growth will be stimulated through the use of green infrastructure. A district-wide greening regime, as described by Wolf (2005), is one of the best means to attain a perceptual richness, sense of place and increased aesthetics that businesses depend on.

5.3.1 Task Objectives

The objective of the second link table task was to produce a Downtown Core Greening Index, a rankable index based on whether a management area is within a city's Central Business District (CBD) and its existing tree cover. The intention of including this index within the UFBM is to increase tree cover so as to benefit the greatest number of businesses and people in Thunder Bay's two downtown cores and to ultimately help establish more attractive, functional, and prosperous downtowns. It differs from the Economic Development Greening Index (task 4) in that this task focuses only on the two central business districts of Thunder Bay.

5.3.2 Modeling Approach

Two variables are used to determine the Downtown Core Greening Index: tree cover score and those areas zoned as Central Business Districts. The data to assist in the quantification of tree cover were provided by the City of Thunder Bay Parks Department in the form of street tree data. These data, in addition to the private tree inventory discussed in the stormwater task, made up the dataset required for this task. Since both public and private tree cover data had already been processed for the stormwater task, that dataset was simply imported into this task. The Central Business Districts zones were digitized from the City of Thunder Bay Official Plan (Thunder Bay 2005) land use map. A complete list of data requirements for this task is found in Table 5.1.

The following section provides a detailed description of the methodology used in developing the Downtown Core Greening Index, including a discussion of GIS operations, equations used, data requirements and simplifying assumptions. The methodology to calculate the tree cover score was previously discussed in section 4.2.2.1 (i.e., in the stormwater section), hence most of the details on how the tree cover score is calculated is omitted here to avoid unnecessary repetition. The discussion of the Downtown Core Greening Index is organized into three sections based on the stages shown on Figure 5.5: (1) central business districts (Stages 1- 5);

(2) tree cover (Stages 6-7); and (3) the Downtown Core Greening Index (Stages 8-10).

5.3.2.1. Central Business District Score

The City of Thunder Bay has two main Central Business Districts (see Figure 5.6). These two districts are what determine the study area for the task. The first stage was to digitize and import the Central Business Districts shapefile (provided by the City of Thunder Bay) and the vector grid created originally in the stormwater task, into ArcGIS (Stages 1 and 2 in Figure 5.5). Many of the boundary lines of the Central Business Districts follow major roads; hence, to ensure the study area would encompass potential trees on either side of these roads, a buffer of 50 meters was applied to each central business district (Stage 3 in Figure 5.5). The Hawth's Polygon to Polygon Analysis Tool was then used to calculate the amount of Central Business District area within each grid cell of 100m resolution. Hawth's Polygon to Polygon Analysis tool uses a weighted mean approach, which means it has the ability to derive a weighted mean statistic from each polygon in the summary layer (Central Business District) that overlaps a zonal polygon (vector grid). It then generates the weighted mean of the summary layer and writes it to a new field in the zonal layer (Stage 4 in Figure 5.5)(refer to Figure 4.21 and 4.3.2.1 for further discussion). Every management area completely within a Central Business Districtsreceived a count of 1ha, or a score of 1. Any management areas that intersected a boundary received a weighted mean derived from the polygon to polygon analysis. Any management area completely outside the central business district received a value of 0 ha, or a score of 0. The area results generated from Hawth's Tools was then standardized on a scale between 0 to 1, with 1 representing the most area of a central business district in a given management area (Stages 5 in Figure 5.5). The standardization formula used was:

Equation 5.2

$$S_i = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}}$$

where S_i is the standardized value for the original value X_i (area of central business district per cell), X_{min} is the lowest original value (is the minimum area for central business district per cell), and X_{max} is the highest original value (is the maximum area for central business district per cell).

5.3.2.1. Tree Cover

To determine the tree cover within each management area, the tree cover score was imported from the previous stormwater task (see section 4.2.2.1). American Forests recommends on average between 15 percent tree cover in central business districts (American Forests 2002). Therefore, a mean target of 20 percent was established as a desired canopy cover for any management area in the Central Business District zones. Before standardizing the tree cover per cell, the maximum tree cover levels were adjusted to 2000m^2 per cell, or 20 percent (Stage 6 in Figure 5.5). This readjusted the range based on the new desired target to provide more precise results. The tree cover was then standardized based on the 20% target, so any cells

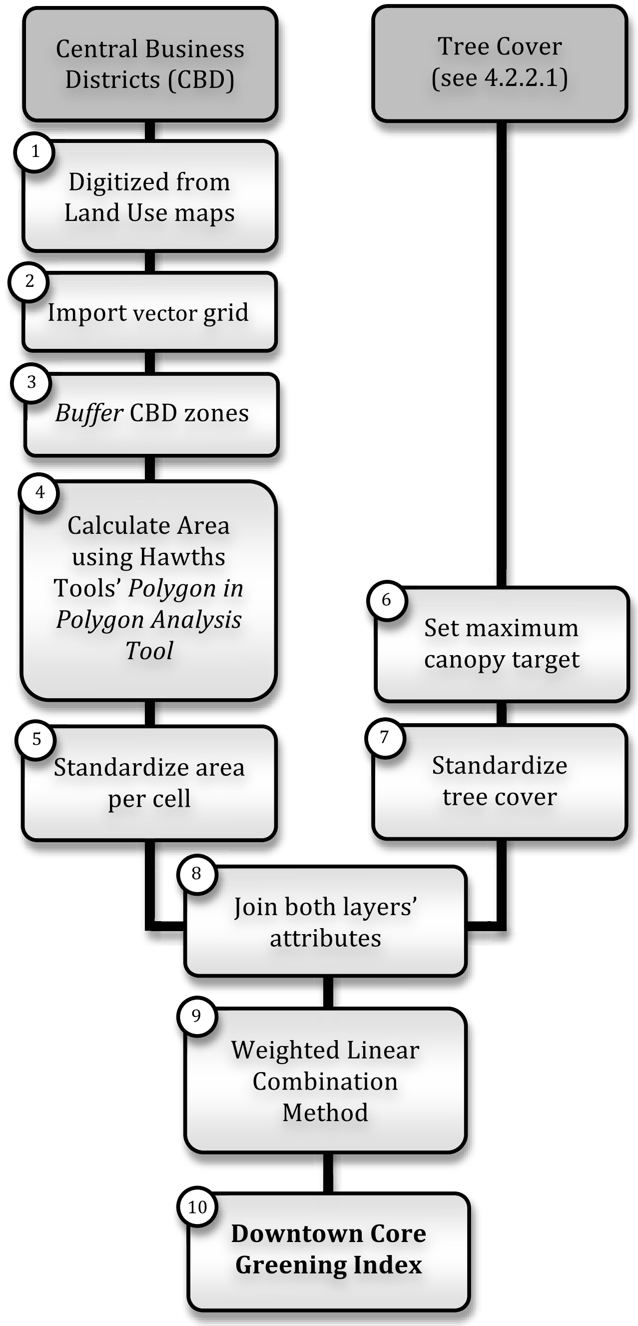


Figure 5.5. Conceptual diagram of GIS steps used in the Downtown Core Greening Index. It involves the analysis of central business districts and tree cover variables to generate the final index.

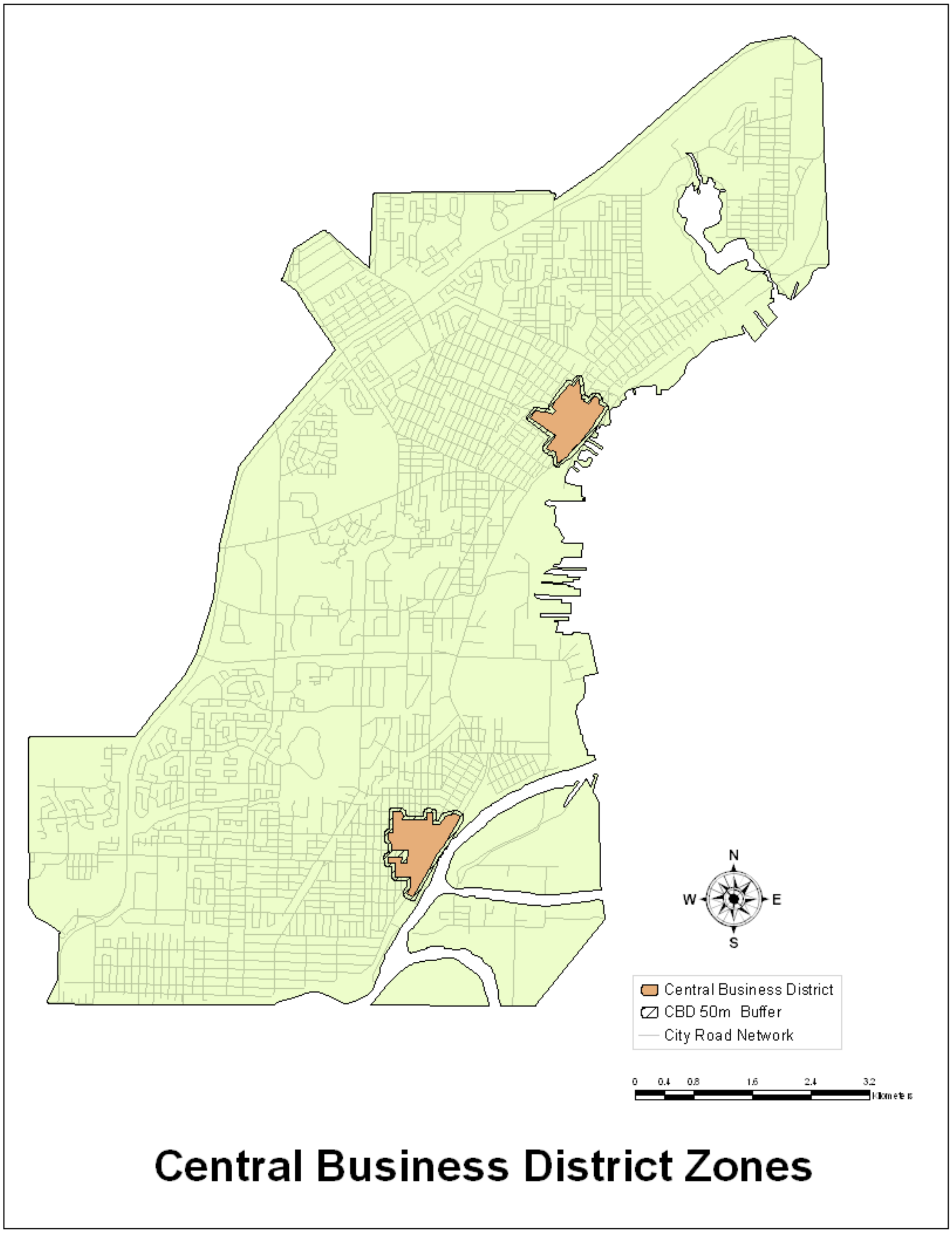


Figure 5.6 A map displaying Thunder Bay's two Central Business Districts (CBD) with a 50-meter buffer (white border). Both the CBD's and buffers make up the downtown core study area.

above 2000 m^2 were given a value of 0 (i.e., no need for planting)(Stages 5 in Figure 5.5). Values greater than 0 and tending towards 1 are those areas with tree cover less than 2000 m^2 and in need of planting.

5.3.2.2. Downtown Core Greening Index

After both the tree cover and CBD zone variables were standardized on a scale of 0 to 1, with 1 representing the management areas with the lowest tree cover and largest amount of central business district area, the individual scores were combined using the *join table* tool in ArcGIS (Stages 8 in Figure 5.5). A weighted linear combination method (Chang 2010) was then applied (Stages 9 in Figure 5.5) to calculate the Downtown Core Greening Index (Stages 10 in Figure 5.5). The weighted linear combination method is a frequently used technique of computing an index value for a vector-based model (Chang 2010). This method was discussed earlier in the stormwater task (see section 4.2.2.3) and allows for the weighting of the criterion depending on the users specification. Since no researchers to date have developed a formula or a weighting scheme for an index of this kind (like that of the PPI) the author chose to perform multiple weighting scenarios to demonstrate the effects of various weighted variables (Figure 5.7). The focus groups, used to select the link table tasks (see section 3.1.1), identified central business density as the priority and key variable. Therefore, the central business density variable was given a weight of four times the importance of tree cover.

5.3.3 Model Results

The Downtown Core Greening Index uses two variables: central business district score and tree cover score. This section provides the results of the central business district score and the final Downtown Core Greening Index. The tree cover score discussed earlier (see section 4.2.2.3) will be omitted in this section.

5.3.3.1. Central Business Districts Score

The City of Thunder Bay has two main Central Business Districts (see Figure 5.6). These two districts, with a 50-meter buffer, determined the study area for this task. Every management area completely within a Central Business District received a score of 1 (i.e., it had the entire 1 ha management area completely within the Central Business District). Any management areas that intersected a boundary received a value proportional to area within the Central Business District (using the weighted mean analysis using Hawth's Polygon to Polygon Tool). The results of this task were not summarized by neighbourhood because the study area was limited to within the boundary of the two Central Business Districts and made for easy interpretation (Figure 5.8).

5.3.3.1. Downtown Core Greening Index

The Downtown Core Greening Index is the combination of the Central Business District score and tree cover scores. Tree cover scores were imported from the stormwater task and a full description of its results is discussed in section 4.2. A

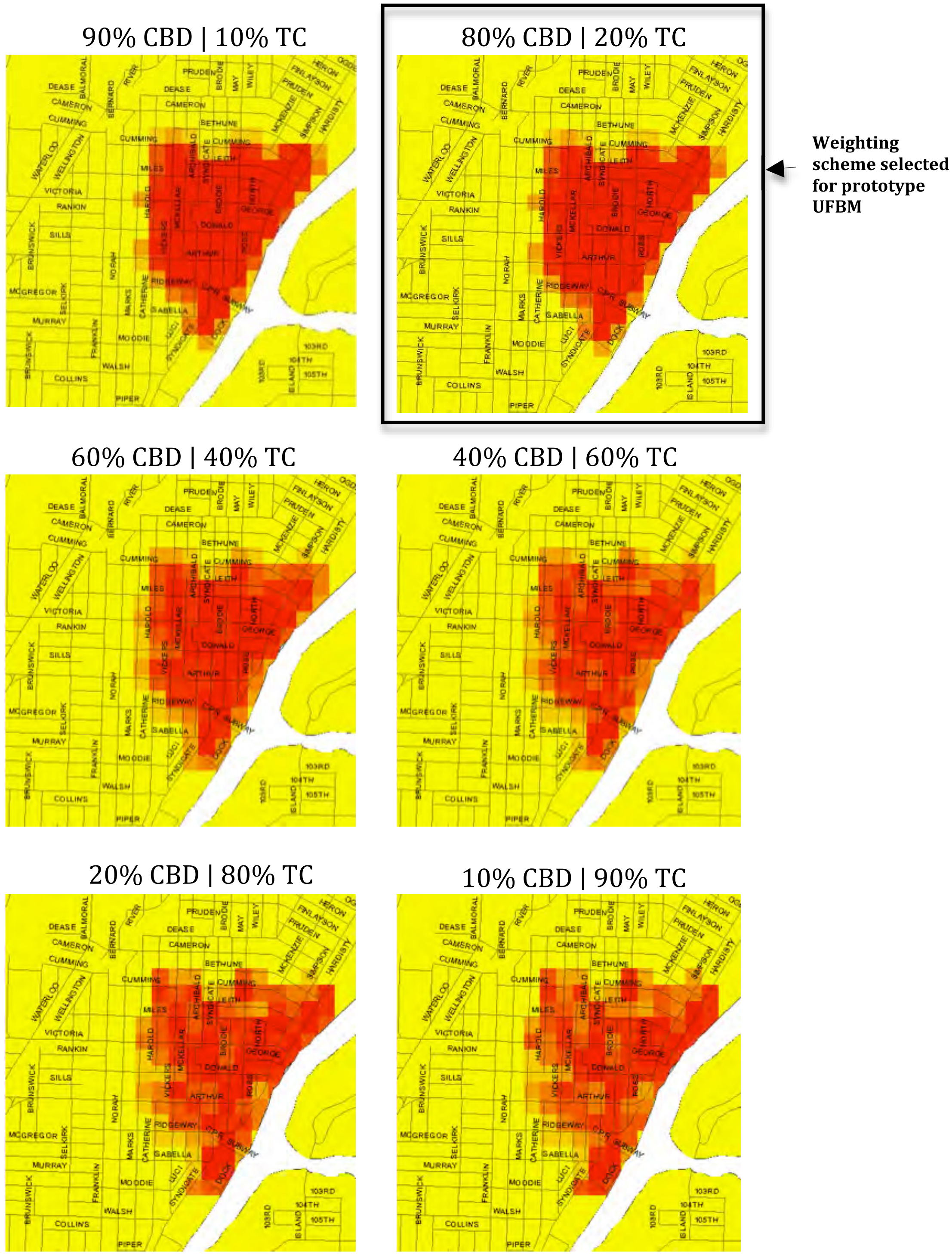


Figure 5.7. Maps of the downtown core greening index values for the south core of Thunder Bay displaying the various weighting scenarios of the central business district (CBD) zone and tree cover (TC) variables. Values tending towards 1 (red) indicate management areas that require focused greening, while those tending towards 0 (yellow) do not require greening. Each grid cell represents 1 hectare.

weighting of 4 was given to Central Business District score and a 1 to the tree cover score. The results were summarized in management areas of 1 ha in size and various colour shades (yellow to red) were used to denote a priority for greening (Figure 5.9).

5.3.4 Discussion and Recommendations for Planting Locations

Research has demonstrated the positive impact trees have on creating healthy and attractive downtown districts. The increase in aesthetics and functional space created by trees and other green infrastructure helps stimulate and strengthen the economic vitality of a downtown core. The Downtown Core Greening Index is a simple means to help municipalities prioritize greening schemes to the downtown core where present tree cover does not exist or is sparse. This task did not require sophisticated data inputs or analysis, like some of the other tasks, to determine the high priority zones. However, the areas that delineated the downtown cores needed to be spatially represented in vector grid format in order to be combined with other tasks in the final UFBM analysis. It is, therefore, recommended that this tasks be used in combination with the other UFBM tasks to help develop a more comprehensive priority greening (planting, maintenance and protection) index for the City. If there was a desire to better delineate priority areas within a downtown core or CDB zone, one could have used one or two other weighting scenarios shown in Figure 5.7.

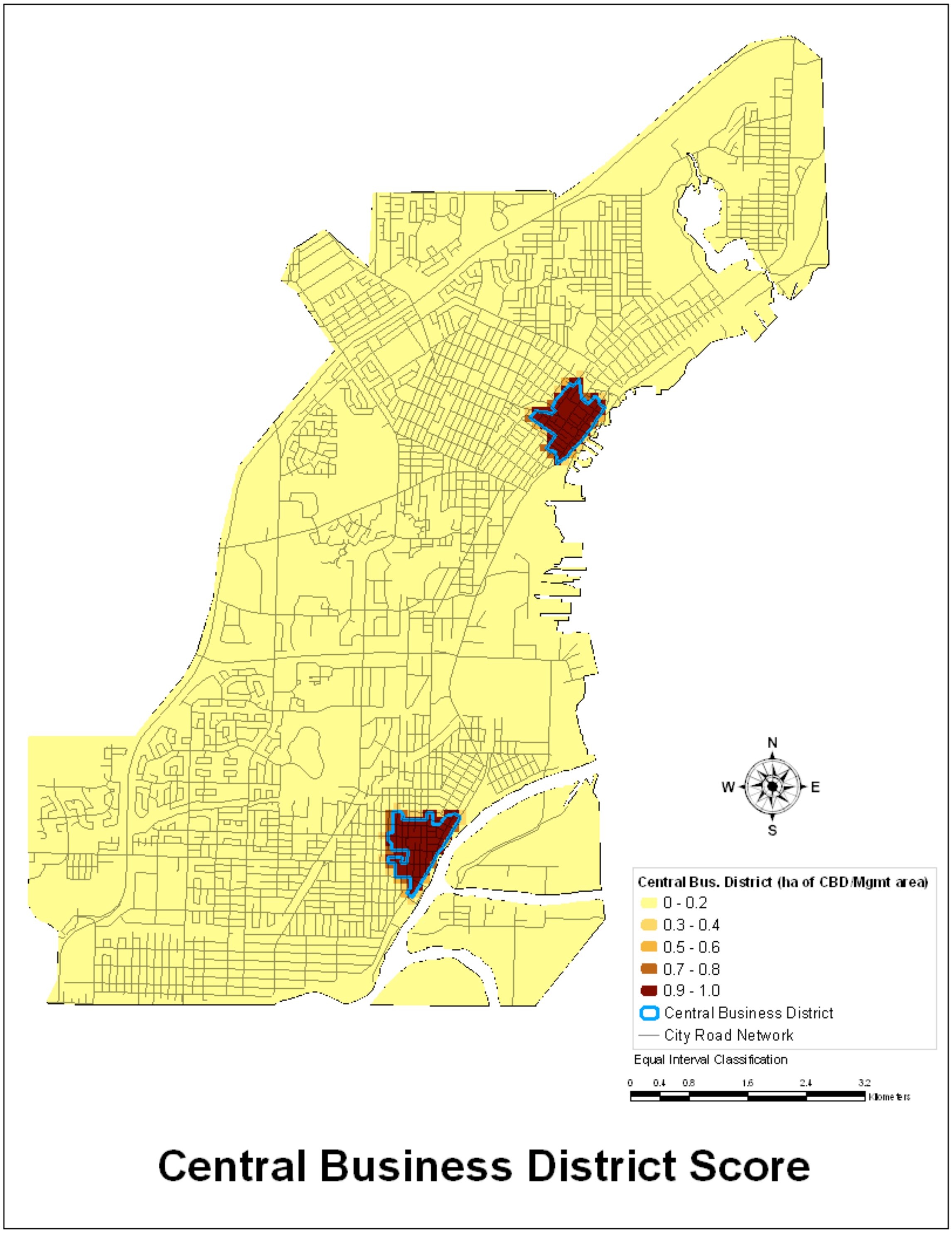


Figure 5.8. A map displaying the values of the Central Business District (CBD) variable for each management area. The score is determined by the amount of CBD area that is within a respective grid cell. Each grid cell represents 1 hectare. The darker shaded management areas have higher amounts of CBD area and hence, a greater priority for greening.

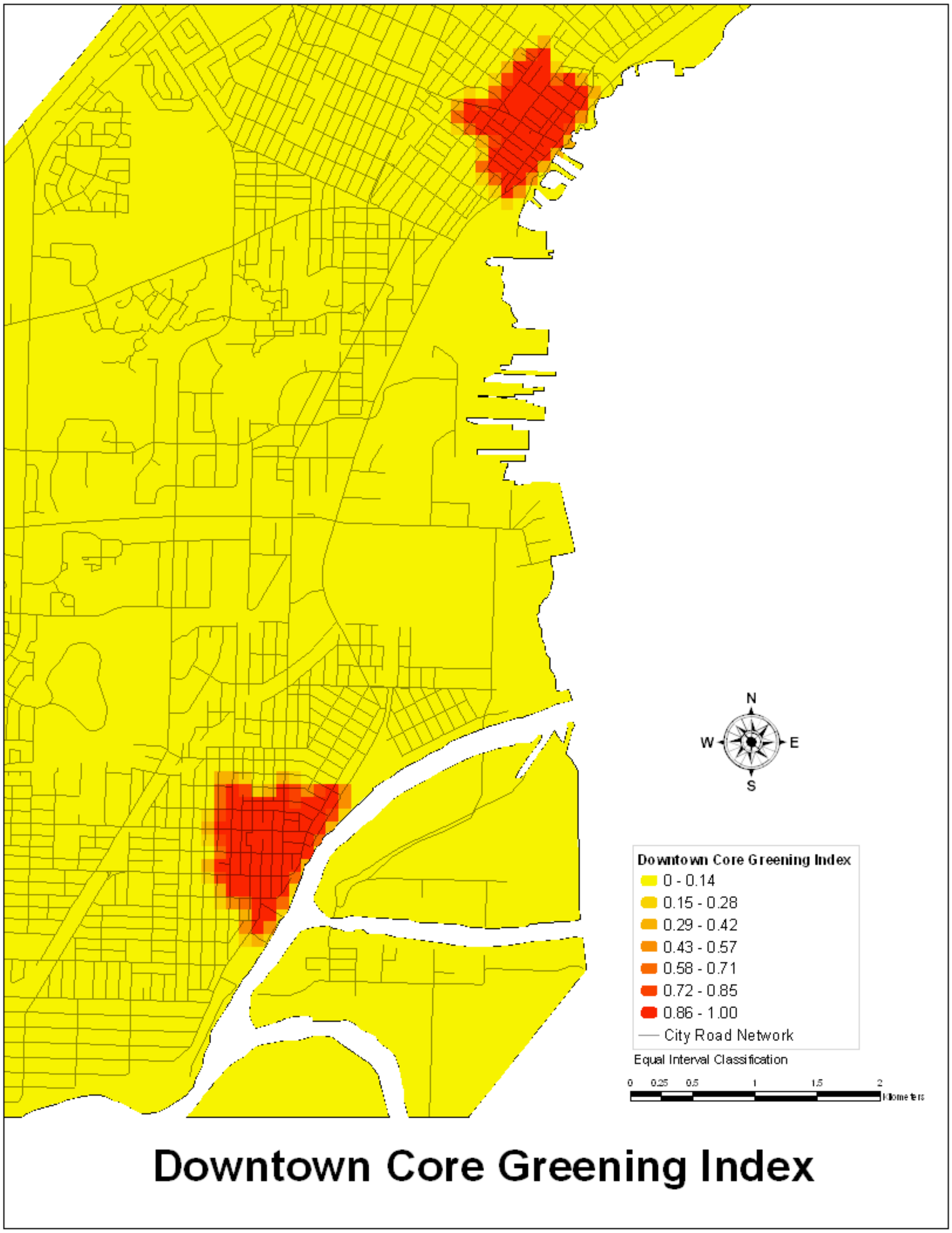


Figure 5.9. A map displaying the value of the Downtown Core Greening Index score for each management area. Each grid cell represents 1 hectare. The darker management areas have lower amounts of tree cover per capita and hence, a greater priority for greening.

5.4 Link Table Task Three: School Travel Greening Index

Rising levels of childhood obesity in North America and a 75% decrease in children walking to school has spurred the creation of policies and guidelines surrounding new ways to encourage active commuting to school (McDonald 2007). Policymakers in Ontario have begun to support active commuting through the development of child- and youth-friendly land use and transport planning guidelines (Gilbert and O'Brien 2009). The Ontario Professional Planners Institute also recently endorsed a set of 21 similar guidelines to prompt new approaches to plan for youth and foster healthy communities (OPPI 2009).

Research has demonstrated that a variety of obstacles deter active commuting by children to school: primarily poor neighbourhood and infrastructure design (no lights and/or signaled crossings, lack of sidewalks), parental perception of crime and safety, and busy roads/intersections (Timperio 2004; Timperio *et al.* 2006). Distance is also a factor that influences walking behaviour. One study suggests that 48% of children/youth living less than 1.6 km from school were shown to walk compared with 3% living further than 1.6 km (McDonald 2007). Other reports suggest that planners and community committees should focus their strategies within a 3-kilometer walkable and bicycle zone, and a closer walking zone within a kilometer of school (McDonald 2007; Gilbert and O'Brien 2009).

The negative factors, such as parental perception and distance, however, can be mitigated through good urban design and the integration of green infrastructure (OPPI 2009; Gilbert and O'Brien 2009). A study by O'Brien and Gilbert (2003) suggested that 75 percent of 6000 Ontario elementary school children would prefer to walk or cycle on a regular basis to school if the various limitations they faced were minimized. In the transition to redesigning neighbourhoods with an active-transport culture, green infrastructure plays an increasing integral role. The direct and indirect benefits provided by green infrastructure, most notably trees, are numerous. One of the strongest forces is an increase in the aesthetics of a street. Beautified streetscapes are more attractive and are used more frequently by pedestrians (Wolf 2004b). The more people actively commute on a street, the more people use a street, and the safer the street becomes. The safety of children also increases through the integration of trees that safeguard youth from traffic while functioning as a traffic-calming device (Wolf and Bratton 2006). As pedestrian traffics increases, so do social interactions among neighbhours and their community. These kind of social interactions are valuable for the development of children (Taylor *et al.* 2001).

Trees also affect the biophysical environment that can lead to a variety of benefits for youth as pedestrians. Trees moderate the extreme temperatures in both summer and winter and provide shade from harmful UV rays (Raciti 2006). The air and noise filtering capacity of green infrastructure is also significant (Nowak 1994; Beckett 2000) and creates more pleasant and healthy routes to school. Consequently with an increase in active transportation, the number of cars and congestion on the road are reduced, also decreasing harmful emissions.

Trees also support the healthy development of cognitive and other mental functions (Wells 2000). Walking to school is a perfect way to allow youth to be physically and mentally stimulated. A large body of literature suggests that humans have an innate connection with nature. Thus, the biophilic phenomena stimulated through such connections suggests that having daily interaction with nature helps to reduce stress, ADHD/ADD, poor temperaments/moods and helps to foster creativity and inquiry (Velarde *et al.* 2007; Taylor *et al.* 2001; Kuo and Sullivan 2001; Rappe 2007). In addition encouraging children to walk to school increases their independent mobility and contributes toward healthy mental development.

5.4.1 Task Objectives

The objective of the third link table task was to produce a priority greening index to benefit children when engaging in active, non-vehicle, transportation to and from school. The index ranks public tree greening locations (planting, maintenance and protection) based on proximity of roads to a school and existing tree cover. The closer a section of road is to a school and the less tree cover exists along that road, the greater the priority for increased canopy cover.

5.4.2 Modeling Approach

Two variables are used in the School Travel Greening Index: road proximity to a school and target tree cover per road length. The data to assist in the quantification of tree cover were provided by the City of Thunder Bay Parks Department in the form of street tree data. Only public street tree data were used for this study, primarily because street trees play a critical role in influencing active transportation (e.gs., providing shade, beautifying a streetscape, calming traffic, protecting pedestrians), when compared to trees further set back from the road (e.g., a resident's backyard tree). The public tree data were processed in the same manner the public and private tree data were for previous management tasks and will be discussed further in section 5.4.2.1. The spatial locations (and selected attributes) of Thunder Bay schools (both public and seperate school boards) were provided by Dr. Todd Randall (pers. comm., 2011). These data consisted of 37 operational schools (as of 2008) that serve students between Grade 1 and Grade 12. The City of Thunder Bay Planning Department provided the road data used in proximity to schools. A complete list of data requirements used for this task is found in Table 5.1.

The following section provides a detailed description of the methodology used in developing the School Travel Greening Index, including a discussion of GIS operations and equations used, data requirements, and simplifying assumptions. The discussion of the School Travel Greening Index is organized into three sections based on the stages shown on Figure 5.10: (1) tree cover per road length (Stages 1-11); (2) proximity to school (Stages 12-20); and (3) the School Travel Greening Index (Stages 21-23).

5.4.2.1. Optimum Tree Cover per Road Length Score

The optimum tree cover per road length score (or variable) provides an indication of the amount of tree cover found along a given section of road and identifies how much additional tree cover is required to meet some target tree cover. If the current tree cover is below the desired target amount, then greening activities (i.e., planting, maintenance, and protection) are prioritized for these areas over others. To determine tree cover per road length, the public tree point locations were first imported into ArcGIS where the tree height attributes were converted to canopy width classes (see methodology and justification in Section 4.2.2.1)(Stage 2 in Figure 5.10). The tree data were then buffered based on the canopy class attribute using the *Buffer* tool to produce a realistic representation of canopy cover on the spatial layer (Stage 2 in Figure 5.10). A *Multipart to Singlepart* function was applied (Stage 3 in Figure 5.10) and a vector grid was created at a resolution of 100m using Hawth's Tools (Stage 4 in Figure 5.10). Hawth's Polygon to Polygon Analysis Tool was then used to determine the amount of tree area in each vector grid cell. This tool has the ability to derive a weighted mean statistic from each polygon in the summary layer (tree canopy) that overlaps a zonal polygon (vector grid cell). It then generates the weighted mean of the summary layer and writes it to a new field in the zonal layer (Stage 5 in Figure 5.10)(see previous detail in Figure 4.21 and its associated text for further discussion).

The next step is to intersect the road network with another 100m-resolution vector grid (Stage 6 of Figure 5.10). This allows the road network to be cut into lengths within the boundary of each grid cell. The *calculate geometry* function was then used to calculate the length of road. The *summarize* function then provided the sum length of road found in each cell and prints the results to a DBF file (Stage 7 of Figure 5.10). This DBF file is then joined back to a new vector grid (Stage 8 of Figure 5.10) and displays the results in road-meters per management area.

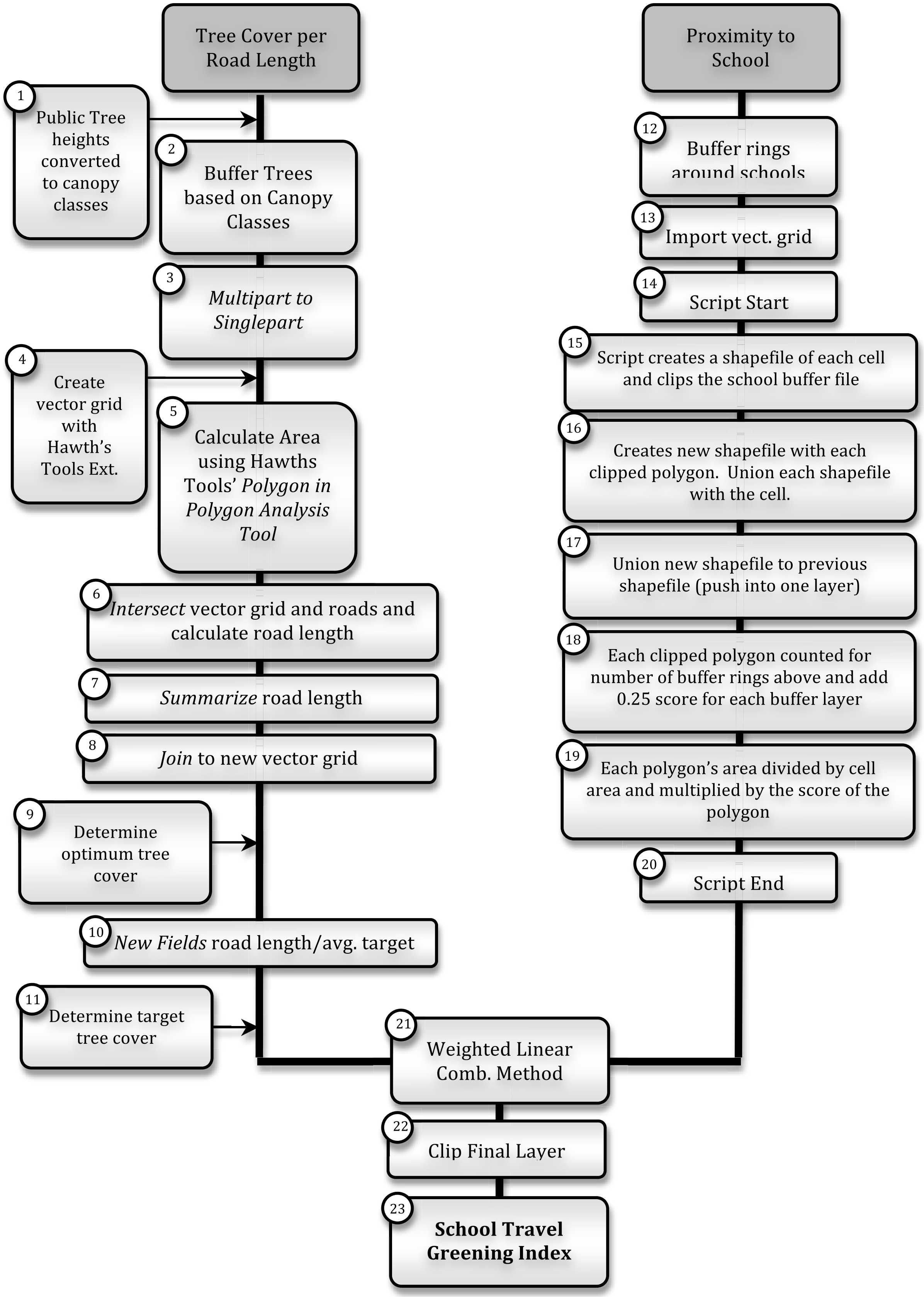


Figure 5.10. A conceptual diagram of GIS steps used in the school travel greening index task. It involves the analysis of tree cover per road length, and a management area's proximity to school.

The target tree cover for streetscapes was then determined. According to *The Road to a Thoughtful Street Tree Master Plan*, intermediate sized trees have a mature crown spread of 35 to 50 feet (or 10.6 to 15.2 m) (Simons and Johnson 2008). These sized trees are similar to those of average mature trees in Thunder Bay (Vescio, pers. comm. 2010), and should be spaced somewhere between 30 to 50 feet apart (or 9.1-15.2 m)(Simons and Johnson 2008). Therefore, an average of 40 feet (12.2 m) spacing was used. To determine the optimum tree cover for a street, the following formula was developed and applied (Stage 9 of Figure 5.10):

Equation 5.3

$$OTC = \left(\frac{r}{t}\right) \times 2 \times c$$

where, OTC is the optimum tree cover along a road, r is road length (in meters), t is the average ideal spacing for planting trees along a road (in meters), and c is the average canopy area for one mature intermediate tree (in square meters). In a new attribute field, the existing tree cover (Stage 5 in Figure 5.10) is then subtracted from the optimum tree cover to determine the target tree cover for a given management area (Stage 10 and 11 in Figure 5.10) (Figure 5.11).

5.4.2.1. Proximity to School Score

The proximity to school score (or variable) indentifies the management areas that are closest to schools. The closer a management area is to a school, the more important it is to carry out greening activities (planting, maintenance, protection) in

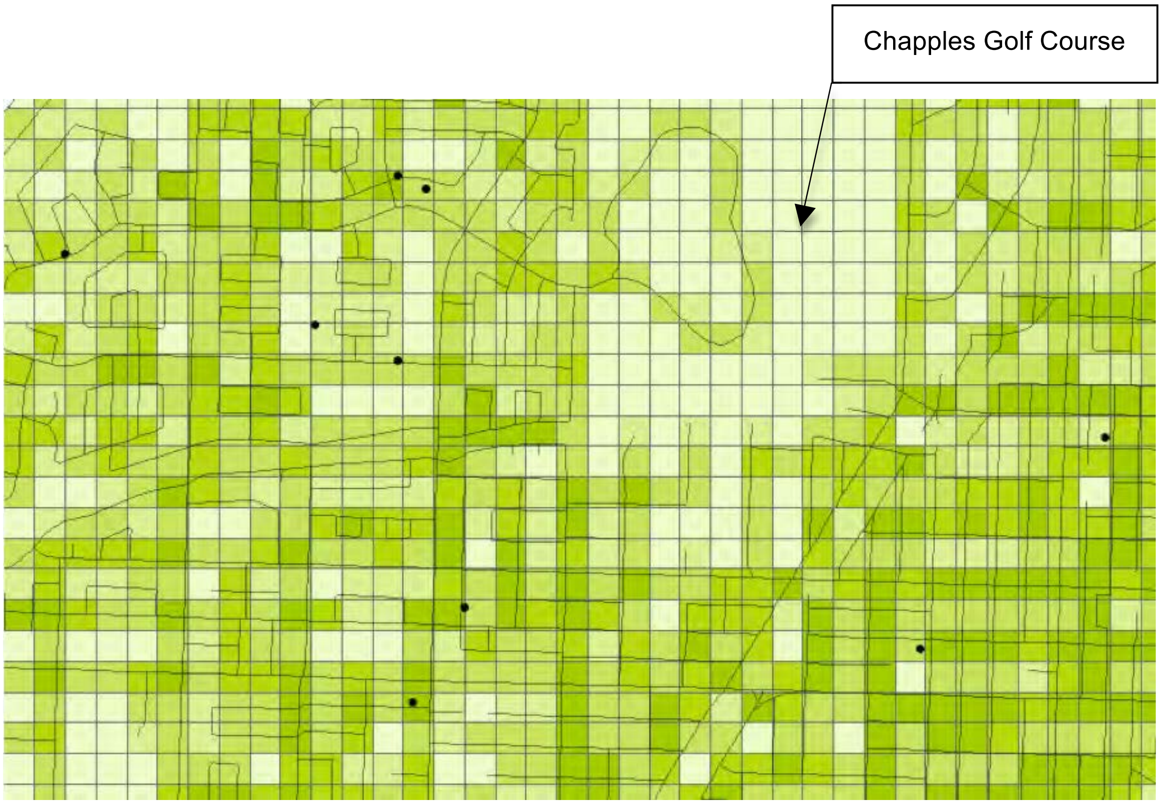


Figure 5.11. A map from ArcGIS displaying the target public tree cover summarized for each management area. Each grid cell (management area) represents 1 hectare. In this map, the darker the management area the lower the amount of tree cover per road length and thus, a greater priority for street tree greening. Operating Thunder Bay schools are represented by black dots.

it. Studies suggest that age plays a role in determining how far a student will walk to school (i.e., elementary school students will walk less of a distance than high school students)(Gilbert and O'Brien 2009). It should be noted that for the prototype UFBM, school type (e.g., elementary and high schools) was not differentiated. The school locations data (as a point shapefile) were imported into ArcGIS and a *Multiple Ring Buffer* function was applied to each school (Stage 12 in Figure 5.10). The buffers applied to each school were at a distance of 250m, 500m, 750m and 100m. A variety of urban planning documents and guidelines have established home-to-school walking distances and have suggested that students will walk between 1-3 kilometers to school, although these vary with age. A number of walkability indices also use approximately 1 km as a threshold distance to suggest that walking rates significantly drop as this value increases (Timperio *et al.* 2006; McDonald 2007). Therefore, the School Travel Greening Index used 1 km as the priority zone for greening around schools. As discussed earlier, trees foster healthier neighbourhoods and encourage active transportation by creating safer, quieter, and social avenues to school. With the 1 km threshold being established as the target area, the buffer was split into four 250-meter priority zones (Figure 5.12). As a generalization, more children will walk through the 0 to 250-meter zone going to and from school than the other zones (children walking from 500 meter and 750 meter zone still have to travel through the 250 meter zone to reach school) and therefore it receives a higher priority (or weight). The various zones and their respective buffers and weights are seen in Table 5.3.

Table 5.3. Zones and their respective buffer distances and weights used in the School Travel Greening Index.

Zone	Buffer distance	Weight
250m	0 - 250m	1
500m	251 - 500m	.75
750m	501 - 750m	.5
1000m	751 - 1000m	.25

Figure 5.12. A screenshot of the various multiple ring buffers surrounding schools for a portion of Thunder Bay schools. The schools are represented by black dots, the red buffers are the 250m zones (weight of 1), the orange buffers are the 500m zones (weight of .75), the light green buffers are the 750m zones (weight of .50), and the dark green are the 1000m zones (weight of .25).

The school buffers created in stage 12 (in Figure 5.10) were not dissolved to allow for continued analysis in stages 14 – 20 (in Figure 5.10). A vector grid with a 100m resolution was then imported into the ArcGIS project (Stage 13 in Figure 5.10). At this point, normally Hawth's Polygon to Polygon Analysis would be sufficient to determine total area of buffers within each cell (like other previous polygon to polygon analysis performed with the other management tasks). However, non-dissolved multiple ring buffers that are layered on top of each other, like those in this index, require a different method of analysis due to the complexity and number of calculations (Figure 5.13). An analysis of this kind is possible using a manual approach but time consuming. To expedite repetitive calculations, a script was developed with the assistance of T. Sapic in conjunction with Lakehead University's GIS Lab (pers. comm., 2011)(see Appendix VII for the script). The script, developed in Python programming language was needed to calculate the weighted mean area and final weight for each overlapping segment in a management area. It began by creating a shapefile of each grid cell in the Thunder Bay study area. All intersecting buffer lines in each cell then get cut up into different polygons with the clip tool (some as numerous as 30 polygons) (Figure 5.14)(Stages 15 in Figure 5.10). The script then takes each individual clipped polygon and creates a new individual shapefile with it (e.g., a cell with 30 polygons would have 30 new shapefiles associated with it). These new shapefiles are then individually unioned back to its origin cell (i.e., based on the example of 30 polygon sections above, 30 individual shapefiles are unioned to its origin cell)(Stage 16 in Figure 5.10). Each shapefile (polygon in a cell) is then unioned to the previous shapefile, until the process re-flattens all shapefiles into one plane (Stage 17 in Figure 5.10). The script then takes each polygon in the flattened cell and measures how many buffer zones occupy that same space, above or below it. For each buffer zone occupying the same space the script adds a weight value of 0.25 to that polygon (Stage 18 in Figure 5.10). The weight of 0.25 is used to correspond with the weighting values of multiple ring buffers discussed earlier (Figure 5.15). Once each polygon had been counted and multiplied by the weight of 0.25, the script divides the polygon area by the area of the cell (10,000 m^2) to calculate the proportion of area occupied by the polygon. The resulting polygon area is multiplied by the polygon's weight and results in a final score for that polygon. Subsequently, the sum of all the polygon's scores in a cell (or

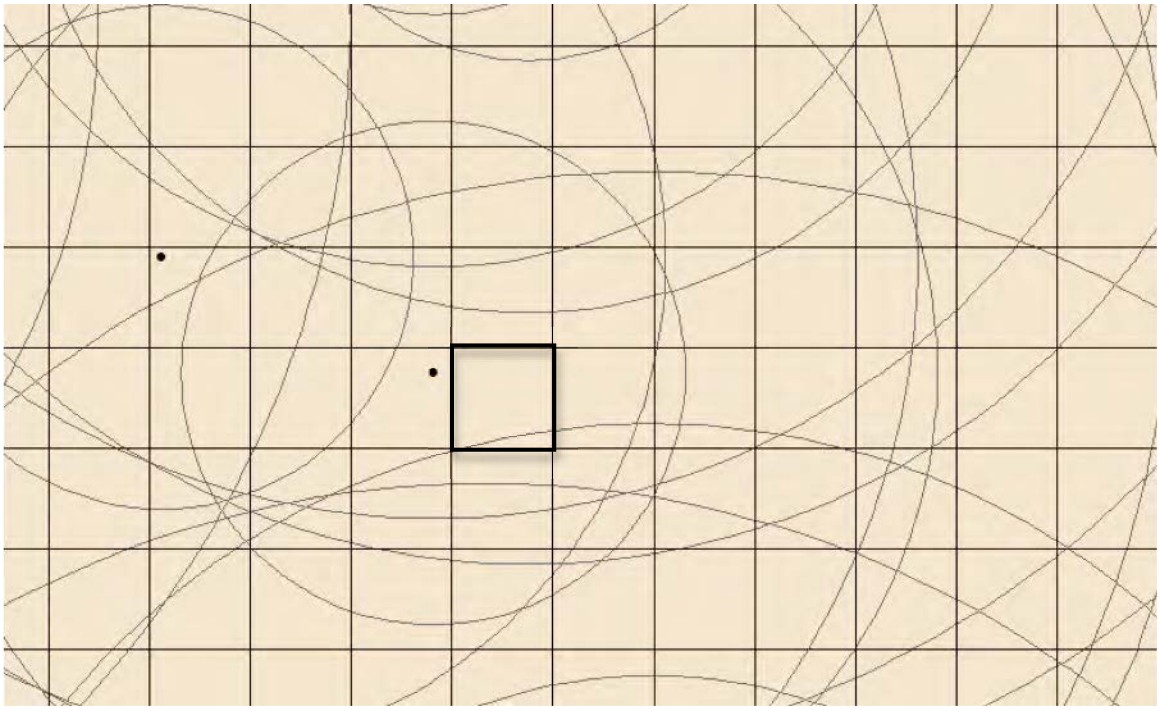


Figure 5.13. A screenshot demonstrating the various layers of buffer zones that can intersect management areas (or grid cell). In school-dense areas, the buffer zones are numerous and overlapping. For example, the outlined cell above, intersects with 12 different buffer zones (from 4 different schools). Schools are represented by black dots, and buffer zones are represented by curved light-black lines. The method to calculate the results of each cell's score is discussed and illustrated further in Figure 5.15.

management area) result in the Proximity to School score (see example in Figure 5.16) (Stage 19 in Figure 5.10). These results provide an indication of how important a management area is to increase tree cover, based on its proximity to schools. The methods used to standardize these scores are discussed in the following section.

5.4.2.1. School Travel Greening Index

After both the Tree Cover per Road Length score and Proximity to Schools score were determined, both variables were standardized on a scale of 0 to 1, with 1 representing the management areas with the lowest tree cover per road length and the largest proximity to schools score (closest to a school). To calculate the School Travel Greening Index (Stage 23 in Figure 5.10), the scores were standardized and weighted using Chang's (2010) weighted linear combination method (Stage 21 in

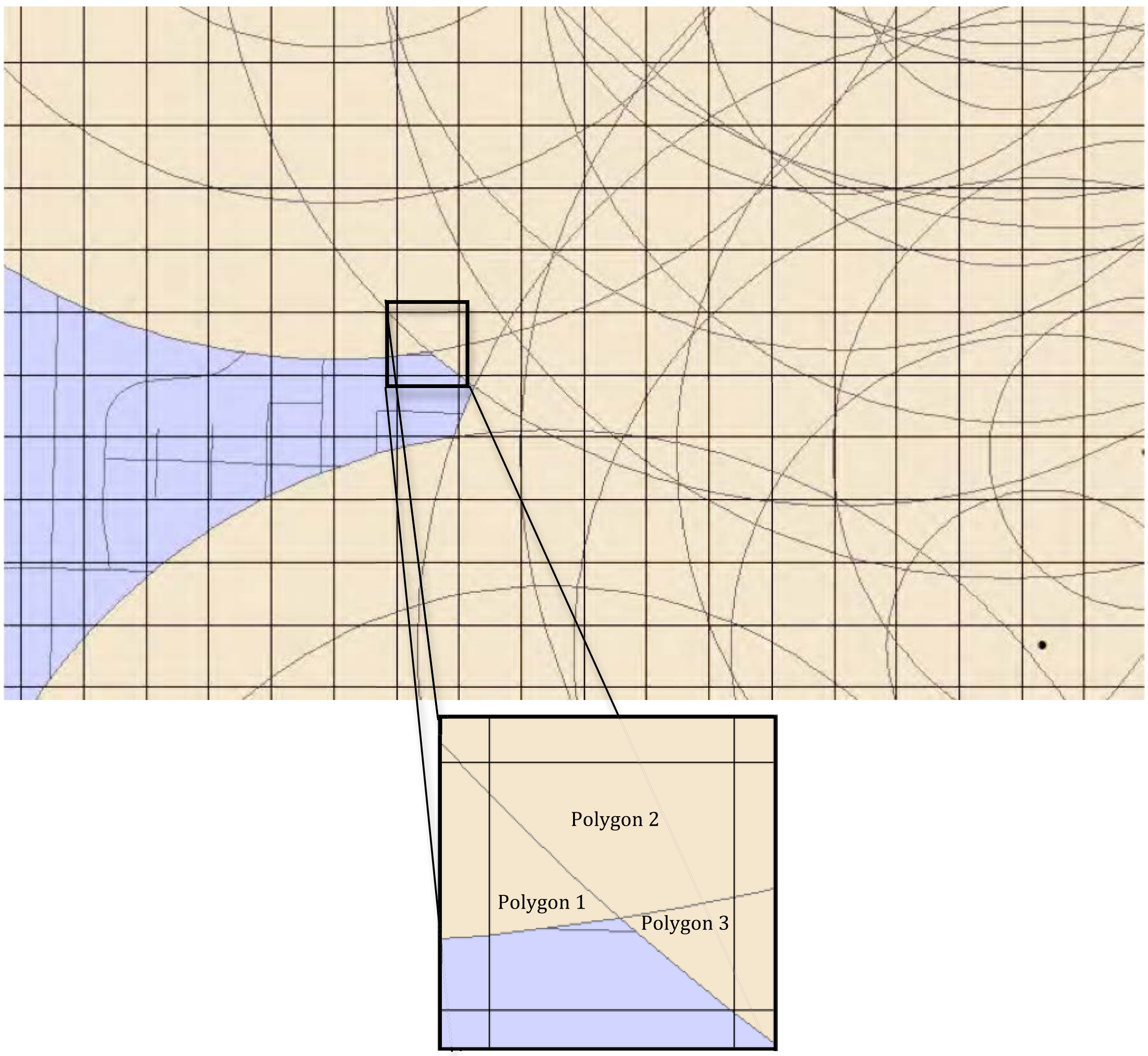


Figure 5.14. The script has clipped 3 separate polygons in this management area (or grid cell)(at stage 15 in Figure 5.9.)

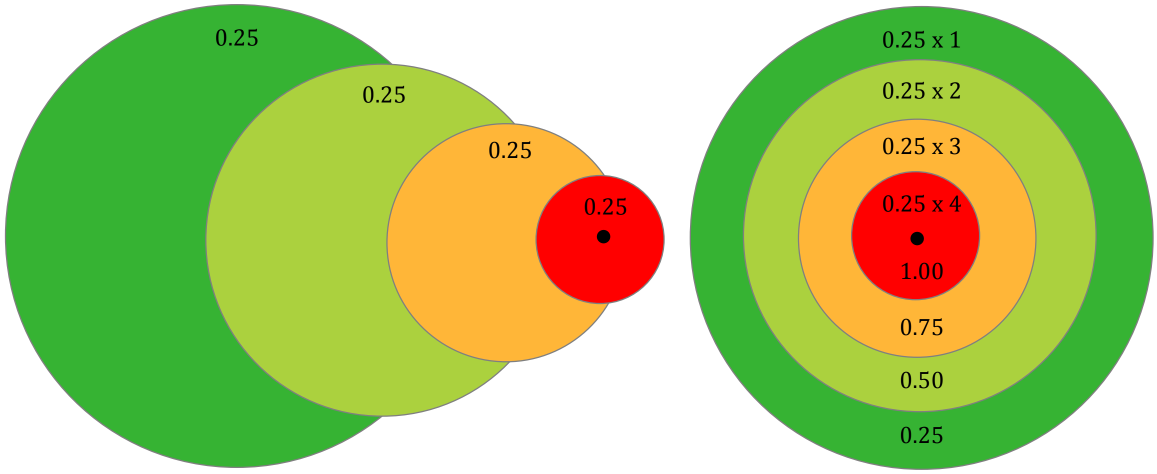
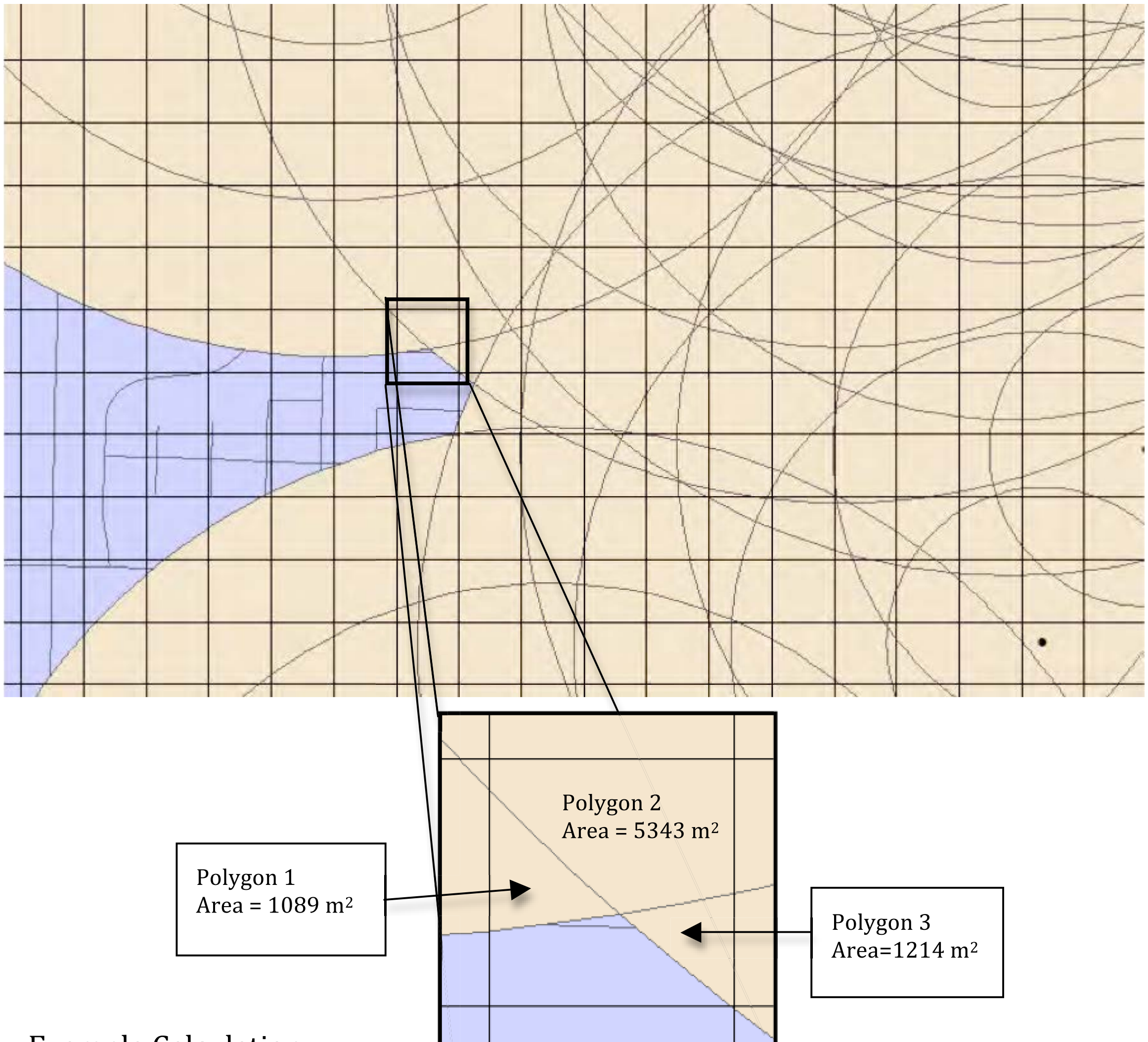


Figure 5.15. A multiple ring buffer indicating that each buffer is weighted individually with a score of 0.25 but when added together with overlaying buffers its weight is the sum of its layers. For example, the centre red buffer has total weight of 1.00 due to the addition of the other buffers below it (0.25 + 0.25 + 0.25 + 0.25).

Figure 5.10). The final index was then clipped to represent only the management areas that intersect with both roads and school buffers (all other areas were given a score of zero) (Stage 22 in Figure 5.10).

The weighted linear combination method was discussed earlier in the stormwater task (see section 4.2.2.3) and allows for the weighting of an index's weighting input variables depending on the user's specification. Since no researchers to date have developed a formula or a weighting scheme (like that of the PPI) for an index of this kind the author chose to perform multiple weighting



Example Calculation

Polygon 1:
1 layer deep
Score = 1 x 0.25 = 0.25
Cell Area = 1089/10000 = 0.11
Polygon Score = 0.022

Polygon 2:
2 layers deep
Score = 2 x 0.25 = 0.50
Cell Area = 5343/10000 = 0.53
Polygon Score = 0.265

Polygon 3:
1 layer deep
Score = 1 x 0.25 = 0.25
Cell Area = 1214/10000 = 0.12
Polygon Score = 0.03

Total Cell Score: 0.022 + 0.265 + 0.03 = 0.317

Figure 5.16. An example calculation used to determine the final Proximity to School score. The score of each polygon in the cell above is summed, resulting in the Proximity to School score.

scenarios to demonstrate the effects of various weighted variables (Figure 5.17). The focus groups, used to select the link table tasks (see section 3.1.1), identified proximity to school as the priority variable. Therefore, the proximity to school variable was given a weight of four times the importance of tree cover.

5.4.3 Model Results

The School Travel Greening Index uses two major variables: tree cover per road length (TC) and a management area's proximity to school (PTS). The results pertaining to each of the two variables and the combined School Travel Greening Index are provided in the following sections.

5.4.3.1. Tree Cover per Road Length Score

The main objective of this score was to identify the need for additional tree cover required along Thunder Bay roads. If the present tree cover is below the targeted tree cover, then greening activities (planting, maintenance, and protection) are prioritized for these areas to benefit and encourage children to walk or bike to school. The results for the tree cover per road length variable for management areas at a resolution of 1 ha are shown in Figure 5.18.

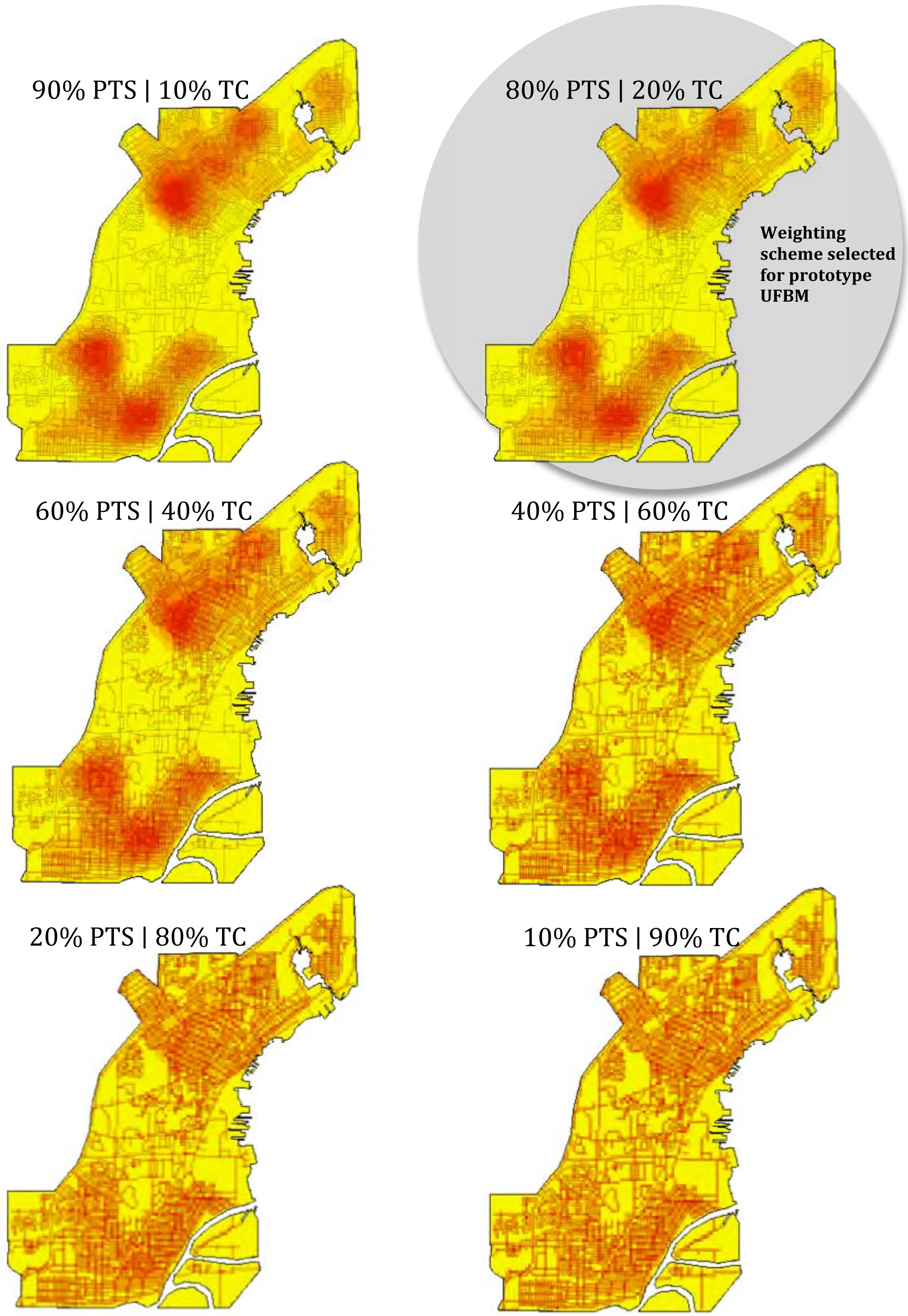


Figure 5.17. Maps of the school travel greening index for Thunder Bay, displaying the various weighting scenarios of proximity to schools score (PTS) and tree cover per road length score (TC). Values tending towards 1 (red) indicate management areas that require focused greening, while those tending towards 0 (yellow) do not require greening. Each grid cell represents 1 hectare.

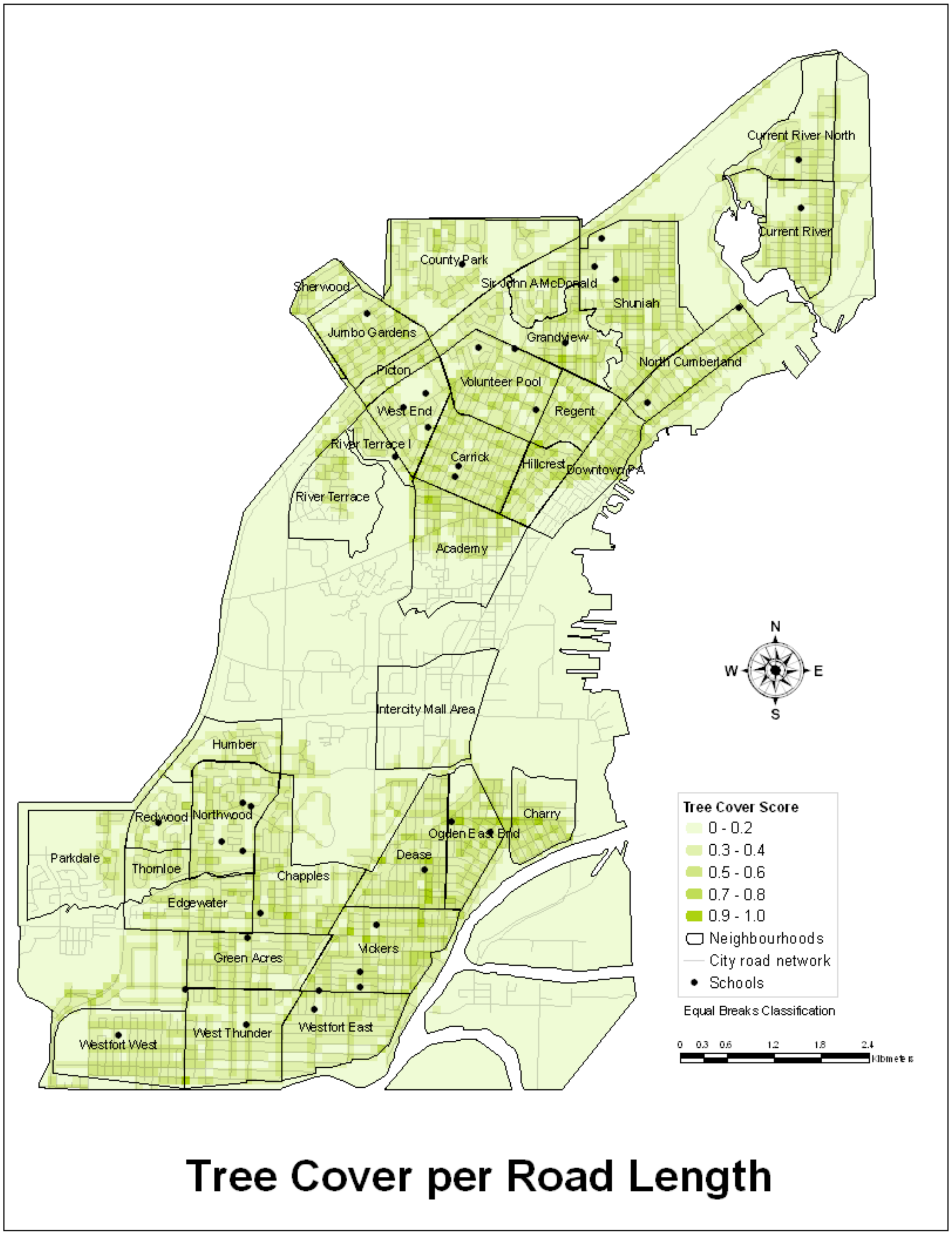


Figure 5.18. A map displaying the value of the tree cover per road length variable summarized for each management area and clipped to within 1 km of a school in Thunder Bay. Each grid cell represents 1 hectare. Darker shades of green have a higher score (or low canopy cover per road length) and hence, a greater priority for planting.

Neighbourhoods were summarized according to score (Table 5.4), and neighbourhoods with the highest average score and priority for greening were Downtown Port Arthur, Hillcrest, and Vickers with average scores of 0.47, 0.46, and 0.45 respectively. These sections scored the highest because of the denser road network (in areas) which increases road length value per management area, in conjunction with a lower presence of tree cover along these roads. The neighbourhoods with the lowest mean scores, were Parkdale, River Terrace, and County Park with a .0.20, 0.25 and 0.27 mean score respectively. These scores were influenced by the large tracts of land without roads that are included in their boundary. The skewing of the neighbourhood summary results due to boundary lines were discussed in previous sections (see 4.3.3.2). The neighbourhood summary results provide a general overview and indication of the average results, however it should be noted that the individual management areas are the intended focus for supporting decision makers in their greening activities, and not the neighbourhood zones.

5.4.3.1. Proximity to School Score

The estimate of the proximity to school score is to identify the management areas that are closest to schools. The closer a management area is to a school (or a cluster of schools), the higher the score and the more important it is to carry out greening activities (planting, maintenance, and protection). The results for the proximity to school score variable for management areas at a resolution of 1 ha are shown in Figure 5.19.

Table 5.4. Summary by neighbourhood of average tree cover per road length score, average proximity to school score, and average School Travel Greening Index. Values of this index tending toward one are in greater need of greening. Average proximity to school score and average School Travel Greening Index results will be discussed in sections 5.4.3.2 and 5.4.3.3 respectively.

Neighbourhood	Area (ha)	# of Grid Cells[1]	Average Tree Cover per Road Length Score	Average Proximity to School Score	School Travel Greening Index
Academy	170.8	206	0.24	0.11	0.14
Carrick	119.9	152	0.43	0.56	0.53
Chapples	148.3	239	0.34	0.38	0.37
Charry	79.4	105	0.32	0.11	0.16
County Park	217.4	264	0.27	0.20	0.22
Current River	119.6	151	0.32	0.22	0.24
Current River North	113.8	147	0.28	0.18	0.20
Dease	128.6	158	0.42	0.32	0.34
Downtown PA	90.8	126	0.47	0.07	0.15
Edgewater	101.9	132	0.35	0.30	0.31
Grandview	134.6	191	0.32	0.41	0.39
Green Acres	118.2	145	0.37	0.48	0.46
Hillcrest	59.2	80	0.46	0.11	0.18
Humber	72.8	99	0.29	0.13	0.17
Intercity Mall Area	179.8	211	0.29	0.01	0.06
Jumbo Gardens	105.9	136	0.35	0.23	0.26
North Cumberland	87.2	120	0.38	0.17	0.22
Northwood	131.8	162	0.33	0.60	0.55
Ogden East End	91.1	122	0.43	0.36	0.38
Parkdale	158.6	180	0.20	0.03	0.06
Picton	30.1	49	0.39	0.44	0.43
Redwood	61.4	84	0.29	0.33	0.33
Regent	68.3	94	0.41	0.25	0.29
River Terrace	120.2	152	0.25	0.07	0.11
River Terrace I	27.9	47	0.29	0.49	0.45
Sherwood	42.1	73	0.27	0.10	0.14
Shuniah	226.6	280	0.35	0.32	0.33
Sir John A McDonald	65.6	89	0.32	0.38	0.37
Thornloe	43.1	58	0.30	0.16	0.20
Vickers	161.4	198	0.45	0.49	0.48
Volunteer Pool	133.8	165	0.39	0.51	0.49
West End	83.6	113	0.32	0.72	0.64
West Thunder	155.3	187	0.34	0.31	0.32
Westfort East	131.2	157	0.36	0.42	0.41
Westfort West	148.6	178	0.31	0.18	0.21

[1] This is a count of full and partial grid cells intersecting each defined neighbourhood.

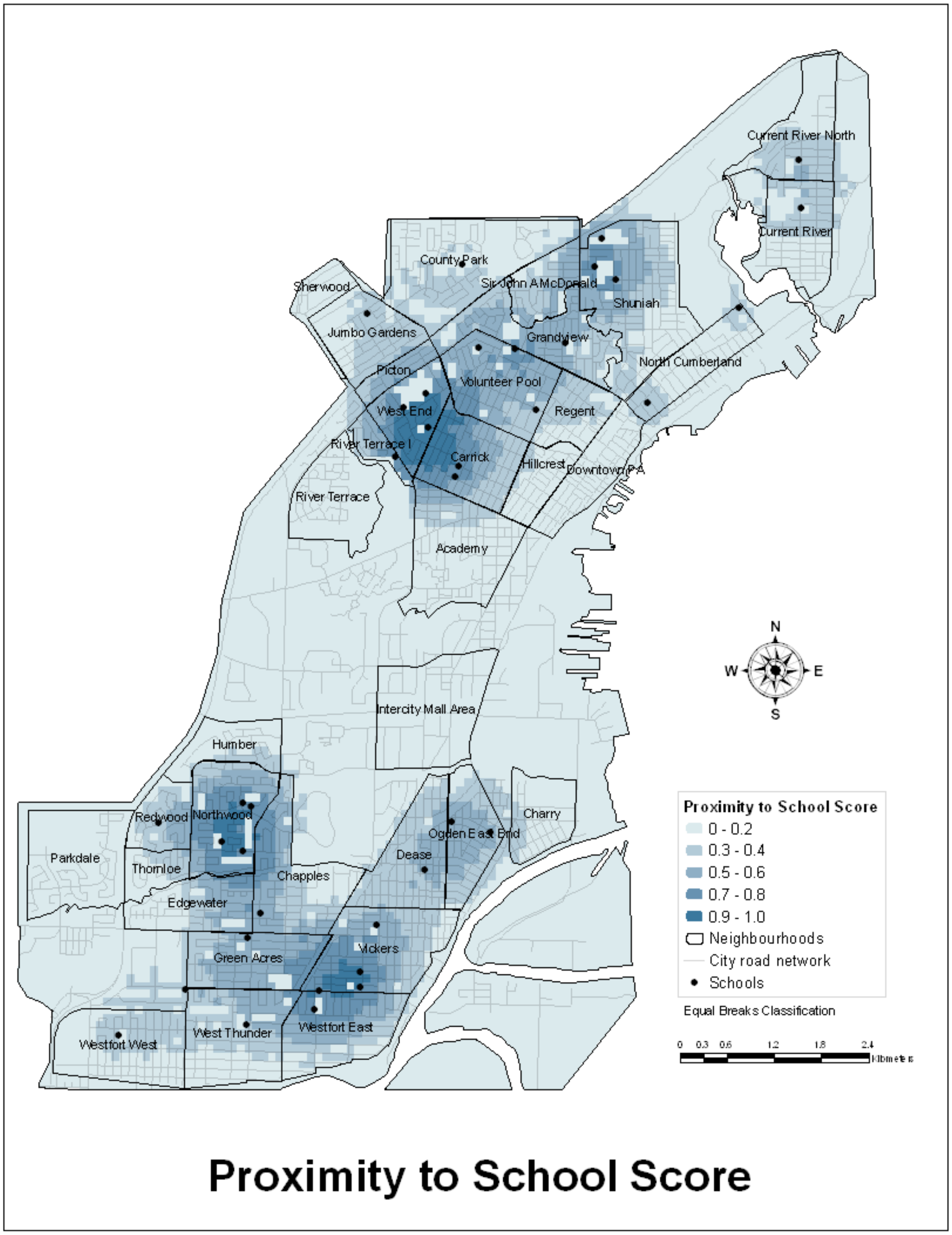


Figure 5.19. A map displaying the value of a management area's proximity to school variable for the City of Thunder Bay. Each grid cell represents 1 hectare. Darker blue management areas have higher scores (close to school) and hence, a greater priority for planting.

Management areas that were surrounded by multiple schools scored the highest. The five highest scoring management areas were located in the West End and Carrick Neighbourhoods (Figure 5.20) and were surrounded by seven schools. A summary of tree proximity to school by neighbourhood (Table 5.4) demonstrated that the West End, Northwood, and Carrick neighbourhoods had the highest average score at 0.72, 0.60, and 0.56 respectively. Intercity Mall Area, Parkdale, River Terrace, and Downtown PA had the lowest average score at 0.01, 0.03, 0.07 and, 0.07 respectively.

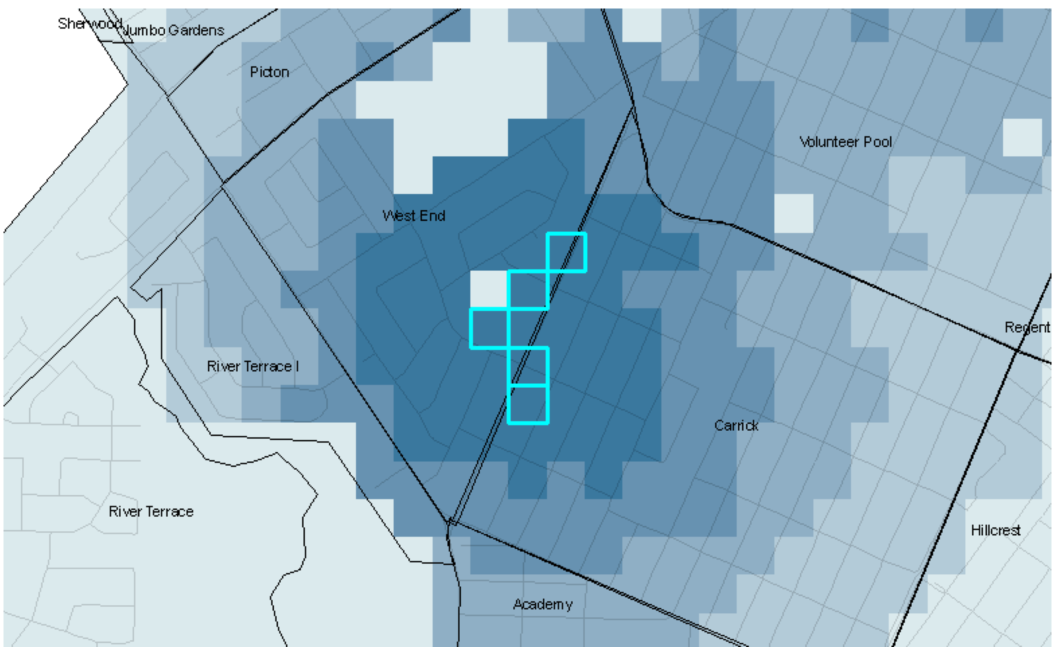


Figure 5.20. A screenshot from an ArcGIS project of Thunder Bay displaying the five highest scoring *proximity to school* management areas in Thunder Bay (highlighted cells). Their scores ranged between 1 and 0.95. Each grid cell represents 1 hectare.

5.4.3.2. School Travel Greening Index

The School Travel Greening Index is the combination of both previous scores (tree cover per road length and proximity to schools) into one index. The results were summarized in management areas of 1 ha in size and various colour shades (yellow to red) were used to denote a priority for greening (Figure 5.21). Higher scores indicated a greater priority for planting. The results were also summarized in tabular form (Table 5.4)

Five management areas with the highest index value were located in the West End and Carrick neighbourhoods (Figure 5.22). These differed from the highest scoring cells in the Proximity to School score (see Figure 5.20), due to the influence of existing tree cover in this area. Neighbourhoods were also summarized by average index values. The highest average index value (highest priority to plant) were from the West End, Northwood and Carrick values of 0.64, 0.55, and 0.53 respectively. These neighbourhoods ranked highest due to the dense concentration of schools that were contained within the neighbourhood or adjacent neighbourhoods. Neighbourhoods that ranked the lowest average index score were Intercity Mall Area, Parkdale, and River Terrace neighbourhoods at 0.06, 0.07, and 0.11 respectively. These neighbourhoods ranked the lowest primarily because their distance to a school exceeded 1km.

5.4.4 Discussion and Recommendations for Planting Locations

Trees play a significant part in growing strong healthy communities that embrace a culture of active-commuting to and from school. The School Travel Greening Index is an attempt to help prioritize greening activities so as to benefit the largest number of people who walk and bike to school. It also serves as a means to encourage and increase active-commuting rates in youth who live close to

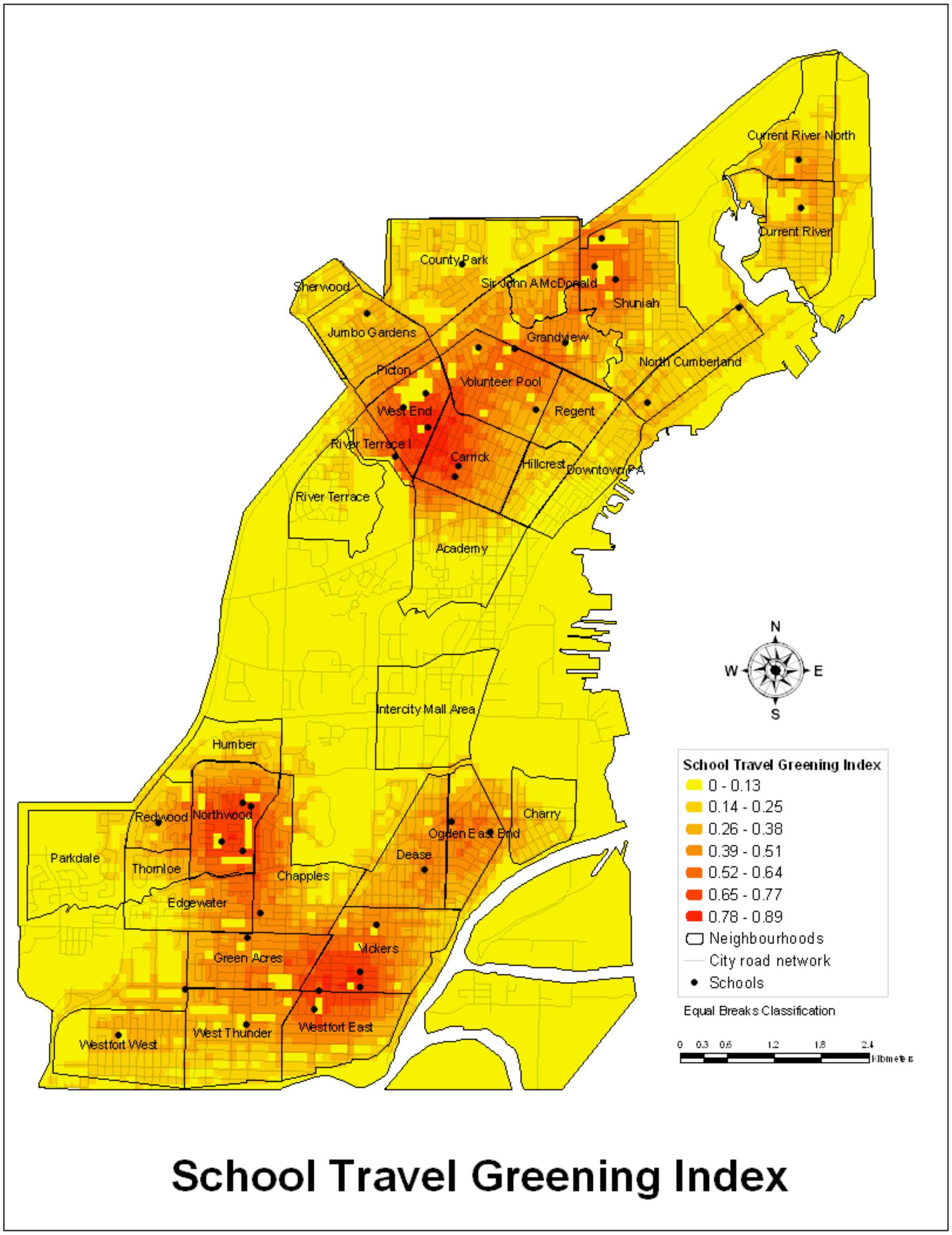


Figure 5.21. A map displaying the values of the School Travel Greening Index for management areas in Thunder Bay. Each grid cell represents 1 hectare. Dark shades of red have higher scores and hence, a greater priority for greening. Since the study area focuses on road proximity to schools, the cells that do not intersect with a road and the cells that are outside the 1km buffer distance to an operating school are given a value of zero.

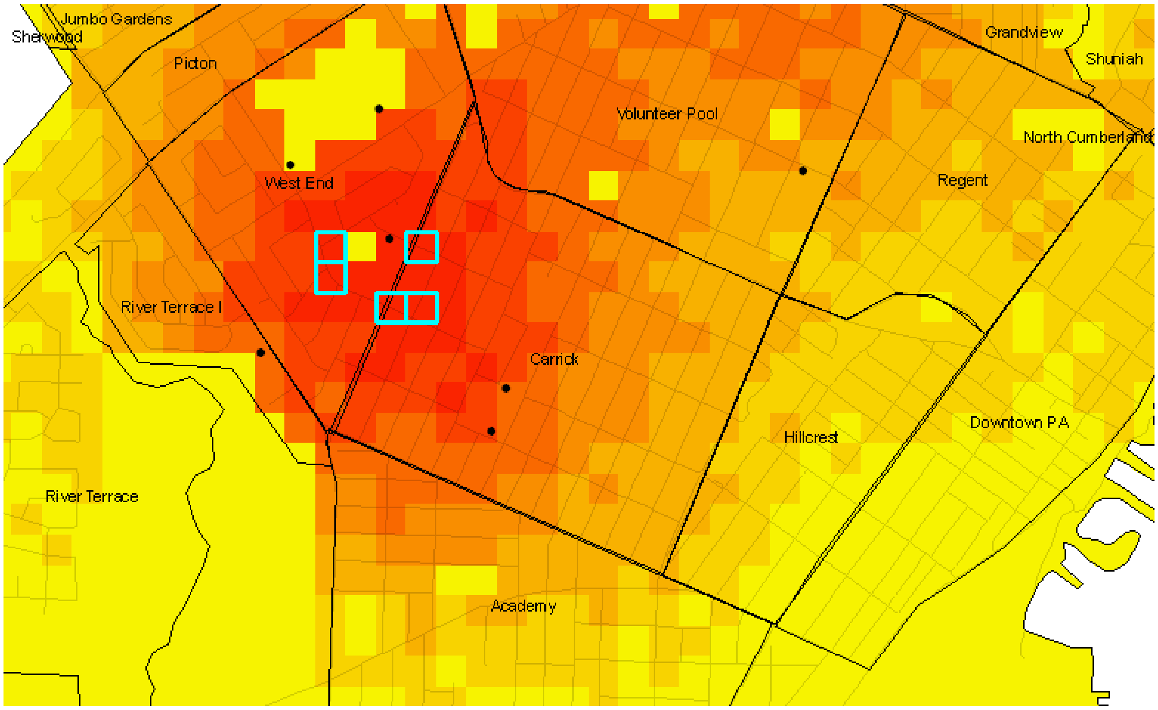


Figure 5.22. A screenshot from ArcGIS of the north section of Thunder Bay displaying the five highest scoring School Travel Greening Index management areas. Their index scores ranged between .89 and 0.85. Each grid cell represents 1 hectare. The highest scoring management areas for this final index differ slightly from the management areas in Figure 5.19 due to the influence of existing tree cover in this region.

schools. A buffer of 1km around schools was used based on the research to target the area where the most children and youth are likely to walk to schools. The results demonstrated that tree planting, maintenance, and protection should occur in the most heavily clustered school areas in Thunder Bay, that are devoid, or lacking in existing tree cover. One region in the north that intersected the West End and Carrick neighbourhoods, and two regions in the south that intersected the Vickers and Northwood neighbourhoods were determined as the focal point for greening.

The methods undertaken for this task did not include walking pathways, because the public tree data was not available for such areas. In reality, such paths should be considered as a possible route to school and would therefore be a route worth greening. Future research could aim to include such infrastructure if the necessary data existed.

5.5 Link Table Task Four: Needs of Special Groups Index

Just like youth, people with special needs (i.e., physically or mentally disabled) are often particularly vulnerable to present land use and transportation infrastructure designs. Up until recent support for social equality in cities, many people with special needs have had their mobility restricted due to hostile urban conditions. Temperature extremes, excessive traffic noise and pollution, and poorly designed infrastructure frequently restrict the mobility and independence of people with disabilities. Restricted mobility, or exposure to hostile urban environments often leads to other health-related issues, such as negative effects on the overall well-being (physiological and psychological) of people and the reduction in general personal comfort (Gant 1997).

Since the late 20th century, trees and other green infrastructure have been recognized for their therapeutic effects. Hospitals, geriatric centers, drug rehabilitation centres, prisons, and residence for the disabled began using trees in “healing” and “sensory” gardens because of the widespread benefits to patients and prisoners (Maller *et al.* 2002). A multitude of studies have since purported that patients heal quicker from physical and psychological trauma when exposed to greened environments, and have found that patients have increased motivation for physical exercise and have more social interactions (Gullone 2000; Maller *et al.* 2002; Rappe 2007;). More specifically, Park *et al.* (2010) has demonstrated that exposure to green settings promote lower concentrations of cortisol, lower pulse rate, lower blood pressure, and lower sympathetic nerve activity than do non-treed urban areas. Many of these benefits can be realized by greening the immediate premises because views through windows to greenspace throughout the day can be as valuable to patients with restricted access and mobility (Kaplan 1992; Maller *et al*. 2002).

The restorative benefits of trees also directly and indirectly transpire through a decrease in traffic noise and pollution, a reduction in temperature and wind extremes, and a decrease in exposure to UV light. These factors, mitigated by trees, play a significant role in determining if a resident will go outside. It will also help increase the overall well-being and increase the effectiveness of a patient's therapy. The City of Thunder Bay, in its 2005 Official Plan, has recognized the need for increased care and attention to people with special needs. This task has been developed to help support and increase the quality of life for people with disabilities.

5.5.1 Task Objectives

The objective of the fourth link table task is to produce a priority greening index to benefit the needs of special groups, in particular persons with disabilities.

The index is to target areas that are in proximity to long-term care residences whose patients are people with special needs (i.e., those with disabilities). The index is primarily meant to increase the aesthetics, safety, and cleanliness around the residence's neighbourhood and to moderate extreme temperatures, traffic and noise that can be hostile to people with special needs. The index ranks public tree greening locations (planting, maintenance and protection) based on proximity of roads to a residence and existing tree cover. The closer a section of road to a residence and the less existing tree cover it has, the greater the index and the priority for increased canopy cover.

5.5.2 Modeling Approach

Two variables are used in the Special Needs Greening Index: proximity to a residence (PTR), and optimum tree cover per road length (TC). The data to assist in the quantification of tree cover were provided by the City of Thunder Bay Parks Department in the form of street tree data. Only public street tree data were used for this study, primarily because street trees play a more critical role in influencing active transportation (e.gs., providing shade, beautifying a streetscape, calming traffic, protecting pedestrians) and plays an important role in benefiting those with special needs. The public tree data required for this index was imported from the School Travel Greening Index, which uses the same data and analysis. The spatial data for the residence in Thunder Bay were collected and digitized by a summer student. The data consisted of 28 public and private long-term care residences that serve people with special needs (but did not include long-term care facilities for the elderly). The residences selected for the study were care groups/facilities and community housing facilities so as to target the areas where people with special needs lived. The City of Thunder Bay Planning Department provided the road data used to determine the proximity of roads to care residences. A complete list of data requirements used for this task is found in Table 5.1.

The following section provides an abbreviated description of the methodology used in developing the Special Needs Greening Index, including a discussion of GIS operations and equations used, data requirements, and simplifying assumptions. Most of the methodology used for this task was also used for the School Travel Greening Index task, hence some details are omitted here to avoid unnecessary repetition. The discussion of the Special Needs Greening Index is organized into three segments based on the stages shown on Figure 5.23: (1) tree cover per road length (Stages 1); (2) proximity to long-term care residences for the people with disabilities (Stages 2-10); and (3) the Special Needs Greening Index (Stages 11-13).

5.5.2.1. Tree Cover per Road Length Score

The optimum tree cover per road length score (or variable) provides an indication of the amount of tree cover found along a given section of road and provides an indication if it falls short of some target. If the current tree cover is below the desired target amount, then greening activity (i.e., planting, maintenance, and protection) are prioritized for these areas. The methodology to carry out this

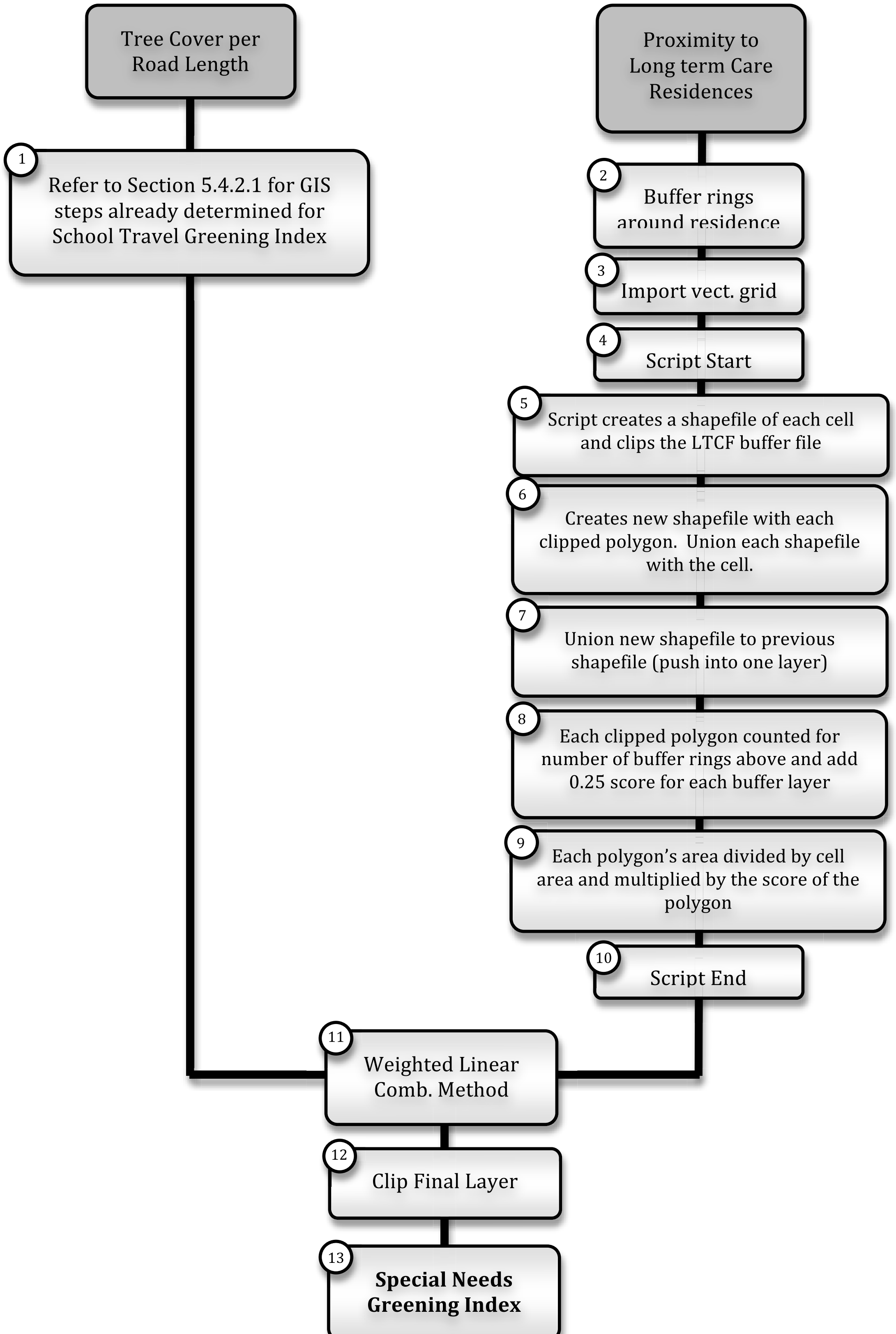


Figure 5.23 A conceptual diagram of GIS steps used in the Special Needs Greening Index Task. It involves the analysis of tree cover per road length, and a management area's proximity to a care residence.

analysis was determined in the previous task (see 5.4.2.1) and will be omitted from this section.

5.5.2.2. Proximity to residence

The proximity to residence score (or variable) indentifies the management areas that are closest to where special groups reside. The closer a management area is to a residence, the more important it is to carry out greening activities (planting, maintenance, protection). The residence location data (as a point shapefile) were imported into ArcGIS and a *Multiple Ring Buffer* function was applied to each (Stage 2 in Figure 5.23). The buffers applied to each residence were at a distance of 100m and 200m. These buffer zones were selected to prioritize the areas immediately adjacent to a residence to soften traffic noise, moderate the temperature, attracts birds, and provide an attractive environment to expand the interior living quarters of a care residence. A buffer of these distances also provides the visual appeal for a resident's daily view out the window if they are not able to leave the facility. The inner buffer was given a weight of 0.5 because of its high priority, and the second buffer was given a weight of 0.25 (Figure 5.24).

The residence buffers created in stage 2 in Figure 5.23 were not dissolved to allow for continued analysis in stages 4 – 10 in Figure 5.23. A vector grid with a 100m resolution was then imported into the ArcGIS project (Stage 3 in Figure 5.23). The Python script used for the School Travel Greening Index was then adapted (filenames changed to reflect this task's files) and run to determine a score that reflects a management area's proximity to a residence (Stages 4 to 10 in Figure

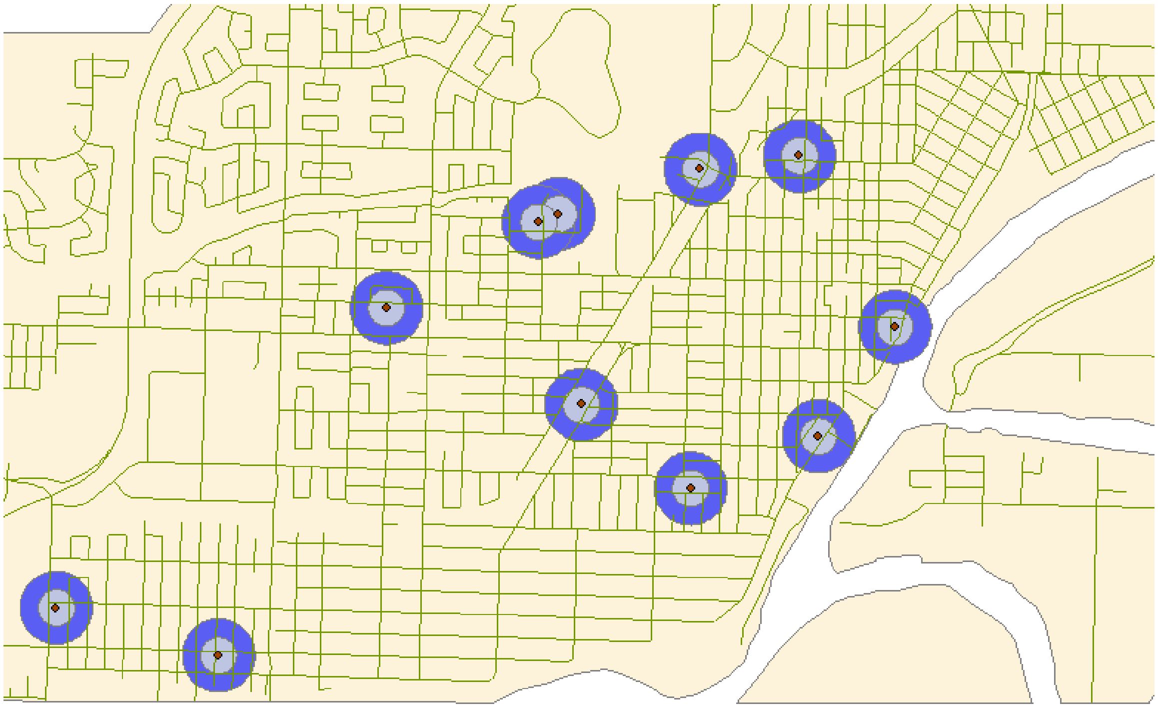


Figure 5.24. A screenshot of the various multiple ring buffers surrounding a portion of Thunder Bay residences for special needs. The residences are represented by dark red dots, the light blue buffers are the 100m zones (weight of .5), and the dark blue buffers are the 1000m zones (weight of .25).

5.23). A detailed description and GIS steps used for this process is previously provided in Section 5.4.2.2.

5.5.2.3. Specials Needs Greening Index

After both the tree cover per road length score and proximity to residence score had been determined, both were standardized on a scale of 0 to 1, with 1 representing the management areas with the lowest tree cover per road length score and the largest proximity to residence score (closest to a residence). To calculate the Special Needs Greening Index (Stage 13 in Figure 5.23), the scores were standardized and weighted using Chang's (2010) weighted linear combination method (Stage 11 in Figure 5.23). The final index was then clipped to represent only the management areas that intersect with both roads and residence buffers (Stage 12 in Figure 5.23).

The weighted linear combination method was discussed earlier in the stormwater task (see section 4.2.2.3) and allows for the weighting of the criterion depending on the users specification. Since no researchers to date have developed a formula (like that of the PPI) or a weighting scheme for an index of this kind the author chose to perform multiple weighting scenarios to demonstrate the effects of various weighted variables (Figure 5.25). The focus groups, used to select the link table tasks (see section 3.1.1, identified proximity residence as the priority variable. Therefore, the proximity to residence variable was given a weight of four times the importance of tree cover

5.5.3 Model results

The Special Needs Greening Index uses two major variables: tree cover per road length (TC) and a management area's proximity to a care residence (PTR). The results pertaining to each of the two variables, and the combined Special Needs Travel Greening Index are provided in the following sections.

5.5.3.1. Tree Cover per Road Length Score

The main objective of this score was to identify the need for additional tree cover required along Thunder Bay roads in proximity to care residences. If the present tree cover is below the targeted tree cover, then greening activity (planting, maintenance, and protection) are prioritized for these areas to benefit the people

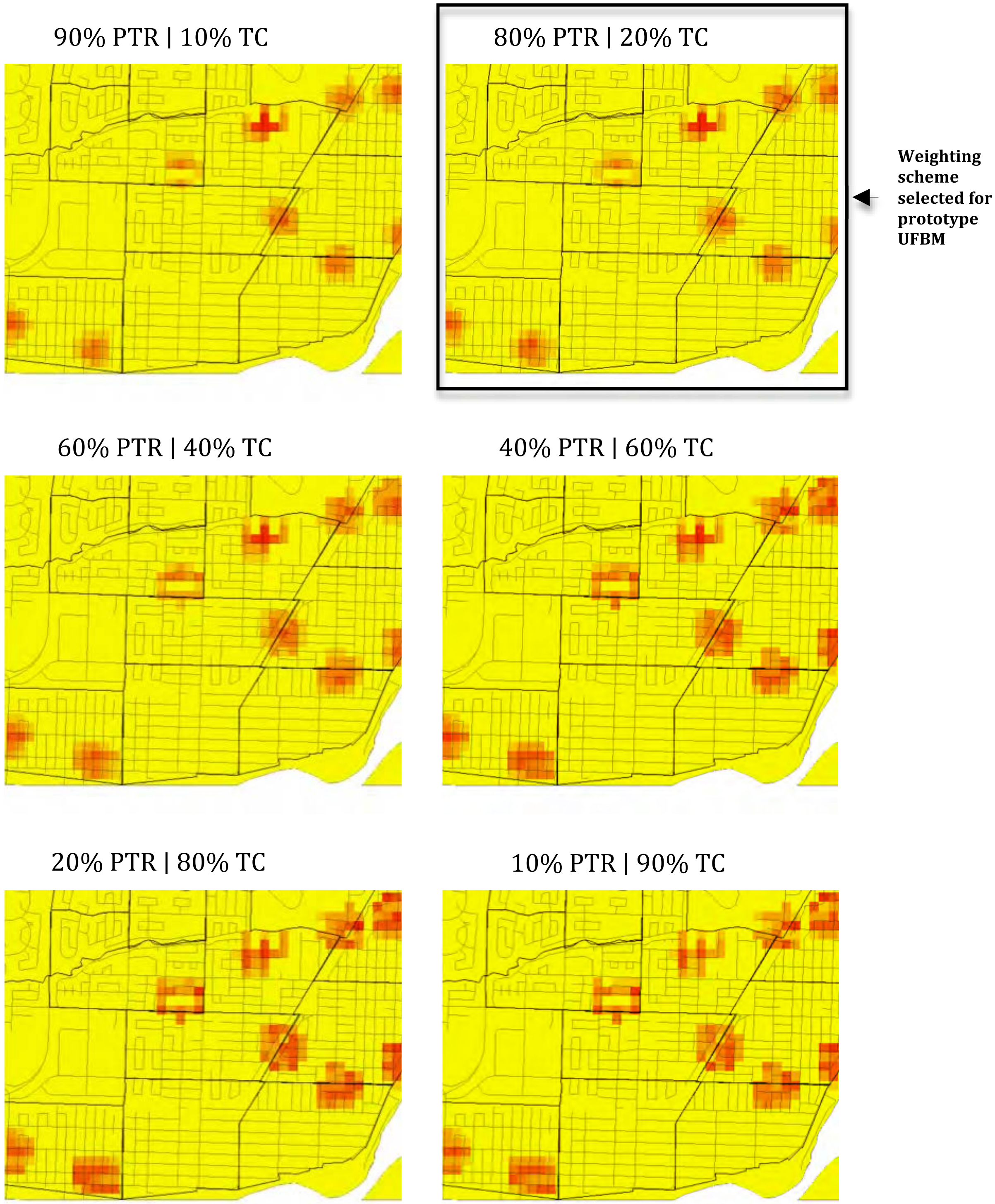


Figure 5.25. Maps of the special needs greening index for Thunder Bay displaying the various weighting scenarios of proximity to residence score (PTR) and tree cover per road length score (TC). Values tending towards 1 (red) indicate management areas that require focused greening. Each cell represents 1 hectare.

who live in the care residences. The results for the tree cover per road length variable for management areas at a resolution of 1 ha are shown in Figure 5.26.

Neighbourhoods were summarized according to score (Table 5.5), and neighbourhoods with the highest average score and thus, highest priority for greening, were Downtown Port Arthur, Hillcrest, and Vickers with average scores of 0.46, 0.46, and 0.45 respectively. These sections scored the highest due to slightly higher road densities (in some sections), which increases road length per management area, in combination with a lower presence of tree cover along these roads.

5.5.3.1. Proximity to Residence Score

The estimate of the proximity to residence score is to identify the management areas that are closest to care residences. The closer a management area is to a residence (or a cluster of residences), the higher the score, and the greater the importance to carry out greening activities (planting, maintenance, and protection). The results for the proximity to residence variable for management areas at a resolution of 1 ha are shown in Figure 5.27.

Management areas that scored the highest were those that intersected two or more residence buffers. The management areas ranged between a score of 1 and 0.91 and were located across the city – one in County Park, Downtwon PA, Academy respectively, and two in Chapples. A summary of tree proximity to residence by neighbourhood (Table 5.5) demonstrated that the Downtown Port Arthur, North Cumberland, and Vickers neighbourhoods had the highest average score at 0.14,

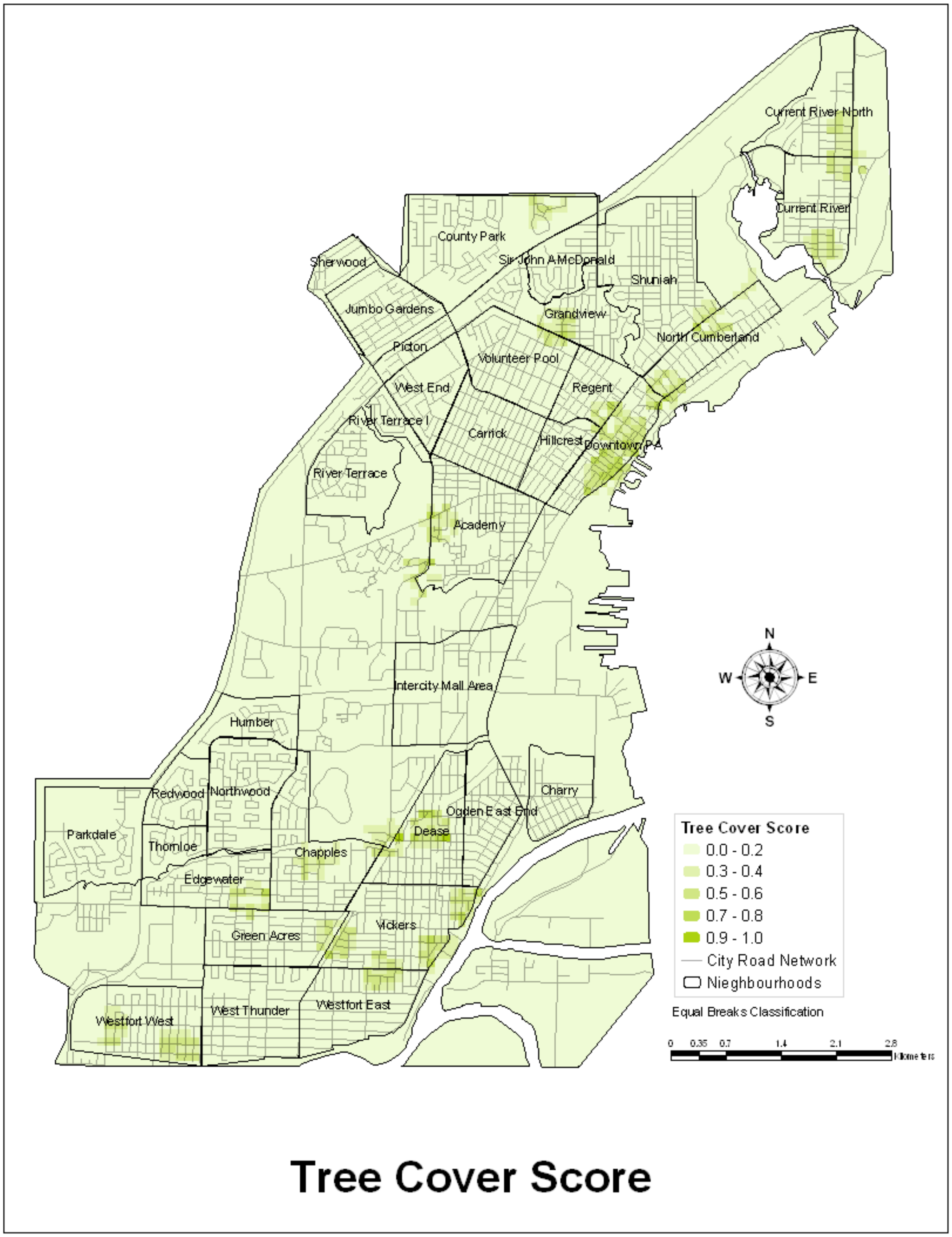


Figure 5.26. A map displaying the value of the tree cover per road length variable summarized for each management area in Thunder Bay. Each grid cell represents 1 hectare. Darker green management areas have higher scores (or low canopy cover per road length) and hence, a greater priority for planting.

Table 5.5 Summary by neighbourhood of average tree cover per road length score, average proximity to residence score, and average Special Needs Greening Index. Values tending toward one are in greater need of greening. Average proximity to residence score and average Special Needs Greening Index results will be discussed in sections 5.5.3.2 and 5.5.3.3 respectively.

Neighbourhood	Neighbourhood Area (ha)	# of Grid Cells[1]	Average Proximity to Residence Score	Average Tree Cover per Road Length Score	Special Needs Greening Index
Academy	170.8	206	0.05	0.39	0.05
Carrick	119.9	152	0	0	0
Chapples	148.3	239	0.05	0.34	0.04
Charry	79.4	105	0	0	0
County Park	217.4	264	0.05	0.27	0.03
Current River	119.6	151	0.05	0.32	0.06
Current River North	113.8	147	0.03	0.27	0.03
Dease	128.6	158	0.04	0.42	0.05
Downtown PA	90.8	126	0.14	0.46	0.16
Edgewater	101.9	132	0.03	0.35	0.03
Grandview	134.6	191	0.02	0.32	0.026
Green Acres	118.2	145	0.03	0.37	0.03
Hillcrest	59.2	80	0.01	0.46	0
Humber	72.8	99	0	0	0
Intercity Mall Area	179.8	211	0	0	0
Jumbo Gardens	105.9	136	0	0	0
North Cumberland	87.2	120	0.07	0.38	0.08
Northwood	131.8	162	0	0	0
Ogden East End	91.1	122	0	0	0
Parkdale	158.6	180	0	0	0
Picton	30.1	49	0	0.39	0
Redwood	61.4	84	0	0	0
Regent	68.3	94	0.03	0.41	0.03
River Terrace	120.2	152	0	0	0
River Terrace I	27.9	47	0	0	0
Sherwood	42.1	73	0	0	0
Shuniah	226.6	280	0	0.35	0
Sir John A McDonald	65.6	89	0	0	0
Thornloe	43.1	58	0	0	0
Vickers	161.4	198	0.06	0.45	0.08
Volunteer Pool	133.8	165	0.01	0.38	0.01
West End	83.6	113	0	0	0
West Thunder	155.3	187	0	0	0
Westfort East	131.2	157	0.02	0.36	0.02
Westfort West	148.6	178	0.05	0.31	0.05
Total Average	112.3	144.3	0.0	0.2	0.0

[1] This is a count of full and partial grid cells intersecting each defined neighbourhood.

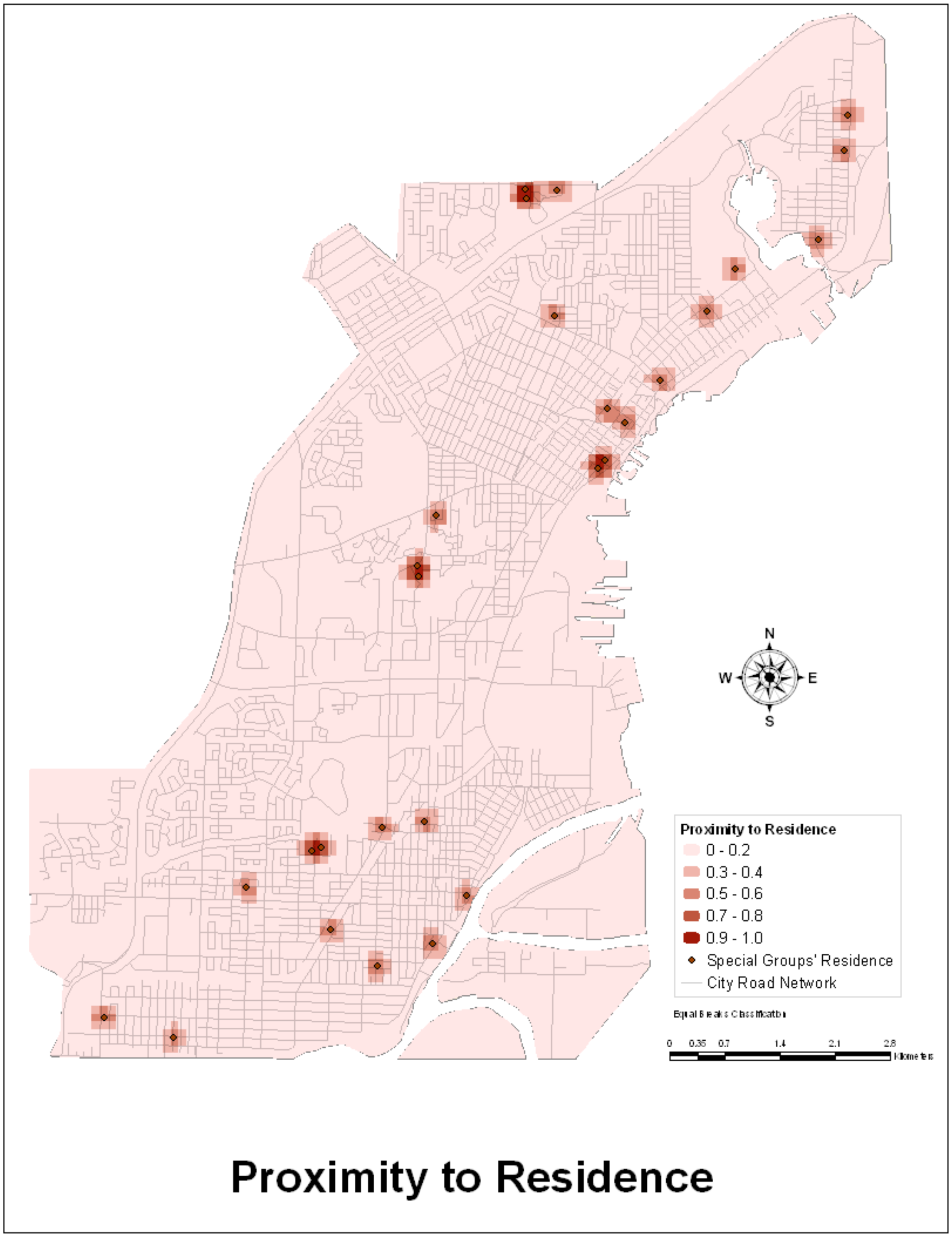


Figure 5.27. A map displaying the value of the proximity of management areas to care residences variable. Each gird cell represents 1 hectare. Management areas with darker shades of red have higher scores (close to residence) and hence, a greater priority for planting.

0.07, and 0.06 respectively. 18 neighbourhoods resulted in an average of score 0 because no care residences (or their 200m buffer) occurred within their boundary.

5.5.3.2. Special Needs Greening Index

The Special Needs Greening Index is the combination of both previous scores (tree cover per road length and proximity to residence) into one index. The results for the Special Needs Greening Index for management areas at a resolution of 1 ha are shown in Figure 5.28.

Five management areas with the highest index value were located across the city with final scores ranging between 0.90 and 0.80. The neighbourhoods containing these highest scoring management areas were County Park, Downtown Port Arthur, Academy and Chapples (Figure 5.29). Neighbourhoods were also summarized by average index values (Table 5.5). Due to the heavy weighting on residence proximity, these scores followed closely with the results found with that indicator (i.e., residence proximity). The highest average index value (highest priority to plant) were from the Downtown Port Arthur, North Cumberland and Vickers neighbourhoods with a score of 0.16, 0.08, and 0.08 respectively. As discussed above, numerous neighbourhoods resulted in an average index score of 0 because no care residences (or their 200m buffers) occurred within the neighbourhood boundary.

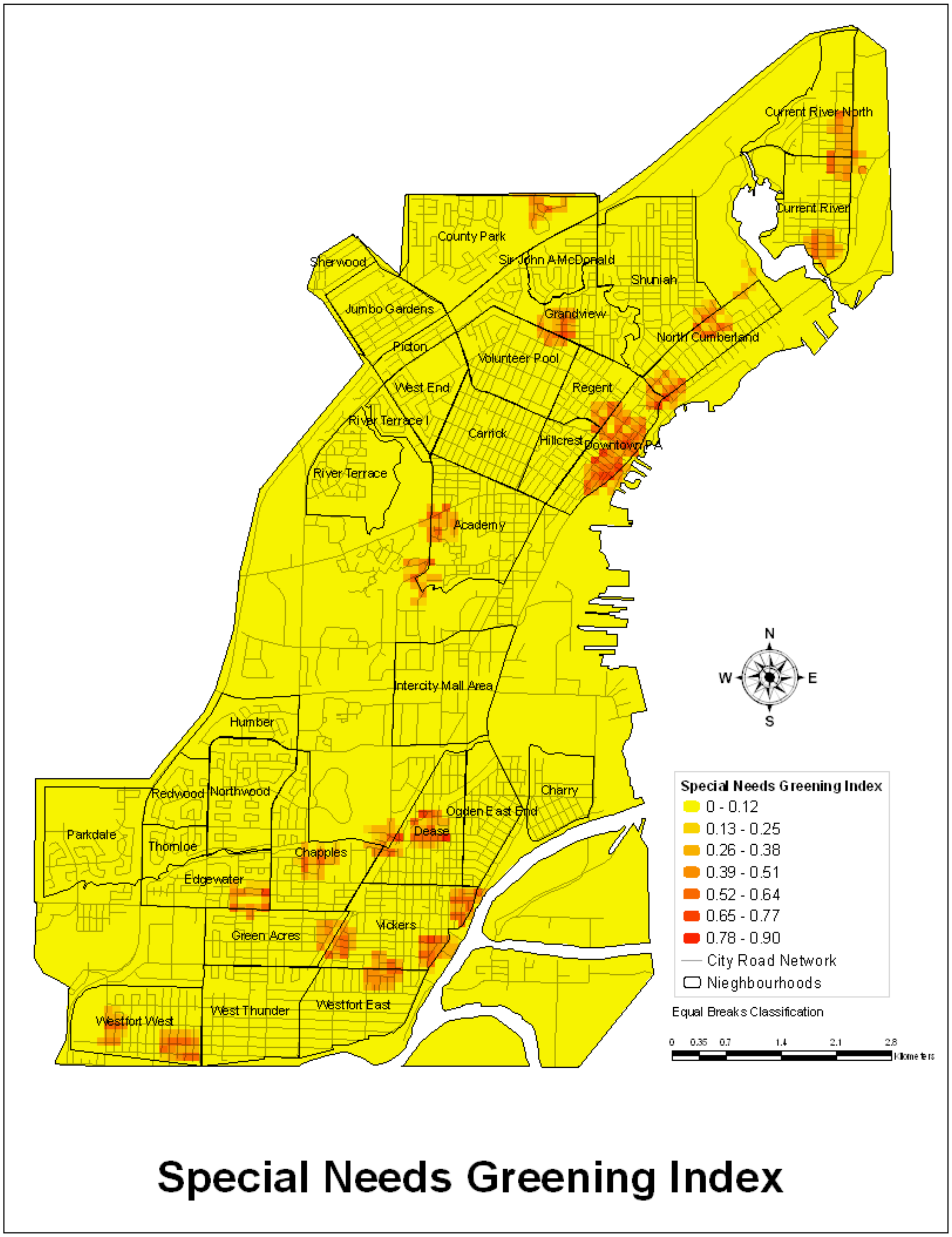


Figure 5.28. A map displaying the value of the Special Needs Greening Index. Each grid cell represents 1 hectare. The darker shaded management areas have higher scores and hence, a greater priority for planting. Since the study area focuses on road proximity to care residences, the cells that do not intersect with a road and the cells that are outside the 200m buffer distance to a residence are given a value of zero.

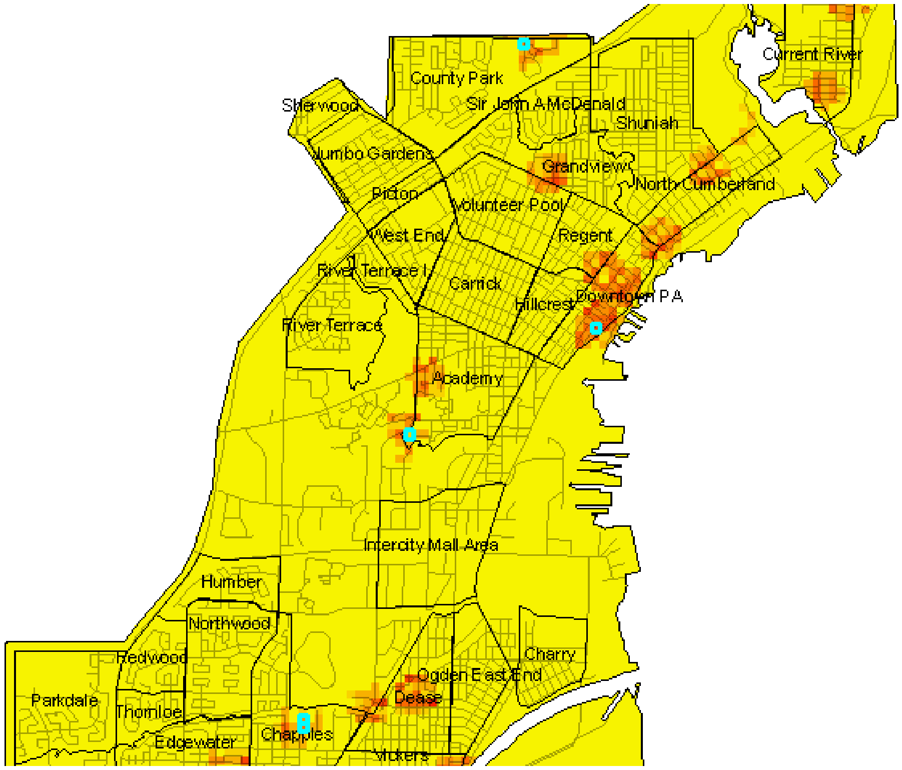


Figure 5.29. A screenshot from ArcGIS displaying the management areas with the highest index scores (highlighted cells in blue) as discussed in the text.

5.5.4 Discussion and Recommendations for Planting Locations

People with disabilities are more vulnerable to the hostile conditions of the urban environment, especially along roadways. An increase in greening around care residences for the disabled is a important way to mitigate the effects of urban conditions, and it is another pro-active techniques to providing holistic and restorative environments for people in need. The Special Needs Greening Index is an attempt to help prioritize greening activities so as to benefit these types of people. A buffer of 200 meters around care residences was used to target the areas that should first be greened. The results demonstrated that tree planting, maintenance, and protection should occur where care residences are clustered together (within 200m of each other). Downtown Port Arthur neighbourhood contained the highest level of clusters and the highest average score. It will be particularly important to address these needs in this area, simply because of the level of urbanization in this neighbourhood and the common problems associated with dense urban areas (e.gs., air pollution, noise, heat). Other high scoring management areas were dispersed across the city and should also be addressed as priority.

5.6 Conclusion

The tasks derived through the link table process helped to target and accomplish a broad spectrum of Thunder Bay's urgent sustainability goals through prioritizing increased tree cover. The comprehensive process used in the link table helped select four main objectives above and beyond the three standard UFMB tasks discussed in chapter 4. The Economic Development Greening Index prioritized greening activities so as to benefit the greatest number of businesses across the City. The results demonstrated that priority tree planting, maintenance, and protection should occur in the downtown cores, intercity area, along Memorial Avenue, Algoma Street and Central Avenue. The Downtown Core Greening Index provided a simple means to create healthy, functional, and attractive central business districts by targeting a district-wide greening regime. The fourth link table task called the School Travel Greening Index produced a priority greening regime to benefit Thunder Bay children when engaging in active commuting to and from school. The index ranked three main regions as priority for public tree greening, one in the north, and two in the south of Thunder Bay. These priority areas were within heavily school-clustered regions. The forth and final link table task focused on greening around care residences for people with disabilities, as a means to mitigate the hostile urban environments they can face on a daily basis. This Special Needs Greening Index demonstrated that priority areas were relatively dispersed across the city, with the highest priority focusing on regions where residences were within 200 meters of each other (e.g., Downtown Port Arthur neighbourhood).

The link table tasks are beneficial in directing management activities that pertain to specific sustainability goals. However, both the standard and link table tasks were processed with the intentions of being combined into one set of results to demonstrate a comprehensive priority planting, maintenance and protection scheme to increase tree cover in Thunder Bay. The combined results with discussion will be provided next.

6.0 Discussion

The amalgamation of all previous recommended greening locations from the standard and link table tasks described in the previous two chapters is referred to as the Combined Greening Index. The priority regions identified in this combined index reflect the management areas that should ideally increase in tree cover in order to produce the numerous benefits that simultaneously attain a variety of desired sustainability goals. Consequently, the Urban Forest Benefits Model (UFBM) provides a prioritized greening scheme to maximize the amount of services rendered to the community by trees. This chapter begins with a description of two versions of the Combined Greening Index, one "ideal" and one "realistic", and a discussion of their resulting values. This is followed by a discussion of formal recommendations at two levels. At the first, site specific recommendations for community greening that the City of Thunder Bay should adopt are described. At the second level, the implications of this study to modeling and calculating urban forest benefits are discussed as well as commentary on how this modeling process could be adapted to other jurisdictions. The chapter concludes with an acknowledgement of the limitations of the prototype UFBM and an identification of future research topics resulting from this work.

6.1 Integration of Results

The intended purpose of the final Combined Greening Index is to identify the areas that require a higher level of tree cover to ensure that an optimum level of desired benefits will flow to the surrounding community. These desired benefits are based on the seven sustainability objectives selected for the prototype model – three standard tasks and four link table tasks. Each of the task's results were standardized and merged to form the combined index layer. The study area for the Combined Greening Index was limited to the task with the smallest study area (i.e., the stormwater, PPI and the economic development tasks).

There were two types of combined indexes developed for the UFBM. The first – the Ideal Combined Greening Index - demonstrates the *ideal* greening locations (i.e., areas that should be planted, maintained, or protected to deliver maximum services). This index, for example, may potentially target management areas that have a little amount of land available to plant (i.e., grass or bare soil), such as the downtown cores of Thunder Bay. The Ideal Combined Greening Index was developed in the event that the municipality was interested in converting its hardscapes to greenspaces (which is increasingly undertaken by municipalities). However, converting pavement to plantable areas for greenspaces is costly. Therefore a *Realistic C*ombined Greening Index was also developed to help demonstrate areas that can be more realistically and affordably greened (i.e., areas that have existing greenspace and bare soil) based on the present distributions of impervious and pervious cover land use areas. The *Ideal* Combined Greening Index is considered the core index in this text and provides the basis for formal recommendations. The results pertaining to each of the two combined indexes are outlined in the following sections, as well as discussion regarding the use of the ideal index over the realistic index in this study.

Ideal Combined Greening Index

The Ideal Combined Greening Index integrates the average score of all management tasks into one final layer (Figure 6.1). The results for the Ideal Combined Index for management areas at a resolution of 1 ha are shown in Figure 6.2. The higher the index score for a given management area, the greater the need to intensify greening activities (i.e., planting, maintenance, and protection) in these managements areas to increase or to enhance the benefits received from tree cover.

In compiling the *prototype* version of the Combined Greening Index, the contributing sub-index scores (one from each of the seven management tasks) were weighted equally rather than placing greater priority (or weight) on one or more tasks. Future research might involve a detailed sensitivity analysis to determine appropriate weighting schemes to explore how alternate weightings of the contributing sub-index scores affect the final Combined Greening Index results. The formula used to determine the Combined Greening Index is:

Equation 6.1

$$CGI = \frac{(SWGI \times w_i) + (SNGI \times w_i) + (STGI \times w_i) + (PPI \times w_i) + (DCGI \times w_i) + (EDGI \times w_i) + (EABGI \times w_i) \times 100}{\sum w_i}$$

where, *CGI* is the Combined Greening Index, *SWGI* is the Stormwater Greening Index standardized score, *SNGI* is the Special Needs Greening Index standardized score, *STGI* is the School Travel Greening Index standardized score, *PPI* is the Priority Planting Index standardized score, *DCGI* is the Downtown Core Greening Index standardized score, *EDGI* is the Economic Development Greening Index

Figure 6.1. The combination of all tasks into the final Combined Greening Index to demonstrate priority greening management areas. The Combined Greening Index is the average score of all tasks.

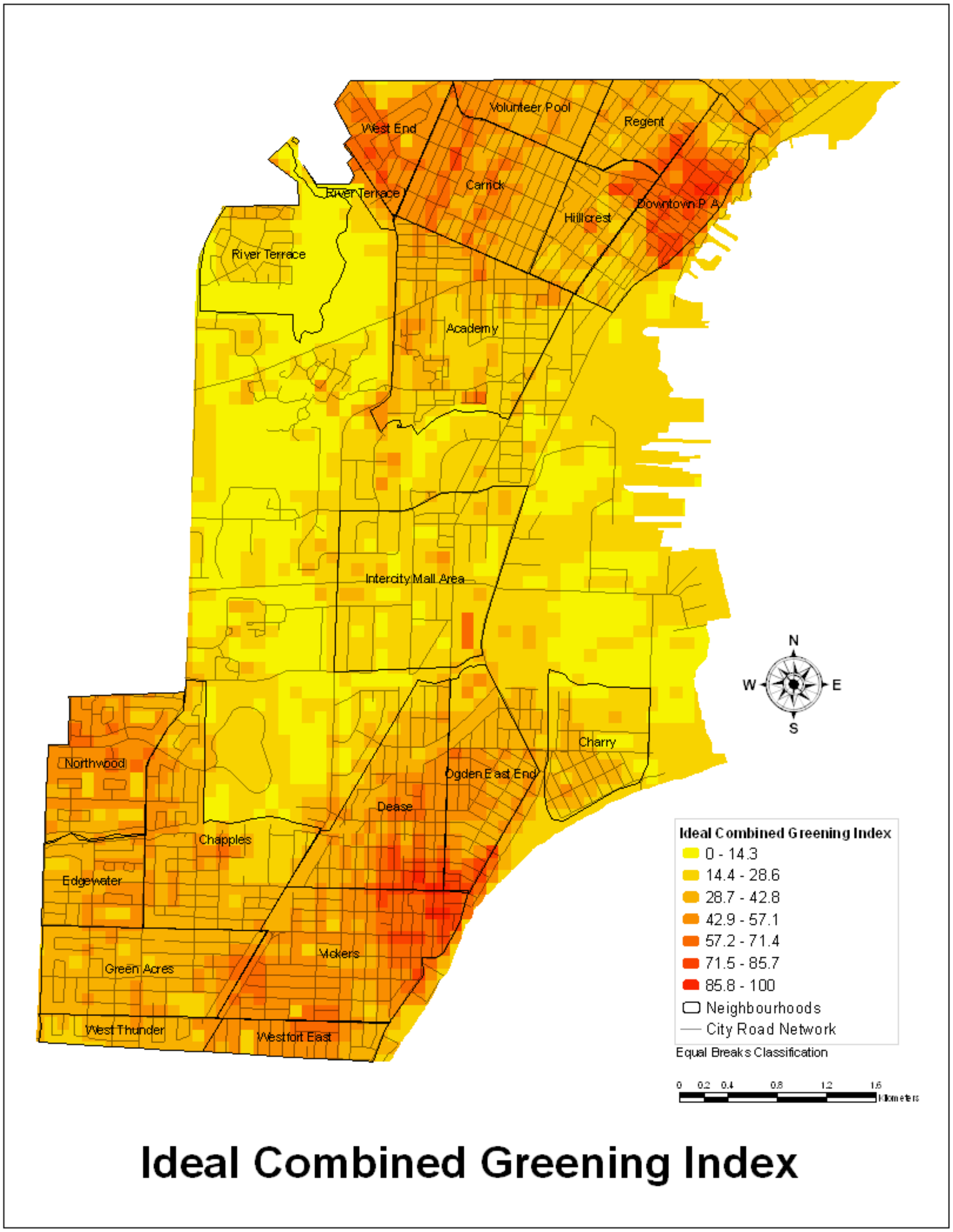


Figure 6.2 A map displaying the values of the Ideal Combined Greening Index for management areas for most of the City of Thunder Bay. Each grid cell represents 1 hectare. Darker management areas indicate a need for more focused greening.

standardized score, *EABGI* is the Emerald Ash Borer Greening Index and w_i is the weight given to each of the seven sub-indices.

The formula used to calculate the Combined Greening Index within the GIS incorporates the score of each 1 ha management area from each task to form a final score based on the combined average. When a particular management area receives a high score in the combined index, this indicates that it either scored high in one or more of the individual sub-indices, or scored moderately well in most of the seven standard and link table tasks (Figure 6.3).

The management areas contained within the top 1st percentile (i.e., 34 of 3427 management areas within the study area) were largely located near or within the two downtown cores, with the exception of one in Carrick and one in West End neighbourhoods (Figure 6.4). These areas are the most critical management areas that require a concentration of greening activities. The management areas within the top 10th percentiles (343 management areas) were also identified (Figure 6.5).

The five management areas across the study area with the highest overall Ideal Combined Greening Index values were located in the Thunder Bay north core (two management areas) and in the Thunder Bay south core (three management areas) (Figure 6.6). These areas were heavily influenced by high scores stemming from the Economic Development Greening Index, Downtown Core Greening Index, and the Priority Planting Index. The two north core management areas were also influenced by strong scores from the Special Needs Greening Index. It is important to note that significant sections in Carrick and West End neighbourhoods were also high priority areas (see Figure 6.5). These areas were mainly influenced by high

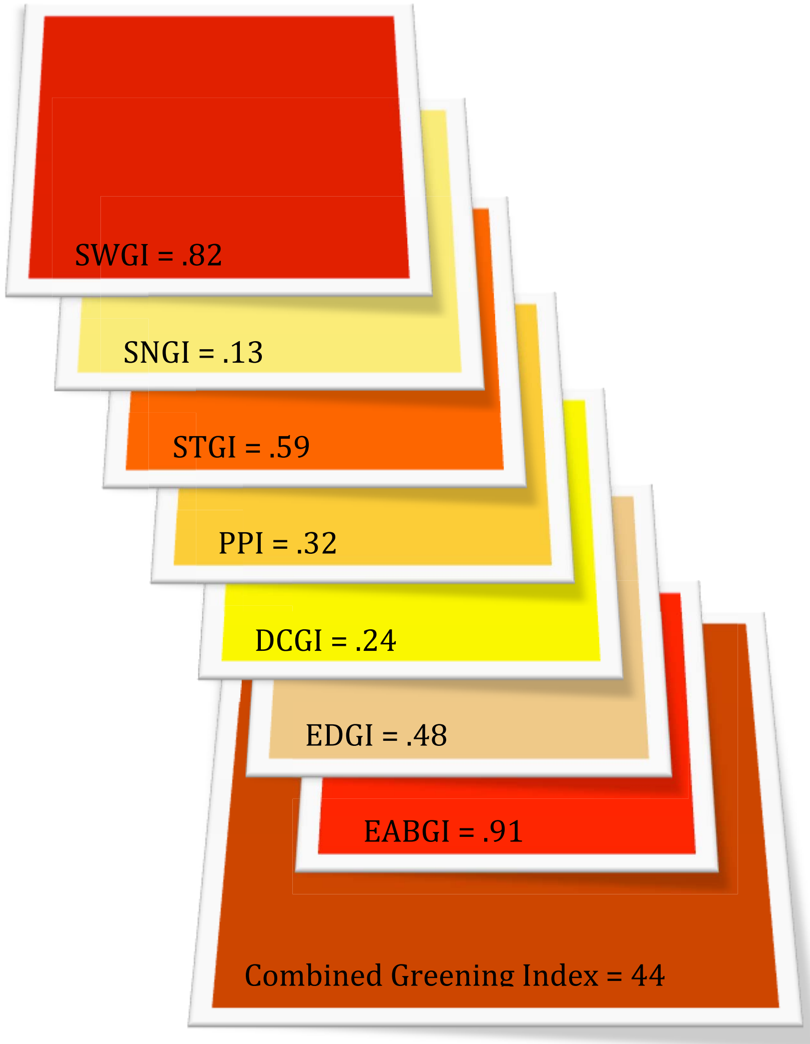


Figure 6.3. An example of the combination of values from the seven management tasks and the resulting Combined Greening Index for the same management area (or grid cell). Values of the contributing tasks vary between 0 and 1; those for the combined index vary between 0 and 100. Values tending toward 1 and 100, respectively, indicate areas that required more focused greening (planting, maintenance, and/or protection). The Combined Greening Index is calculated by equation 6.1 discussed in the text.

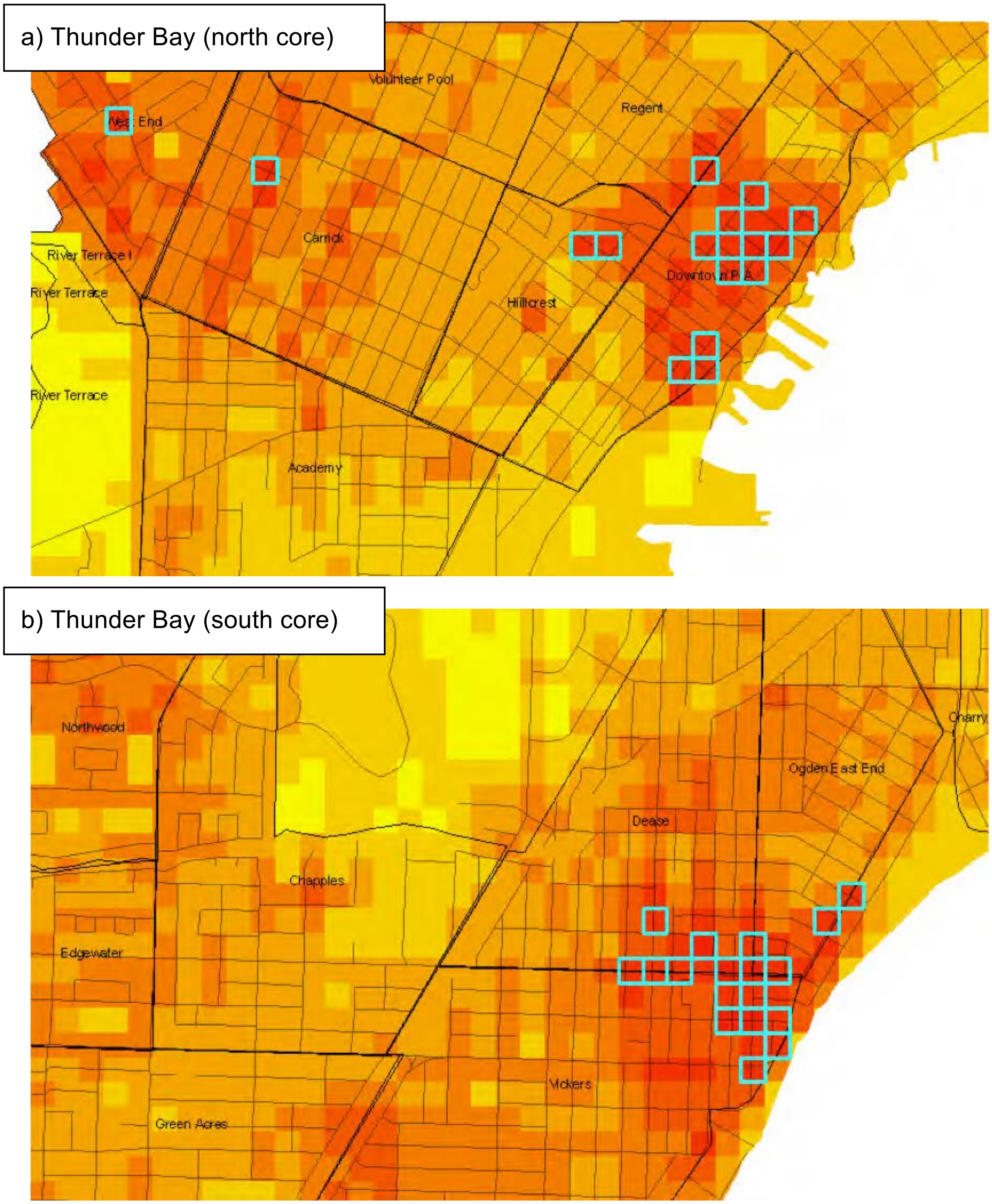


Figure 6.4. Thirty-four management areas (highlighted in blue) identified as critical priority (1st percentile of areas considered) with an index score between 76 and 100 for (a) Thunder Bay north core (top) and (b) Thunder Bay south core (bottom).

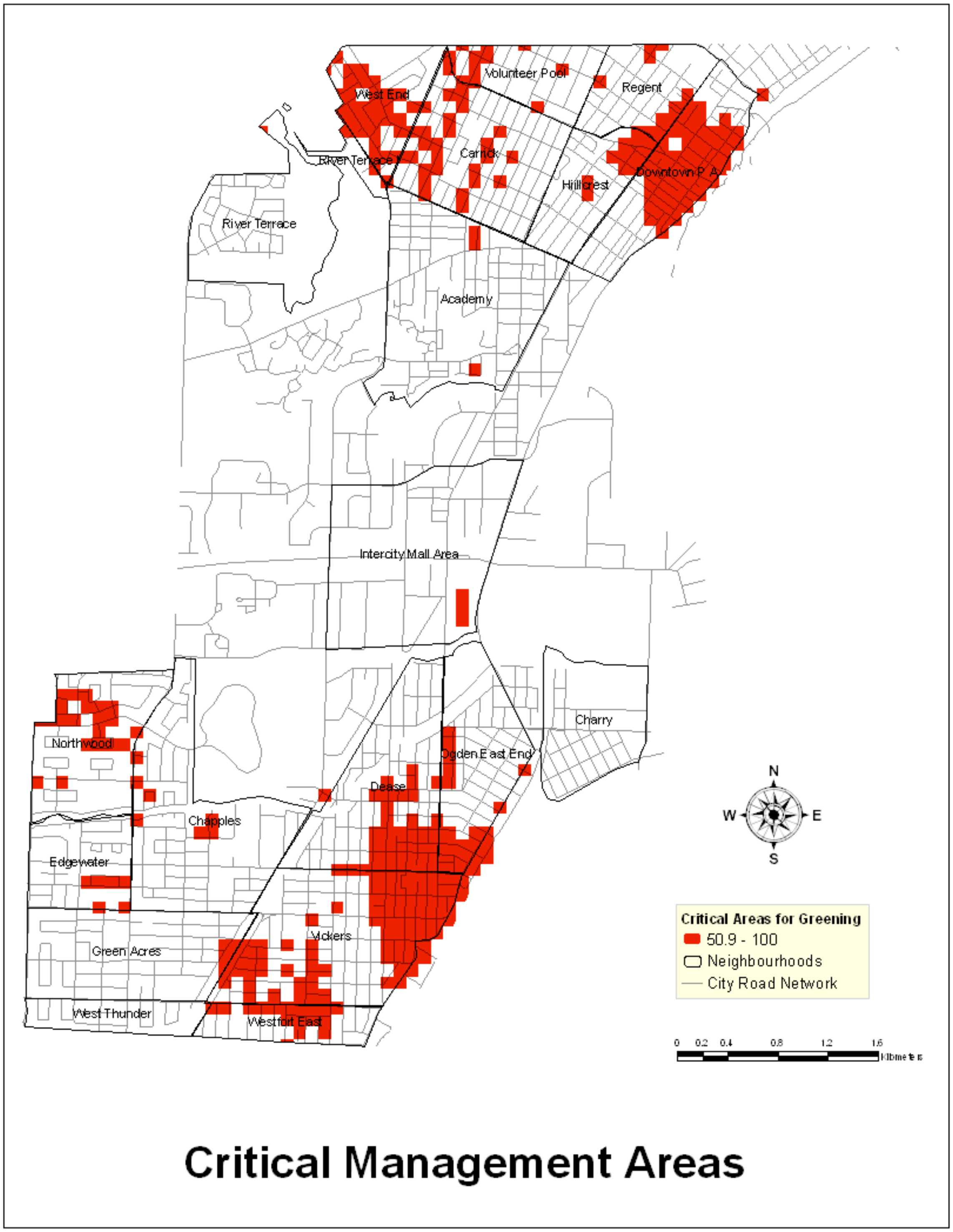


Figure 6.5. Map of the critical management areas within the top 10th percentile (343 of a possible 3427) identified as high priority for focused greening with a Combined Greening Index score between 50.9 and 100.

scores stemming from the School Travel Greening Index, the Priority Planting Index and the Emerald Ash Borer Greening Index. A concentration of high scoring management areas between the Vickers and Westfort East neighbourhoods were influenced strongly by the combination of the Special Needs Greening Index, the School Travel Greening Index, and the Priority Planting Index. A conglomerate of management areas found within the Northwoood neighbourhood also ranked high on the Combined Greening Index due to strong influences by the School Travel Greening Index and Priority Planting Index.

Figure 6.6. The five management areas across the study area with the highest overall Ideal Combined Greening Index values (highlighted in blue) representing the most critical priority areas with index scores between 88 and 100. The left figure demonstrates the critical management areas in Thunder Bay north core and the figure on the right demonstrates those in Thunder Bay south core.

Neighbourhoods were also summarized according to index score (Table 6.1). The neighbourhoods with the highest average index score and thus, highest priority for greening, were Vickers, Downtown Port Arthur, and West End with an average value of 53, 49, and 49 respectively. Lowest average index scores came from the

Charry, Intercity Mall Area, and River Terrace neighbourhoods with a score of 23, 21, and 13 respectively.

Table 6.1 Summary by neighbourhood of the range and average Ideal Combined Greening (Ideal CG) score and of the average Realistic Combined Greening (Real CG) score.

Neighbourhood	Neigh-bourhood Area (ha)	# of Grid Cells[2]	Min. Ideal CG Score	Max. Ideal CG Score	Average. Ideal CG Score	Average Realistic CG Score
Academy	171	206	12	62	31	22
Carrick	120	152	29	81	45	40
Chapples	148	239	10	61	35	29
Charry	79	105	0	42	23	19
Dease	129	158	17	89	45	37
Downtown PA	91	126	18	100	49	43
Edgewater[1]	102	82	19	56	41	33
Green Acres	118	145	17	67	39	32
Hillcrest	59	80	19	83	39	33
Intercity Mall Area	211	211	0	66	21	10
Northwood[1]	132	130	19	69	44	40
Ogden East End	91	122	19	87	45	37
Regent[1]	68	81	17	83	40	35
River Terrace[1]	120	143	1	55	13	11
Vickers	161	198	19	91	53	47
Volunteer Pool[1]	133	75	18	64	41	37
West End[1]	84	86	14	76	49	49
West Thunder[1]	155	62	18	55	36	29
Westfort East[1]	131	58	21	67	46	39
Total Average	**121**	**129**	**15**	**71**	**39**	**33**

[1] Only a portion of the neighbourhood was analyzed because part of the neighbourhood fell outside the study area.
[2] This is a count of full and partial grid cells intersecting each defined neighbourhood.

The Realistic Combined Greening Index

The Ideal Combined Greening Index summaries until now have indicated the best greening sites for Thunder Bay. The Ideal Combined Greening Index, as discussed earlier, does not account for management areas lacking adequate growing space (e.g., the Intercity area and downtown cores may lack space to plant trees due to high levels of impervious cover). Therefore a realistic greening index was developed to help demonstrate a more realistic and affordable greening scheme based on available greenspace or plantable land (Figure 6.7).

To create these results, the impervious cover (taken from the stormwater task, see Figure 4.14) was standardized on a scale between 0 and 100, 100 being a management area with 100 percent impervious cover. These values were subtracted from the ideal combined index score to provide an estimate of the areas that may be more difficult to plant trees due to the current high amounts of impervious cover. The following formula was used:

Equation 6.2

$$RCGI = \left[\left(\frac{IM}{CA}\right) \times 100\right] - ICGI$$

where, *RCGI* is the Realistic Combined Greening Index, *IM* is area of of grid cell with impervious cover (in square metres) taken from the stormwater and other management tasks, *CA* is the area of a grid cell (in square meters), and *ICGI* is the Ideal Combined Greening Index.

Although the visual differences are subtle between the ideal and realistic combined indexes when mapped (cf Figures 6.2 and 6.7). The five management areas with the overall highest Realistic Combined Greening Index value across the study area were all located in the Thunder Bay north core (Figure 6.8). One of these management areas also scored in the top five highest in the Ideal Combined

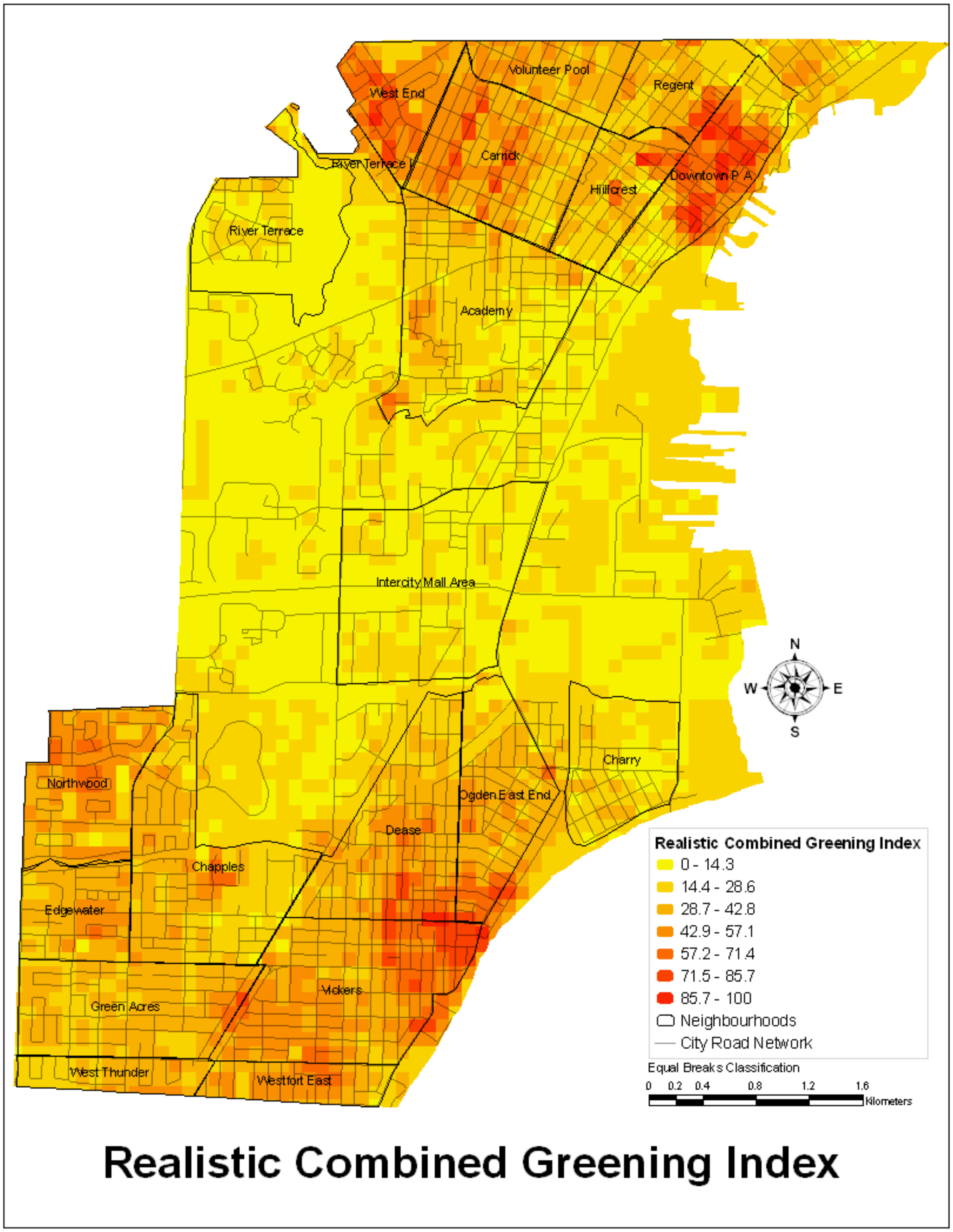


Figure 6.7. A map displaying the values of the Realistic Combined Greening Index for management areas for most of the City of Thunder Bay. Each grid cell represents 1 hectare. Darker management areas indicate a need for more focused greening.

Greening Index. In addition, there are some other statistical distinctions. In particular, summaries of the Realistic Combined Greening Index by neighbourhood are shown to be on average 15 percent lower (or a score of six) when compared to the ideal index scores (see Table 6.1). The neighbourhoods with the highest average index scores and thus, the highest priority to plant according to the Realistic Combined Greening Index, were West End, Vickers, and Downtown Port Arthur with an average score of 49, 47, and 43, respectively. These were also the highest scoring neighbourhoods according to the Ideal Combined Greening Index, although West End and Vickers exchanged positions. Lowest average index scores came from Charry, River Terrace, and Intercity Mall Area neighbourhoods with a score of 19, 11, and 10, respectively. These also were the lowest ranking neighbourhoods according to the Ideal Combined Greening Index.

6.2 Discussion

The Ideal and Realistic Combined Greening Indexes described above demonstrate two approaches to using the combined data from the standard and link table tasks. Both are relevant and meaningful to decision makers in determining greening schemes for a municipality. Although both indexes provide similar results, the *realistic* index (reconfigured results from the *ideal* index based on available plantable land) represents management areas that can be realistically and more affordably planted. However, the Realistic Combined Greening Index is primarily focused on determining planting locations, and its results undermine the UFBM's ability to determine maintenance and protection regimes. When the realistic index

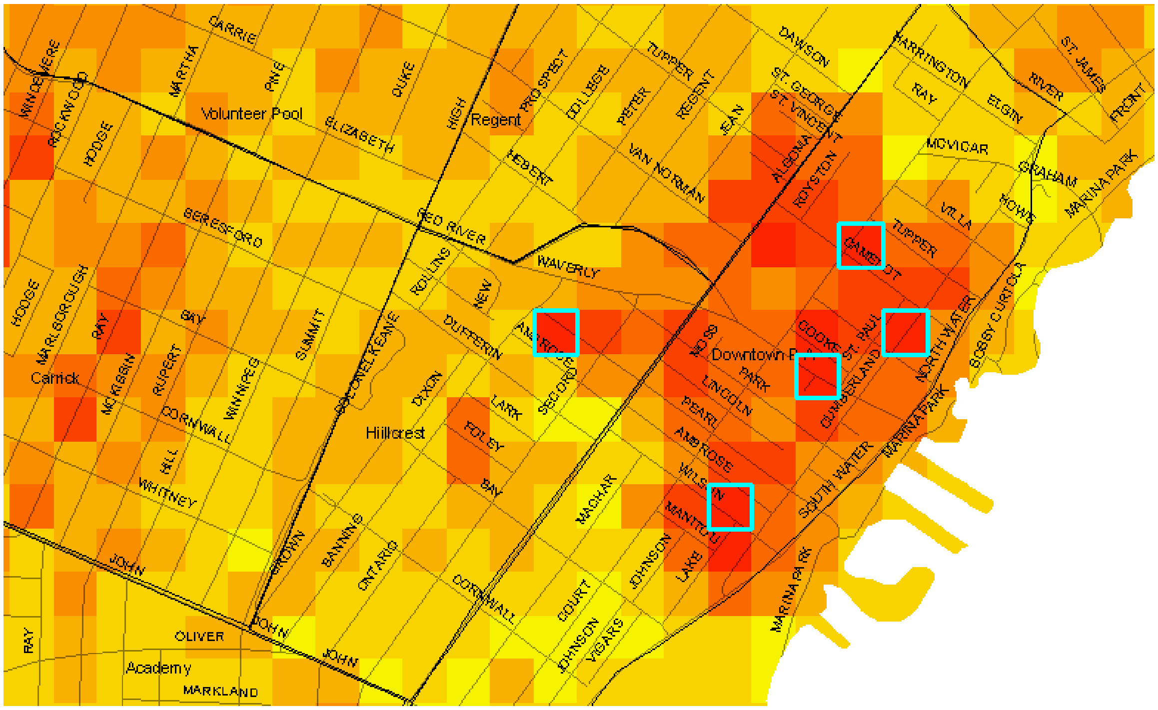


Figure 6.8. The five management areas across the study area with the highest overall *Realistic* Combined Greening Index values (highlighted in blue) ranging in scores between 90 and 100. With the exception of one, these management areas differed from the management areas with the highest *Ideal* Combined Greening Index scores (Figure 6.6) because these areas contained more greenspace to allow for planting.

reduces the ideal score because a particular management area has little to no plantable area, it negates the fact that an increase in maintenance and protection is also required for existing trees in that particular management area. For this reason, the realistic index should primarily be used for supporting the development of planting regimes and should not inform the overall greening activities (i.e., planting, maintenance, and protection) of a municipality.

For three reasons it is recommended a municipality use the Ideal Combined Greening Index to inform its greening activities. First, it provides an idealized (or visionary), long-term goal to inspire decision makers to identify and innovate new approaches to create space for trees through brownfield conversion, planting pit development, and hardscape land conversions. It also provides opportunity to demonstrate new ways of integrating green infrastructure into urban developments and could be used to inspire and persuade decision makers to increase funding toward greening initiatives.

Second, the Ideal Combined Greening Index offers more accurate results for providing prioritized maintenance and protection to existing trees in high priority areas (see earlier discussion above). Tree benefits are positively influenced by an increase in tree cover (or leaf area), and therefore properly maintained and protected existing trees will foster larger, healthier functioning tree canopies that will provide maximum services to the community.

Third, Thunder Bay has large tracts of impervious cover (e.g., large tracts of pavement in the Intercity Area and its two downtown cores). Ironically, the Realistic Combined Greening Index targets areas that have less impervious cover to plant trees. In terms of sustainability, it is within these areas particularly (e.g., Intercity Area) where more trees and healthier tree cover are required to mitigate the negative effects of large areas of impervious cover (e.g., urban heat island effect and stormwater runoff).

The compilation of all tasks to form the Ideal Combined Greening Index completes the third and last objective identified in this thesis. In summary, there were three key objectives: (1) to develop an exhaustive list and framework of urban forest benefits calibrated to the City of Thunder Bay, (2) to develop a prioritized list of Thunder Bay's sustainability goals and identify how greening efforts contribute toward these goals and, (3) to develop the GIS-based UFBM that will assist with the sequencing of greening activities (planting, maintenance and protection) in order to optimize community benefits and attain long-term community sustainability goals. The first objective was accomplished by the development of a list of contributions made by urban trees and greenspaces to urban communities. The compiled benefit list, gathered from arboriculture and urban forestry research, was used in a focus group to determine the benefits provided by Thunder Bay's urban forest. This framework of benefits, developed via the literature and focus group, was presented in chart format and was later used in the link table (objective 2).

The second objective was achieved through a literature review of the City of Thunder Bay's major guiding documents, which identified the core goals and direction of the City that pertains to sustainability. This was necessary to determine how an urban forest contributes to the sustainability goals of a community and was accomplished through the link table process. A focus group ranking exercise was performed in order to prioritize and rank these various sustainability goals. The second component of objective two was fulfilled by summarizing the results of urban forest benefits and sustainability goals in a matrix entitled the link table. The link table was used to display connections, both visually and statistically, between the benefits provided by trees and the sustainability objectives of the City of Thunder Bay. The third objective was achieved by selecting the various compelling standard and link table tasks and inputting them into the GIS to be spatially analyzed. The standard tasks were chosen by reviewing popular criteria used by other municipalities to mitigate an urban challenge through greening. Both standard and link table tasks were modeled individually using ESRI's ArcGIS software producing an independent set of recommended greening locations (or a map) based on a given task's objectives. These seven maps were then combined to form a final comprehensive map demonstrating optimum locations for greening (planting, maintenance, and protection) in Thunder Bay.

With an understanding of the input tasks used in the prototype UFBM, the author expected that the two downtown cores along with sections of the Intercity Mall area (i.e., the developing business and light industrial area between the two downtowns; see Figure 6.2) would be the main focal points for greening. The results (shown in Figure 6.2) indicate there is, in fact, an emphasis towards the downtown cores due to the strong influence of the economic capital and physical capital tasks (i.e., link table tasks 1 and 2). However, few critical management areas were located in the Intercity Mall area due to the weak emphasis in these areas by five of the seven standard and link table management tasks.

An urban forestry professional in Thunder Bay might suspect the major arterial roads (i.e., Red River Road, Arthur Street) – including those within the Intercity Mall area (i.e., Memorial Avenue, Fort William Road, Harbour Expressway) – to be significant priority areas for greening due to the low tree cover along many sections of them. With some exceptions, many of these arterial roads were not identified in the application of the prototype UFBM as a greening target largely because no single task focused solely on either beautification along or infilling canopy gaps along arterial roads. This is the main reason why the Intercity Mall area is not modeled as a critical area in this application of the UFBM. Future versions of the UFBM could be configured to include these and other criteria if deemed important by a given focus group and/or researcher.

In addition, an urban forestry professional might *not* have expected that mature residential neighbourhoods (>50 years old) - including Northwood, West End and Carrick neighbourhoods - would be emphasized for greening activities as these areas typically have higher-than-average levels of tree cover. However, as indicated through the application of UFBM, these neighbourhoods are in close proximity to facilities (e.gs., schools, care residences) and people who depend on the tree's benefits and services resulting in high scores for the School Travel Greening, Special Needs Greening and PPI management tasks, respectively (Figure 6.2). Although unexpected by many urban forestry professionals, these areas should continue to be a focal point for tree planting, maintenance and protection to ensure that the community needs (and goals) are met by living green infrastructure.

6.3 Formal Recommendations

The development of the prototype UFBM has led to two levels of recommendations. The first set of recommendations pertain to greening suggestions specific to the city used in the case study application of the UFBM – the City of Thunder Bay. The second set of recommendations focuses on the how the approach for modeling and calculating the benefits of an urban forest could inform the wider research and professional literatures. Based on the rationale discussed above, it is recommended that the Ideal Combined Greening Index be used over the Realistic Combined Greening Index as the primary source for influencing greening recommendations in Thunder Bay. Based on the Ideal Combined Greening Index, it is recommended that the City of Thunder Bay focus a majority of its planting, maintenance, and protection efforts in the highest scoring management areas. The areas of primary focus are highly concentrated management areas within the two downtown cores and concentrated sections within the West End, Northwood, and Vickers neighbourhoods (see Figure 6.4). A greening regime should be developed to include an intensification of tree cover in these areas. Naturally, this model does not replace routine planting, maintenance, and protection regimes entirely, but is recommended that these results, based on the seven top sustainability goals of the community, be used considerably, and in conjunction, with existing schemes.

This prototype model was developed as a case study for the City of Thunder Bay, and includes both public and private lands. Typically municipalities have little jurisdiction over private lands within the City (e.g., residential front or back yards). The City is therefore encouraged to employ creative strategies to inspire homeowners to increase tree cover on private land in high priority greening areas. Possible approaches may include arbor days, tree campaigns, partnerships with local tree advocacy organizations and utility companies, rebates and incentives, and media releases, which may enhance community awareness and increase private tree cover where it is most important. Of course, by planting trees along public sections of desired streetscapes, the City of Thunder Bay can lead by example, acting as a catalyst for future greening in a neighbourhood.

As the UFBM helps to inform new planting and planning schemes for the City, management areas that are targeted for greening will require diligent application of best management practices in the field. The UFBM provides recommendations based on 1 ha areas, and to increase existing tree cover (i.e., benefits), foresters, arborists, and field technicians must choose the proper tree species, microsite, and management approach to facilitate the greatest potential of the targeted UFBM benefits. For example, if the targeted tasks were stormwater, school travel, and special needs, then a large street tree, such as Silver Maple (*Acer saccharinum*) or Basswood (*Tilia Americana*) could be prescribed given the other site characteristics are met, such as available growing space and soil. Figure 6.9 demonstrates some of the factors that should be accounted for when greening. It should be noted that the ultimate success of the UFBM decision support model hinges particularly on field technicians and arborists in using best management field practices to implement the model's results. With a comprehensive understanding of best management practices and with the integration of local knowledge of climate and tree species, arborists will ensure optimum health, growth and supply of tree benefits long term.

The second level of recommendations focuses on the modeling approach used in the development of the UFBM, including modeling urban forest benefits and lessons learned in the process. Thunder Bay was used as a case study city, that is, it was used to help determine the usefulness and application of the model to other jurisdictions. The UFBM's framework and modeling approach was designed to be compatible with other small- to medium-sized cities, primarily because of the flexibility in data and software requirements. To be compatible, however, the model would require adjustments to suit the study community, including the modification of weighted variables used in the GIS.

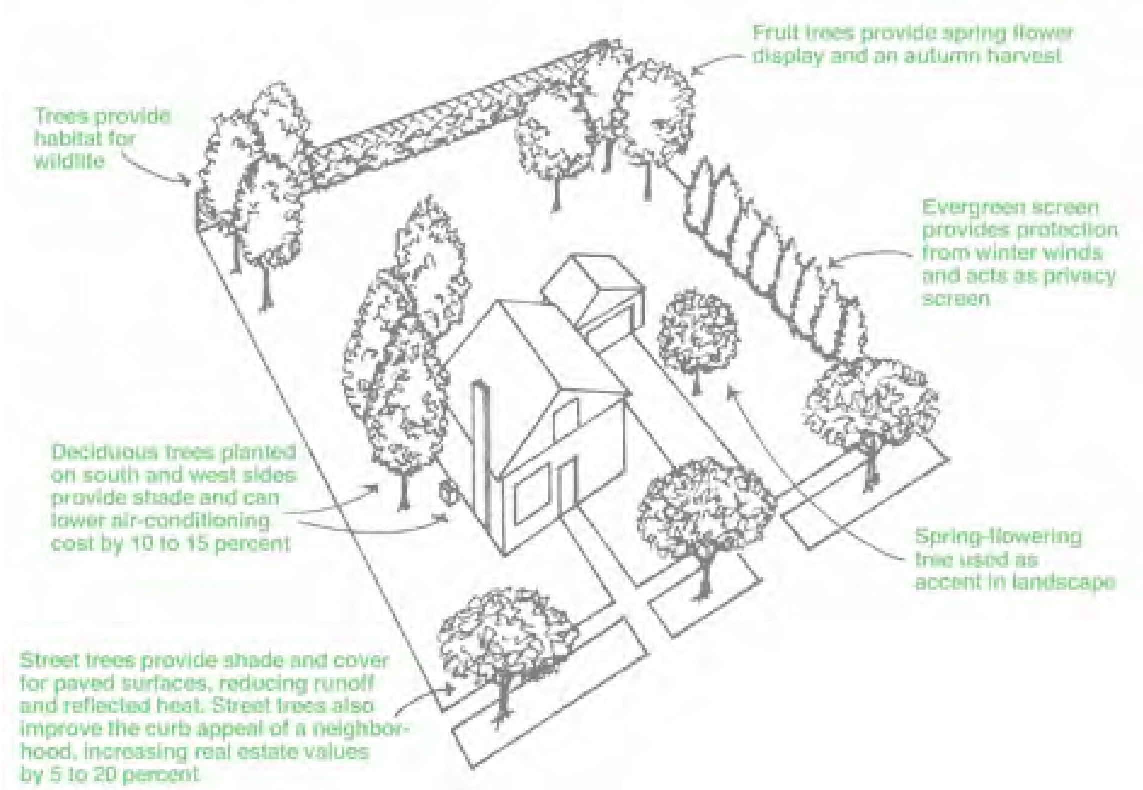


Figure 6.9. Pictorial representation of the various considerations that should be accounted for by arborists and field technicians before tree planting and maintenance. In addition to the above, other site characteristics must be considered such as soil type, species selection, and growing restrictions such as underground or overhead utility infrastructure. Best management practices are required for the successful greening of each management area. Source: from ISA (2007).

The development of the link table provided a framework for sifting through substantial quantities both of urban forest benefits and the sustainability goals of Thunder Bay. These methods allow the link table to be customized to any community, based on their geographical location and sustainability goals, and provides a community with a set of tailor-made greening strategies derived from the strongest connections indicated in the link table. The focus groups and link table, however, required the researcher to have considerable knowledge of the urban forest benefit literature. The application of the UFBM to another city, therefore, would require an individual to possess an extensive background in urban forest benefits. It also requires an understanding of the spatial data needed to support the GIS analysis of specific sustainability tasks.

The use of focus groups provided meaningful input during the customization process, and in addition, it helped in the prioritization of urban forest benefits and community goals. The focus groups were also integral for justifying the assigned weighting to many of the variables used in the formulae during the GIS analysis. For future applications of this model, it is recommended that the individual investigate alternative means of designing and running meetings, conference calls, and focus group meetings. Alternative approaches, such as email surveys and Delphi groups could be used in conjunction with focus groups to provide even more effective results, especially if focus group meetings are not well attended.

In the development stages of the model, the researcher investigated the various advantages and disadvantages regarding the size of area within which the results should be presented in (see Chapter 3). Other models (particularly Locke *et al.* 2010 and CityGreen) based their recommendations on larger more inconsistently-sized areas (e.g., census tract areas). After reviewing the advantages and disadvantages, the researcher chose to display the UFBM results using 1 ha management areas to increase the usefulness to planners and to other decision makers. It is recommended that future applications of this model use a grid of 1ha or smaller to summarize the results in order to increase the accuracy and usefulness for decision makers.

7.0 Conclusion

Urban forests are multi-functional living green infrastructure that contribute significant socioeconomic and biophysical goods and services to society. Extensive urban forest research and modeling using GIS in recent years has demonstrated that an urban forest's structure and function act as bio-technology to purify water and air, reduce the urban heat island effect, reduce health care costs, and encourage active transportation, among other effects. At the same time, cities are in a crisis and are facing problems that challenge their existence. Pollution, obesity, population influx, social injustice and infrastructure degradation are issues that are deteriorating the quality and health of city life (Bourne 2000). Decision makers have begun recognizing the need for restorative, natural services in their communities and are identifying the important role urban forests play in sustaining the health and livability of their cities.

The prototype UFBM evolved out of the need to understand how urban forests might be better integrated into a community to alleviate the existing sustainability problems faced by cities. The UFBM developed in this research is the first of its kind to integrate the mitigating, multifunctional goods and services of trees with the tailored sustainability objectives of a community. By way of focus groups and a review of urban forest benefit and sustainability literature, three standard tasks and four link table tasks were chosen for a customized case study application to the City of Thunder Bay. By way of GIS, these tasks were analyzed individually to determine the optimum locations to green, based on the task's particular sustainability goal. The combination of all seven tasks provided an overall greening management strategy called the Ideal Combined Greening Index. This index targets sites that allow trees to produce multiple types of services simultaneously that contribute toward the most important goals of a community.

The model is customizable and designed for use in other jurisdictions. It depends heavily upon focus groups and a well-informed lead researcher to recreate the link table, identify the tasks, and develop a methodology for each task for a given city. In the case study for Thunder Bay, only seven tasks were modeled, however, ideally, all the tasks presented in the link table (given their priority and data requirements/availability) should be modeled to derive the most comprehensive greening plan.

With resource and budgetary limitations faced by municipalities, the prototype UFBM will provide decision makers with the tools to green their cities in an intelligent, cost-effective manner, based on the needs of a community. It will provide urban foresters the means to modify their existing tree planting and maintenance regimes to increase benefits to the community and bolster the mission of other progressive community-planning strategies such as Smart Growth. Although the prototype UFBM may be only one tool in the decision maker's arsenal, this model provides a strong holistic approach for using living green infrastructure in a manner like never before, to assist in achieving the urban sustainability goals of a city.

7.1 Research Limitations and Future Research

There are a variety of limitations and challenges faced by researchers when developing a new model or research approach. With these challenges come the opportunities to explore alternative methods for attaining the research objectives. Below is a discussion of the various limitations faced in the development of this model, and potentially new research avenues that could be explored.

To determine the best methodological approach, a combination of creativity, academic counsel, and a significant review of GIS, sustainability, and urban forest benefits literature were needed. The replication and customization of the UFBM to other jurisdictions would likely also require the individual to have a significant understanding of GIS, sustainability, and the urban forest concepts. For this reason, the relevance and application to other municipalities could be limited if such individuals lacked any of these areas of expertise. Hence, new approaches and methodology to reduce the expertise required to carry out the UFBM should be explored. Examples could include creating a user-contributed, internet-based database of urban forest benefits and their potential connections with typical community sustainability objectives. Additionally, sections of the model (e.gs., the link table and GIS methods) could be developed with macros, scripts, and even a small software package to help simplify the user experience. Other examples could include a heavier reliance on focus groups and advisory panels to reduce the dependence and need for a single individual that is highly versed in these specialized topics.

The use of focus groups was integral in the development of the UFBM for drawing on expertise and knowledge from a corporate level when the researcher required additional input. As previously discussed, alternative means of gaining the corporate knowledge could be explored. The focus groups were invaluable to create meaningful group conversations, however, the format allowed for only a portion of participants to attend due to scheduling conflicts. In this manner, other methods such as conference calls, emails, and one-on-one meetings could also prove effective in gaining local, communal feedback.

As new strategies are explored regarding community input, it also will be important to uncover ways in which the focus groups can be used to provide input regarding the weighting of parameters of each standard and link table tasks, on their own, and in the combined index. As discussed previously, a sensitivity analysis to determine and justify more appropriate weighting schemes could include an expert advisory panel or a focus group for this process.

The development of the UFBM was made possible with GIS and remote sensing data provided by the City of Thunder Bay and also with financial support from public and private sources. These data and funding sources made it feasible to carry out the core elements of the UFBM successfully, such as the inventory and classification of the city's private trees. However, although the research objectives were met with the available data and funding, recent development of newer technology could possibly provide more precise results. The summer employee who carried out the private tree remote sensing inventory for the UFBM was required to classify tree canopies into diameter classes manually due to the limitations in availability of technological equipment. Manually classifying trees into categories decreases the level of precision of the overall tree population and it is time intensive. In contrast, LIDAR used in conjunction with remote sensing software (e.g., Ecognition) provides more accurate results when estimating tree cover and does so by using an automated, time-saving process. It can also classify other useful land types such as bare soil and impervious cover, which is beneficial for other UFBM analyses. Although LIDAR is less commonly used in small- and medium-sized cities due to its costs, if available, its application to the UFBM would generate more meaningful results.

The purpose of the UFBM is to provide a macro-scale decision support tool to help develop greening schemes within a 1 ha management area. For some decision-makers, this coarse approach could be a limitation due to the lack of support for micro scale tree management (i.e., picking exact locations for tree planting). Although using LIDAR would increase the precision and decrease the size of the management areas, the UFBM was not designed to provide the tools or methods to evaluate potential planting sites on a micro scale level. Therefore, there is opportunity to explore various approaches to merge the UFBM with other micro-scale decision support systems, such as the model created by Kirnbauer *et al.* (2009). A merger of this type could create a more comprehensive set of tools to evaluate potential planting sites at both the macro and micro scale.

Other limitations that exist pertaining to the UFBM include tree planting and care costs that are not accounted for in the model's results. Tree planting can be expensive in urban areas. Most of the tree planting costs are determined by the type of site/soil remediation that is required to provide favourable conditions to grow and sustain a tree. This includes cutting out concrete, removing hard infrastructure, and replacing compacted urban soils with fertile loam. These costs in Thunder Bay for some situations can be as much as 25 times the cost of the tree itself (Vescio, pers. comm., 2010). Determining tree costs would be helpful in such a model, however, they are also very difficult to estimate at a macro scale. Future research could investigate the process of estimating average tree planting costs based on the amount and type of surface cover in a given management area. LIDAR, and its associated classification software, would be an asset for this type of analysis. A GIS layer estimating these figures would provide a form of cost-benefit analysis within the UFBM providing even more direction for decision makers in developing a greening scheme.

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9.0 Appendices

Appendix I - Introduction Letter and Consent Form given to Focus Groups

Lakehead
UNIVERSITY

Bradley Doff
MES NECU
bndoff@lakeheadu.ca
August 4, 2010

Dear Focus Group Participant;

Welcome and thank you for participating in today's focus group! I'd like to provide you with some basic details about my research and why your involvement is important. I will also ask you to review and sign the consent form (attached).

Presently my research focuses on the varying levels of social and biophysical services that trees provide to our communities and how this allows cities to become more resilient and healthy. I am developing a model (Urban Forest Benefits Model) that will help optimize the benefits we receive from green infrastructure so that communities can better achieve their sustainability goals through the use of "smart", GIS decision-supported greening. The research is being undertaken at Lakehead University and is partially funded by the City of Thunder Bay and MITACS Canada.

The purpose of today's focus group is to determine how urban forest benefit research can be applied within the context of Thunder Bay. Each participant of the group will be given an exercise that will ask them to categorize the benefits into five classes (from 'Can't Apply' to 'Fully Apply' in Thunder Bay). Some time will be spent at the beginning of the meeting to discuss instructions about this exercise.

The subject of urban forest benefit research is multifaceted. It is anticipated that the exercise you are asked to complete today may seem indeterminate. Please note that the goal of this meeting is not to find the one "right" answer (which is arguably unattainable), but as a group, to provide some means of clarity and direction in the realm of uncertainty. We will draw on your expertise and knowledge to come up with our best and most informed answers. This meeting is expected to run for about 2 hours. Breaks, refreshments and a light lunch will be provided. This meeting may be audio recorded for note taking purposes.

Your names will be recorded on your own written exercise incase follow up is needed. Your answers and names will be kept confidential when the research is publically presented. If necessary, you may receive an email or telephone call to follow up on some of your input. The information gathered from this meeting will be kept securely at Lakehead University for five years. Also, please note that your participation is voluntary and you can withdraw from the meeting at anytime.

Thank you for being an integral component of this research!

Yours truly,

Bradley Doff

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Lakehead UNIVERSITY

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Lakehead University's Research Ethics Board: Telephone: (807) 343-8283

Consent form

I have read the covering letter and familiar with the process of the focus group. I acknowledge that this process isn't confidential but for any public presentations my name will be kept anonymous. I acknowledge that I can withdraw from this meeting at any point, or may choose not to answer any questions. I agree to participate in today's focus group meeting.

____
Please print name

____
Please sign name

____
Date

Appendix II - Urban Forest Benefits Framework provided to Focus Group

Categorizing How Urban Forest Benefits Apply to Thunder Bay

Benefit Category	Benefit Description	Categorize	Costs	Research Cited	Associated indirect (quantifiable & non-quantifiable) benefits	Other explanatory notes
		From your knowledge and experience, place into categories which level you think the urban forest benefit can be applied to in Thunder Bay. For example, do you believe that trees can mitigate flooding here in the city as the research claims? 1) Can't be applied 2) Possibly applied 3) Applied 4) Strongly applied 5) Fully applied				
Biophysical Benefits						
Urban Hydrology						
Stormwater Flow Control	Trees control stormwater runoff by intercepting and retaining flow of precipitation reaching the ground. Trees reduce stormwater rate and volume and increase wastewater facility performance.			Fraser and Kenney 1985; Nowak and Dwyer 2007; Kimbaue *et al.* 2009; Dwyer *et al.* 1992.	Reduce carbon footprint of water and waste water operations; natural drainage design is 25% cheaper to build than conventional roadside development; reduce flooding hazard, erosion, surface runoff pollution loads.	A study of the Gwynns Falls watershed in Baltimore indicated that heavily forested areas can reduce total runoff by as much as 26% and increase low-flow runoff by up to 13% compared with non treed areas in existing land cover and land use conditions (Neville, 1996). Further, tree cover over pervious surfaces reduced total runoff by as much as 40%; while tree canopy cover over impervious surfaces had a limited effect on runoff. (J. Nowak and John F. Dwyer 2007). Savings in stormwater management costs from trees in Tucson were calculated at $0.18 per tree per year or $600,000 over 500,000 trees and 40 years.
Stormwater Cleaning and Phytoremediation	Trees clean stormwater runoff that can improve the quality of water. Trees absorb and retain toxins in water and decrease the amount of overall contaminated water entering the sanitary sewer system and natural waterways			Nowak and Dwyer 2007; Kimbauer *et al.* 2009.	Increase stream, river and lake water quality; healthier aquatic ecosystems; people can enjoy naturalized, organism rich aquatic areas (e.g. beaches, fish in rivers, etc.)	
Water Conservation	Natural shading provided by trees minimizes lawn scorching and the need for excessive lawn and garden watering (usually treated water)		In arid environments some tree species require large amounts of water (e.g. mulberry) and can offset the water saved by shade.	* References undetermined		
Water Temperature	Tree shading lowers water temperature, vital for riparian ecosystem stability and the survival of many organisms.			LeBlanc 1997; Sweeney 1993.	Stream cooling increases dissolved oxygen necessary for many fish and stream/lake organisms, trees on banks of rivers not only provide shade, but soil stability.	The significance of vegetation near and around streams, rivers and lakes results from a tree's capacity to absorb short-wave radiation that would otherwise be absorbed by the water body. Vegetation also helps to moderate cooler stream temperatures at night by emitting more long-wave radiation than open sky and reducing the water's long-wave radiation losses. In addition, the loss of roots, which provide stream bank stability, may lead to long-term cumulative temperature effects as stream geometry is altered.
Water Habitat Protection	Trees preserve and enhance fish and wildlife habitat, as well as flora environs. Insects that dwell in treed areas provide a rich asset to these aquatic environments.			Sedell, Bisson, Swanson and Gregory 1988; Sweeney 1993.	Healthier aquatic ecosystems, healthier ecosystems that depend on aquatic environments.	The significance of vegetation near and around streams, rivers and lakes results from a tree's capacity to absorb short-wave radiation that would otherwise be absorbed by the water body. Vegetation also helps to moderate cooler stream temperatures at night by emitting more long-wave radiation than open sky and reducing the water's long-wave radiation losses. In addition, the loss of roots, which provide stream bank stability, may lead to long-term cumulative temperature effects as stream geometry is altered.
Lands						
Erosion and Slope Stability	Trees control erosion especially on steep areas and maintain stability on slopes.			Dwyer et al. 1992; LeBlanc 1997; Sedell, Bisson, Swanson and Gregory 1988; Wolf and Bratton 2006; Escobedo and Nowak 2009; Pulford and Watson 2003.	Better water quality downstream (less suspended solids); minimized nutrients leaching.	Trees have massive root systems, which help to bind the soil.
Building Temperature/Energy Savings	Trees lower ground temperature, minimizing the need for air conditioning in the summer. Proper planting around buildings also reduces heating needs by sheltering buildings in the winter from cold winds.		Planted in the wrong areas, trees can undesirably shade buildings in the winter causing higher heating costs	Dwyer and Miller 1999; Dwyer et al. 1992; Nowak and Dwyer 2007.	Reduce fossil fuel use; reduces carbon emissions; increases savings to be used for other home/business needs.	
Road Pavement Life	Tree shading extends the life of road pavement and decreases resurfacing costs.		Some roots cause path and sidewalk cracking if sidewalk depth is shallow.	McPherson and Muchnick 2005.	Reduce fossil fuel use (equipment and energy required to replace asphalt), reduce carbon emissions.	

Categorizing How Urban Forest Benefits Apply to Thunder Bay

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	Soil Contamination (Phytoremediation/ Phytoextraction)	Some tree species are effective at absorbing soil contaminants especially heavy metals on contaminated sites such as along railroads, highways near ESA's, etc.			Pulford and Watson 2003; Nowak and Dwyer 2007.	Brownfields that are left abandoned can be beautified and the soil contained without large expenses. Willow used on contaminated sites can be coppiced/harvested for biomass energy.	The potential use of trees as a suitable vegetation cover for heavy metal-contaminated land has received increased attention over the last 10 years. Trees have been suggested as a low-cost, sustainable and ecologically-sound solution for the remediation of heavy metal-contaminated land, especially when it is uneconomic to use other treatments or there is no time pressure on the reuse of the land. Benefits can arise mainly from stabilization of the soil or waste, although in some cases phytoextraction may be sufficient to provide clean up of the soil. Before these benefits can be realized, the trees must become established on a site (Pulford and Watson 2003). Willow, poplar, maple, ash, alder, sycamore, pine, birch and cottonwood can be used to absorb heavy metals, of which willow is generally the most proficient. Uptake occurs throughout the soil profile to a depth of around 65cm. Lead, chromium and copper tend to be immobilized and held primarily in the roots, whereas Cd, Ni and Zn are more easily translocated to the aerial tissues. This has important implications to the control of movement of heavy metals in the wider environment, which is one of the primary aims of phytoremediation (Pulford and Watson 2003).
	Food	Trees provide food for humans (apples, pears, nuts, mulberries etc.)		Fruit trees if planted the wrong location can cause a litter and wildlife nuisance. Urban fruit trees sometimes require more annual care to produce a crop and added expense to clean up litter.	Schreckenberg *et al.* 2006.	Can play a role in poverty reduction; engages people (and intercity people) with nature/community participation; blossoms are aesthetic assets to the community, encourages stronger (and needed) honey bee habitat in urban areas.	
		Trees provide food and habitat for wildlife		Wildlife can become a nuisance at times in urban areas (bears, birds, etc)	Dickman and Doncaster 1987.	Community can enjoy the benefits of having wildlife/nature in areas where they live, play and work.	
	Increase property value	Trees consistently add value to a home and property (between 3-15%).		Increasing property values isn't always desirable. Mixed home values is needed for sustainable communities so lower income families can afford living accommodations.	Wolf 2007	Properties are more attractive and sell faster over non-treed properties, increased neighbourhood beautification, increased surveillance and appearance of security, increased social interaction.	Price Increase: 2% -mature yard trees (greater than 9-inch dbh), 3-5% -trees in front yard landscaping, 6-9% good tree cover in a neighborhood, and 10-15% mature trees in high-income neighborhoods. Price effect is variable and depends on how tree presence is defined. In addition, the socioeconomic condition of a residential area makes a difference. For instance, greater increments of value are seen for tree planting and landscape improvements in lower-quality neighborhoods. (Wolf 2007)
Air Quality							
	Particulate	Trees remove particulates from the air (ten microns or less).		Some male trees produce large amounts of pollen which can cause increased respiratory ailments. Heavily treed streets that form a continuous canopy along busy streets can retain pollutants in high concentrations within the corridor.	McPherson, Nowak, and Rowntree 1994; Nowak 1994b; Escobedo and Nowak 2009; Nowak and Dwyer 2007.	Reduce health-care costs related to respiratory ailments (especially along heavy-use vehicle corridors)	Urban vegetation can directly and indirectly affect local and regional air quality by altering the urban atmospheric environment: (1) temperature reduction and other microclimatic effects, and (2) removal of air pollutants (pollution removal per m2 of canopy cover in New York in 1994 was 13.7 g/m^2/yr or 1.821 metric tons (Est. value $9.5 million. Trees sequester many pollutants from the atmosphere, including nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), carbon monoxide (CO), and particulate matter of ten microns or less (PM_{10})(Nowak 1994). Other notes on how trees reduce air pollutants: Trees exchange gases with the atmosphere and capture particulates that can be harmful to people. The rate at which trees remove gaseous pollutants such as ozone, carbon monoxide, and sulphur dioxide depends primarily on the amount of foliage, number and condition of the stomata, and meteorological conditions. Results from computer studies indicate that trees can reduce appreciably the amount of ozone in polluted air (McPherson, Nowak, and Rowntree 1994).
	Atmospheric Pollutants	Trees reduce CO_2 by sequestration, and other pollutants (Trees sequester many pollutants from the atmosphere, including nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), carbon monoxide (CO).		Trees may also adversely affect air quality. Most trees emit biogenic volatile organic compounds (BVOCs) such as isoprene's and monoterpenes that can contribute to O_3 BVOC emissions from city trees to O_3 formation. The contribution of formation depends on complex geographic and atmospheric interactions that have not been studied in most cities. See "other explanatory notes" for more details.	McPherson, Nowak, and Rowntree 1994; Nowak 1994b; Escobedo and Nowak 2009; Nowak and Dwyer 2007.		Continued notes about trees producing BVOCs: Some complicating factors include variations with temperature and atmospheric levels of NO_2. As well, the ozone-forming potential of different tree species varies considerably (Benjamin and Winer 1998). Genera emitting the greatest relative amount of BVOCs are sweet gum (Liquidambar spp.), black gum (Nyssa spp.), sycamore (Platanus spp.), poplar (Populus spp.), and oak (Quercus spp.). Studies demonstrated that although removing trees reduces BVOC emissions, this effect was overwhelmed by increased hydrocarbon emissions from natural and anthropogenic sources due to the increased air temperatures associated with tree removal (such as increase ozone due to the heat island effect)(Nowak 2000).

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Air Temperature/Micro Climate	Trees lead to temperature reduction and other microclimatic effects			McPherson and Muchnick 2005; McPherson et al. 2006; Sweeney 1993; Escobedo and Nowak 2009; McPherson, Nowak, and Rowntree 1994; Nowak and Dwyer 2007	Health Benefits - (reduce health costs) from poisonous off gases/vocs in heated cars; reduction of pedestrian heat stress, respiratory illness. Lower energy bills for air conditioning and heating; lower CO2 emissions	Trees lower air, ground and water temperature, thus improving micro climates (cooling downtown cores, reducing the need for air conditioning etc.).
Vehicle VOC emissions	By shading asphalt surfaces, trees minimizes carbon emissions caused by automobile gas tank evaporation.			Nowak 1994b; McPherson and Simpson 2003.		By shading asphalt surfaces and parked cars, trees reduce hydrocarbon emissions from gasoline that evaporates from leaky fuel tanks and worn hoses. These emissions are a principal component of smog, and parked vehicles are a primary source.
	Trees minimize interior car off-gas toxins.			Akbari, Pomerantz, and Taha 2001; Chien 2007.	Increased respiratory and overall health	The manner of vehicle usage, for example, parking in sunlight, can increase the interior temperature and promote the emission of VOC. A high temperature may also induce photo-chemical reactions and subsequently generate new VOC species, which contribute to in-cabin VOC levels. For example, phthalate chemicals (commonly used polymer accelerators/plasticizers) that have been identified in current door-panel and adhesive samples can be transformed to 2-ethyl-1-hexanol via hydrolysis and thermal degradation.
Noise	Trees help reduce noise in the city			Fang, Ling and Kuntze 2003; Moll 1995; Dwyer *et al.* 1992; Nowak and Dwyer 2007; Cook and Haverbeke 1977.	Decrease health issues related to noise exposure: stress, mental fatigue, hearing damage, better employee satisfaction.	Wide belts of tall dense trees combined with soft ground surfaces can reduce apparent loudness by 50% or more. Dwyer, McPherson, Schroeder, and Rowntree 1992.
Social Benefits						
Economic Development						
Attract business investment	Trees attract business investment through increased aesthetics and through increased traffic/tourism.		Trees not properly pruned, or incorrectly selected trees can block business signs.	Wolf 2007; Yannick *et al.* 2010; Wolf 2002; Wolf 2004.		
Stimulate downtown business	Trees support the creation of a positive climate for business, institutions and employees, in order to develop a diversified, growing economy. Trees positively influence consumer behavior; customers are willing to pay more for parking, stay longer, and spend more on goods and services.		Reduced visibility of storefronts and signage due to vegetation is a major concern of merchants. The reduced ratings on the "Wayfinding" perceptions confirmed that customers are not as likely to see internal businesses if a mall is surrounded by trees. Two solutions are possible (see Wolf 2007).	Wolf 2007; Wolf 2005; Wolf 2009; Wolf 1997; Wolf 2004.	Better air and water (micro climate) quality environments, cognitive restoration after shopping, shaded/cool place to have lunch.	
Tourism	Trees positively affect tourism through influence on consumer behaviour and beautification.			Wolf 2002; Wolf 2005; Dwyer *et al* 1992;	Attract downtown business, stronger city economy.	
Worker Productivity	Trees improve worker/employee productivity at the workplace.			Sorrell 2006; Kuo & Sullivan 2001a; Taylor, Kuo and Sullivan 2002; Lohr 1996; Shibata and Suzuki 2002.	Nature has been linked with increasing self discipline - which increases not only productivity, but quality of workmanship.	A view of natural elements was found to buffer the negative impact of job stress, intention to quit and a marginal positive effect on general well-being (Shibata and Suzuki 2002).
Building lifecycle costs	Tree shade/wind/rain diminish some forms of weathering on anthropomorphic surfaces such as shingles, siding, wood decks, roads etc. and allow for longer material lifecycle.		Trees can fail and damage building materials, leading to lower material life-cycle costs.	Rosenfeld *et al.* 1995.	Trees lower replacement costs (longer lifecycle) and thereby reduce carbon emissions and pollutants.	Dark coloured surfaces are damaged by daily thermal expansion and contraction and thus have shorter service lives. Light coloured material or shaded material have longer lifecycles.
Beautification and Design						
Beautification	Trees beautify the neighbourhood.			Regan and Horn 2005; Hartig and Staats 2006; Dwyer *et al.* 2000; Hansmann, Hug and Seeland 2007; Dwyer *et al.* 1992; Dwyer, Schroeder, and Gobster 1991.	Trees compliment historical buildings, they can be a signal of change in a neighbourhood, provide a message of care, provide visual identity and positively influence moods.	
	Trees make street corridors more attractive and appealing.			Wolf 2007; Dwyer et al. 2000; Wolf 2004; Wolf 2007a; Hartig and Staats 2006;Dwyer et al. 1992.	Trees compliment historical buildings, they can be a signal of change in a neighbourhood, provide a message of care, provide visual identity and positively influence moods.	
	Trees improve the condition and appearance of buildings or structures which require upgrading, rehabilitation or re-development.			Regan and Horn 2005; Yannick 2010; Wolf 2005; Dwyer et al. 2000; Wolf 2007a; Hartig and Staats 2006.	Trees compliment historical buildings, they can be a signal of change in a neighbourhood, provide a message of care, provide visual identity and positively influence moods.	
Urban Sprawl/Intensification	Trees increase the value and aesthetics of inner-city properties, thus making them more desirable for higher income families, which leads to more families settling in cities rather than building outside the urban core.			Dwyer et al. 1992; Dwyer, Schroeder, and Gobster 1991.	Less traffic, carbon emission, more inter city carpooling, quieter roads, less stress related to air pollution and traffic congestion	

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	Sense of Place "*Genius Loci*"	Trees make corridors more attractive and appealing and connect a community with its locality (sense of place)			Wolf 2002; Dwyer et al. 1992; Wolf 2004; Paterson and Connery 1997; Nowak and Dwyer 2007; Velarde, Fry, and Tveit 2007; Wolf 2009; McPherson et al. 2006.		
	Civic Pride	Trees transform neighbourhoods (social, economic, ecological) and are a catalyst to attaining civic pride that brings further change and community interaction (Wolf 2005)			Wolf 2002; Dwyer et al. 1992; Dwyer, Schroeder, and Gobster 1991; Wolf 2004; McPherson et al. 2006.	Trees help to create distinction in place and associations and thus create a sense of unity.	
Public Health and Safety	Overall Health	Trees increase the well being of humans. Patients with views or interaction with greenspace heal and are released more quickly, trees reduce air pollution which causes respiratory complications, reduces the number of patients with heat stroke and other over heating complications (heart attacks in seniors etc.), encourages more active transportation and reduces illness relating to obesity and cardiovascular disease.			Velarde, Fry, and Tvei 2007; Hansmann, Hug, and Seeland 2007; Sorrell 2006; Taylor, Kuo and Sullivan 2001; Rappe 2007; Taylor, Kuo, and Sullivan 2002; Akbari, Pomerantz, and Taha 2001.	Trees can decrease health care cost through various direct and indirect means and save tax payer's money.	
	Hospital and Injury Recovery	The visible landscape and association with greenspace is believed to affect human beings in many ways, including aesthetic appreciation, health and well-being which contributes toward faster recovery times			Ultirch 1984; Hansmann, Hug, and Seeland 2007; Erja Rappe 2007; Sorrell 2006; Kuo & Sullivan 2001a; Velarde, Fry, and Tvei 2007	Less of tax-payer's dollars going toward health care which can be spent on other government initiatives.	
	Traffic	Trees calm traffic (slow speeding) and increase road safety		Trees, if planted in the wrong location or incorrectly pruned, can cause obstruction to signs leading to traffic accidents	Wolf and Bratton 2006; Bunn 2009; Pharaoh and Russell 1991.	Quieter neighbourhoods (less high speed traffic), fewer accidents and less damage when they occur. Trees reduce glare and are possibly linked with decreasing incidences of automobile accidents	
	Active transportation	Trees encourage active transportation as sidewalks/paths are cooler, more protected from vehicles, more attractive and quieter (trees reduce traffic speeds and absorb noise)			Hansmann, Hug, and Seeland 2007.	Better citizen health (choosing walking/biking over driving), provides more accessible routes for underprivileged (without car) and lower socioeconomic families to grocery stores (over convenience stores) etc.	
	Pedestrian safety	Trees provide a safety corridor between roads and sidewalks protecting pedestrians and giving the perception of safety			Wolf and Bratton 2006; Bunn 2009; Pharaoh and Russell 1991.	Encourage active transportation.	
	Glare	Trees act as glare control in work, road and living environments, cutting down on irritability and work distraction.			Wolf and Bratton 2006; Akbari, Pomerantz, and Taha 2001.	Possibly linked with decreasing incidences of automobile accidents, and better worker productivity (offices without glare).	
	UV Light	Reduced exposure to cancer-causing UV radiation, lowering the risk of skin cancer and cataracts.			Saraiya 2004; Nowak and Dwyer 2007.	Reduced health-care costs	Skin Cancer is the most common type of cancer in the United States (Saraiya 2004).
Psychological	Stress	Trees improve mental health by providing stress reduction, privacy, etc.		Some stress can be brought on by the potential risk of tree failure.	Velarde, Fry, and Tveit 2007; Hansmann, Hug, and Seeland 2007; Sorrell 2006; Kuo & Sullivan 2001a; Shibata and Suzuki 2002	A reduction in health care costs associated with stress and mental/psychological issues, better worker productivity, healthier family interactions.	A view of natural elements was found to buffer the negative impact of job stress, intention to quit and a marginal positive effect on general well-being.
	Mood	Trees positively affect mood.			Sorrell, John. 2006; Velarde, Fry, and Tveit 2007;Hansmann, Hug, and Seeland 2007; Wolf 1997; Wolf 2004; Kuo & Sullivan 2001a; Dwyer, Schroeder, and Gobster 1991; Shibata and Suzuki 2002	A reduction in health care costs associated with stress and mental/psychological issues, better worker productivity, healthier family interactions.	
	Fatigue	Access or views of natural elements and greenery lower mental fatigue.			Kuo 2001; Shibata and Suzuki 2002; Kuo and Sullivan 2001.	Better worker productivity, healthier family interactions.	Lower mental fatigue: residents with nearby nature were more likely to be able to deal with the major issues of their lives. Such residents felt more hopeful and less helpless about the issues facing them. Higher mental fatigue: residents without nearby nature were less likely to be able to deal with the major issues of their lives. Such residents felt less hopeful and more helpless about the issues facing them (Kuo 2001).
	Aggression	Access or views of natural elements and greenery reduce aggression.			Velarde, Fry, and Tveit 2007; Kuo & Sullivan 2001a; Dwyer, Schroeder, and Gobster 1991	A reduction in health care costs associated with stress and mental/psychological issues, better worker productivity, healthier family interactions	Less aggressive behaviour, fewer crimes reported to the police (both property crimes and violent crimes) than in areas without greenery
	Depression	Access or views of natural elements and greenery alleviate the affects of depression.			Sorrell 2006; Kuo & Sullivan 2001a; Dwyer, Schroeder, and Gobster 1991.	A reduction in health care costs associated with stress and mental/psychological issues, better worker productivity, healthier family interactions	
	Cognitive Function	Green settings replenish cognitive function throughout the day. Research also indicates that children have highest cognitive function when exposed to green settings.			Wells 2000; Velarde, Fry, and Tveit 2007; Sorrell 2006; Kuo & Sullivan 2001a; Shibata and Suzuki 2002.	Better school and employee performance, a reduction in health care costs associated with stress and mental/psychological issues, healthier family interactions.	

Categorizing How Urban Forest Benefits Apply to Thunder Bay

Benefit Category		Benefit Description	Categorize	Costs	Research Cited	Associated indirect (quantifiable & non-quantifiable) benefits	Other explanatory notes
			From your knowledge and experience, place into categories which level you think the urban forest benefit can be applied to in Thunder Bay. For example, do you believe that trees can mitigate flooding here in the city as the research claims? 1) Can't be applied 2) Possibly applied 3) Applied 4) Strongly applied 5) Fully applied				
Food							
	Food Source	Fruit trees, if properly placed in backyards, parks and pathways, can produce edible fruit (apples, pears, cherries, nuts, mulberries, etc.).		Planted in the wrong place, fruit that doesn't get picked by humans/birds can be	Thaman 2002; Ellis 1998; Bolund 1999.	Urban trees producing fruit (parks, public orchards, backyard) require less travel time and less energy than driving to a grocery store or farm outside of the city.	
	Encourage active transportation to grocery stores (reduce impacts of food deserts).	Tree lined streets encourage active transportation by providing protection to pedestrians from cars and high winds, keeping them in the shade, and provide a more meaningful and beautified route. People are willing to walk/bike further in protected/beautified routes to grocery stores rather than relying on unhealthy convenience store food.			Hansmann, Hug, and Seeland 2007; Taylor, Kuo, and Sullivan 2001.	Better overall health (in conjunction with eating better) which leads to less health care expenses.	
Education							
	Attention-deficit/Hyperactivity	Children with ADHD show fewer symptoms when exposed to natural/treed settings and have Improved ability to cope with ADHD.			Kuo & Sullivan 2001a; Taylor, Kuo and Sullivan 2001; Wells 2000; Velarde, Fry, and Tveit 2007; Sorrell 2006; Shibata	Less medication/health care costs associated with ADHD/hyperactivity, increased learning and higher quality students / citizens.	
	Performance	Children's school performance is improved with views of, and interactions with, green settings.			Wells 2000; Kuo & Sullivan 2001a; Taylor, Kuo and Sullivan 2001; Taylor, Kuo and Sullivan 2002; Kuo, Frances and Taylor 2004	Increased learning and better performing students.	
	Enhance Children's play	Urban parks and trees provide more opportunity and encourage children, parents, and grandparents to participate in outdoor activities. It also provides meaningful & educational environmental activities (i.e. tree planting efforts)			Dwyer, Schroeder, and Gobster 1991; Taylor, Wiley, Kuo, & Sullivan, 1998; Kuo 2003; Taylor, Kuo and Sullivan 2001.	Increased physical activity.	
Crime and Other Social							
	Aggression - Violence	Fatigue may increase chances of outbursts of anger and violence. Contact with nature has been reported to mitigate mental fatigue and reduce domestic violence			Taylor, Kuo and Sullivan 2001; Kuo & Sullivan 2001a; Kuo 2001; Wells 2000; Velarde, Fry, and Tveit 2007.	Treed neighbourhoods can be safer neighbourhoods.	Trees can play an important role in reducing crime rates and domestic violence. In a study of Chicago public housing residents, University of Illinois researchers found that buildings with high levels of greenery had 52% fewer property and violent crimes than apartment buildings with little or no vegetation. Why? Green spaces draw people outdoors, increasing surveillance and discouraging illegal activity. The green and groomed appearance of an apartment building is a signal that owners and residents care about a property,and watch over it and each other. Greener common areas also facilitated stronger social ties. The more trees and grass in the common spaces, the more those spaces were used by residents. Those living closer to green spaces enjoyed more social activities, had more visitors, knew more of their neighbors, and reported committing fewer acts of aggression toward household members than those living near barren spaces (Kuo 2001). Less aggressive behaviour, fewer crimes reported to the police (both property crimes and violent crimes) than in areas without greenery. (Kuo 2001)
		Contact with nature has been reported to mitigate mental fatigue which can reduce outbursts of aggression on the road (road rage)			Sorrell 2006; Taylor, Kuo and Sullivan 2001; Kuo & Sullivan 2001a; Kuo 2001; Wells 2000; Velarde, Fry, and Tveit 2007	Reduce accidents caused by road rage, lower health care costs.	
	Neighbourhood Safety	Trees are among the most important features contributing to the aesthetics of a street and neighbourhood. Their presence increases the perception of care and safety.		Some greenspaces that are perceived to be unmanaged can have negative effects on the well being of people by increasing anxiety caused by crime, fear of crime and fear of wild animals in the city.	Kuo and Sullivan 2001; Kuo 2003; James *et al.* 2009; Kuo, Bacalcoa, and Sullivan 1998; Dwyer *et al.* 1992; Velarde, Fry, and Tveit 2007.	Less police intervention/patrol required in well-cared for neighbourhoods.	
		Trees increase social ties & neighboring in public and private lands. Trees provide relief from the sun (cool areas to interact), aesthetics, and appearance of hospitality and care. The various activities surrounding trees, such as leaf raking, tree planting and pruning can increase neighbourhood involvement and ties.			Kuo and Sullivan 2001; Velarde, Fry, and Tveit 2007; Kuo, Sullivan, Coley, and Brunson 1998; Kuo 2003;		
	Cultural and Spiritual	Trees are significant to many cultures, communities and spiritual groups; enriching and complementing cultures and spiritual experiences. Trees also provide creative inspiration to artists, writers, poets and singers.			Dwyer, Schroeder, and Gobster 1991; McPherson *et al.* 2006; Fraser and Kenney 1985;	Higher quality of life for citizens.	

Appendix III - Sustainability Goals Framework provided to Focus Group

Prioritizing our Community's Goals

Goal Category		Goal Description	Priority	Sustainability Citation	Supplementary Explanatory Notes
		The following "Goal Description" are objectives, strategies and policies presented in a variety of the City's guiding documents that relate to	**Prioritize goals into one of five classes:** **1) Not at All** **2) Low Priority** **3) Moderate Priority** **4) High Priority** **5) Extremely High Priority**		
NATURAL CAPITAL					
Lands and Water					
	Water Habitat Protection	Preserve and enhance fish and wildlife habitat, as well as flora environs		City of Thunder Bay Official Plan-May 30, 2005 Official Plan Section 2 Page 14. Environmental Protection Areas	The City is richly endowed with natural heritage features. Lands shown generally as "Environmental Protection" on Schedule "A" are more specifically designated as "Natural Corridor", "Provincially Significant Wetland" and "Areas of Natural and Scientific Interest" on Schedule "B". Schedule "B" also indicates the location of wetlands which, though not identified as being provincially significant, are recognized as important natural heritage features. Any development permitted in, or adjacent to these areas shall be sensitive to the natural heritage values these areas possess and shall have regard to the risks to both people and property because of inherent physical and environmental characteristics.
	Erosion and Slope Stability	Protect people and property from the risks associated with steep or unstable slopes, poor soil conditions, wave impacts, flooding and erosion.		City of Thunder Bay Official Plan-May 30, 2005 Official Plan Section 2 Page 14.3. Environmental Protection Areas	The "Natural Corridor" designation applies to rivers, streams and adjacent lands throughout the City. It is recognized that these features, when maintained in a healthy natural state, perform important ecological functions. Where these areas can be sensitively integrated into the City's trail system, they can represent important public recreation assets. Inappropriate development within these areas, in addition to impeding these ecological functions and undermining recreational values, exposes people and property to risks associated with flooding and erosion. Areas designated as "Natural Corridor" on Schedule "B" include both flood plain areas and lands beyond the outer limits of the flood plain, which may be hazardous due to unstable slopes or the potential for erosion. The "Natural Corridor" designation is also applied to a small number of areas, distant from any watercourse, where steep slopes exist. Erosion and topographic instability represent constraints to development within these areas.
	Water Quality	Policies will be developed to support the City's Pollution Prevention Control Plan and to protect the quality of water in the streams and rivers passing through the City and in Lake Superior		City of Thunder Bay Official Plan-May 30, 2005 Official Plan Section 2 Page 11.6 Servicing	Municipal servicing and infrastructure represents a major investment of public funds. It is important that this investment be protected and managed appropriately. It is recognized that proper planning is required to ensure that adequate public infrastructure is available to meet the City's needs today and into the future.
	Water Conservation	Policies will be developed to encourage conservation in the use of treated water and to minimize the impact on the natural environment through the operation of the City's water system		City of Thunder Bay Official Plan-May 30, 2005 Official Plan Section 2 Page 11.6 Servicing	
	Water Discharge	In the case of new development, no surface water, ground water or building foundation drains will be discharged to the City's sanitary sewer system. To the fullest extent practical, this policy will also be applied to existing development		City of Thunder Bay Official Plan-May 30, 2005 Official Plan Section 2 Page 11.6 Servicing	
	Water Collection System	The collection of surface water and sanitary sewage shall be, to the fullest extent practical, achieved through two collection systems completely separate from each other		City of Thunder Bay Official Plan-May 30, 2005 Official Plan Section 2 Page 11.6 Servicing	
	Surface Drainage	To the fullest extent practical, the quality and quantity of stormwater leaving a site shall be maintained or improved as a result of development.		City of Thunder Bay Official Plan-May 30, 2005 Official Plan Section 2 Page 11.6 Servicing	
		Changes in peak runoff rates and the timing of peak flows are to be minimized so as to reduce downstream impacts and the associated threat to life, property and natural resources		City of Thunder Bay Official Plan-May 30, 2005 Official Plan Section 2 Page 11.21 Servicing	
	Protection of Wetlands	Protect provincially significant wetlands from any use or development that could result in a negative impact on those attributes for which the wetland has been identified.		City of Thunder Bay Official Plan-May 30, 2005 Official Plan Section 2 Page 14.12 Environmental Protection Areas	Wetlands are recognized for the environmental, economic and social benefits they contribute. Wetlands are important for the control and storage of surface water and the recharge and discharge of ground water. They maintain and improve water quality, aid in flood control and often protect shorelines from erosion. Wetlands provide important habitat for a wide variety of plant and animal species and provide passive recreational opportunities. Areas to be designated as "Provincially Significant Wetlands" on Schedule "B" include wetland areas determined to be "Provincially Significant" together with the adjacent lands, where it is considered likely that development or site alteration would have a negative impact on the wetland itself.
	ANSI's (Areas of Natural and Scientific Interest)	Ensure the preservation of "Areas of Natural and Scientific Interest" through the use of appropriate development controls		City of Thunder Bay Official Plan-May 30, 2005 Official Plan Section 2 Page 14.15 Environmental Protection Areas	Areas of Natural and Scientific Interest (ANSI's) are areas of land and/or water containing natural landscapes or features which have been identified as having values related to the appreciation of the natural environment, scientific study or education. ANSI's play an important role in the identification of natural heritage. Through comparative evaluations of natural areas and geological sites, a series of sites that represent the full spectrum of biological communities, natural landforms and environments across the Province have been, and continue to be, identified. Conservation of the best examples of the full spectrum of natural areas is an important aspect of conserving the natural heritage.
	Open Space Areas	Achieve a highly integrated system of recreational areas and trails throughout the City.		City of Thunder Bay Official Plan-May 30, 2005 Official Plan Section 2 Page 15. Open Space Areas	Lands designated as "Major Open Space" shall be used primarily for recreational purposes, both indoor and outdoor. "Major Open Space" uses shall include both active and passive parks. Permitted uses within the "Major Open Space" designation shall include playgrounds, swimming pools, community centres, arenas, golf courses, ball parks, marinas, historical sites, and other similar uses as well as buildings and structures which are accessory to these uses.
	Community Greening	Develop, implement, and provide sustained funding for a comprehensive Urban Forest Master Plan (UFMP) that integrates people, the environment, trees and their continual change and interaction with each other		Earthwise Thunder Bay Annual Report 2009. p22	
	Natural Environment	1) maintain and improve, where possible, the diversity of natural heritage features within the City and **the natural connections between them**; 2) improve property owners' awareness of the value of natural heritage features and increase their understanding of their role in ensuring the protection of these features		City of Thunder Bay Official Plan-May 30, 2005 Official Plan Section 2 Page 2.3 The Natural Environment Chapter 2	The City of Thunder Bay places a high priority on the protection and wise management of natural heritage features. It is recognized that the City has a diverse and abundant supply of natural heritage features and that these resources must be managed wisely in order to ensure their continued existence. These features are the habitat of many species and play an important role in the region's ecology. Changes to natural heritage features can affect the delicate balance between the area's plant, animal, water, air and landscape systems. Through the application of the policies in this Plan, the City will attempt to ensure that development that meets the needs of the current generation can proceed without compromising the ability of future generations to enjoy the benefits of the natural heritage resources that exist today. (OP Chapter 2. The Natural Environment).
	Soil Contamination	Improve the condition of soil contamination (selection criteria for Community improvement Project Areas)		City of Thunder Bay Official Plan-May 30, 2005 Official Plan Section 2 Page 8.3 Community Improvement	Community Improvement is broadly defined as those activities, both public and private, which maintain, rehabilitate and redevelop the existing physical environment to accommodate the social and economic priorities within the community. In the past, the City has participated directly in senior government programs such as Urban Renewal, Downtown Redevelopment and Neighbourhood Improvement Programs, in its efforts toward community improvement. The City encourages eligible private property owners to maintain and improve their properties and participate in the various government rehabilitation and redevelopment programs made available from time to time. Maintenance of property standards is supported through the City's Property Standards By-law. The City also supports the establishment and maintenance of Business Improvement Areas (BIA's) and participates jointly in BIA endeavours to enhance the physical environment and the general promotion of these areas. City initiatives in community improvement contribute significantly towards strengthening the local tax base, economic development, job creation and the economic viability of the business community.
		Seek to ensure, in co-operation with the appropriate government authorities, if necessary, that contaminated soil and groundwater do not create a hazard for the health of natural ecosystems or the people who live, work or play within the City		City of Thunder Bay Official Plan-May 30, 2005 Official Plan Section 2 Page 12.1 Soil Contamination	Soil contamination and contaminated sites refer to lands that, for reasons of public health and safety or environmental quality, are unsafe as a result of past activities. This Chapter outlines policies dealing with the identification of sites and facilities which are known, suspected or potentially contaminated from past land use practices. For the purposes of this Plan, only generic uses that have been known to create possible contamination problems are identified. The following list of general uses suggests activities that are currently in operation, or have been present in the past, that are related to possible environmental contamination: activities involved with the elimination of waste and other residues; industrial and commercial activities involving hazardous substances; storage and transfer of hazardous substance; and sites formerly used for transportation or utility purposes. In addition, where significant filling of property has occurred in the past, contaminants may be present and site remediation may be required.

Prioritizing our Community's Goals

Goal Category	Goal Description	Priority	Sustainability Citation	Supplementary Explanatory Notes
Human and Environmental Health				
Air Quality	To improve outdoor and indoor air quality by reducing air pollutants and greenhouse has emissions.		Earthwise Thunder Bay Annual Report 2009. p32	
Pesticides	To protect the health and well-being of the environment and local citizens today, and ensure a sustainable future, by eliminating the use of pesticides on public and private property;		Earthwise Thunder Bay Annual Report 2009. p33	
Noise, Vibration and Emissions	Minimize or prevent, through the use of various abatement techniques and mitigation measures, the exposure of any person or property to adverse effects associated with noise, vibration or emissions; and encourage the implementation of appropriate mitigation measures to minimize existing compatibility problems;		City of Thunder Bay Official Plan- May 30, 2005 Official Plan Section 2 Page 13.1 Noise, Vibration and Emission	There is a growing awareness of the impacts of noise associated with airport operations, industrial uses, rail and road traffic and other noise generators. Noise can affect people in a variety of ways, the most important of which may be damage to hearing, interference with communication or concentration, disturbance of sleep and general annoyance. Land uses most sensitive to the effects of noise include all residential uses, many institutional uses such as hospitals, churches and schools, some recreational uses such as picnic areas and campgrounds, as well as some commercial uses including day care facilities. Although noise is among the most common forms of negative impact produced in the urban environment, depending upon the particular facility, other adverse effects may be related to vibration, odors and other air emissions.
PHYSICAL CAPITAL				
Energy and Building				
Energy	Reduce total energy usage by 35% within the CTB, and 10% within the community at large, below 2005 levels by 2017		Earthwise Thunder Bay Annual Report 2009. p18	
	Reduce fossil fuel generation by adopting practices that reduce electricity demand during peak periods		Earthwise Thunder Bay Annual Report 2009. p19	
	Encourage the development and use of renewable energy technologies		Earthwise Thunder Bay Annual Report 2009. p20	
	Reduce energy consumption at large City facilities. A strategic priority for the City of Thunder Bay: Making Thunder Bay greener		2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008. p9.	
Green Building	Achieve long-term savings to the citizens of Thunder Bay through reduced operating and life-cycle costs of municipal and private		Earthwise Thunder Bay Annual Report 2009. p15	
Beautification and Design				
Beautification	**Improve image routes through Site Plan Control.** A strategic priority for the City of Thunder Bay: Making Thunder Bay more beautiful		2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008. p10.	
	Design and create Gateways to welcome people to the City. A strategic priority for the City of Thunder Bay: Making Thunder Bay more beautiful		2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008. p10.	
	Improve appearance of Water Street Terminal. A strategic priority for the City of Thunder Bay: Making Thunder Bay more beautiful		2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008. p10.	
Revitalization	Revitalize Fort William Downtown. A strategic priority for the City of Thunder Bay: Thunder Bay will have a High Quality of Life		2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008. p12.	
Intensification/Housing	Encourage efficient residential land use within the City by facilitating the creation of new residential accommodations within existing buildings or on previously developed and serviced land.		City of Thunder Bay Official Plan- May 30, 2005 Official Plan Section 2 Page 6.3 Housing	It is the general intent of this Plan to promote a high standard of residential and urban amenity and to provide for an ample and varied supply of dwelling types to meet the needs of all income groups. It is intended that this Plan promote the development of neighbourhoods that are well planned, safe, friendly, vibrant, inclusive, and places where people feel they belong and contribute. While it is expected that single detached housing will continue to be the dominant housing form, demand for multiple residential development and special needs housing is recognized. In providing for these demands, an appropriate mixture of densities and housing types, in arrangements that will minimize conflicts between different forms of housing, is desirable. During the past two decades, the City's housing stock has grown significantly. This growth can be attributed to a number of factors including the maturing of the baby-boom sector of the City's population and changes in the City's demographic profile resulting in a smaller average household size. Over the next two decades, the City is estimated to require an additional 5,400 dwelling units. Privately owned, single detached dwellings are expected to continue to dominate the City's housing stock; although a broad range of housing with respect to both type and tenure may be more common in new construction. Rehabilitation of existing housing stock is expected to become increasingly important in future years and the conversion of older, larger dwellings to apartment buildings and the conversion of non-residential space to residential use is anticipated to contribute additional residential accommodations. With changes in the age profile of the City's population, it is expected that there will be an increased demand for housing for senior citizens. At the same time, the housing needs of persons with disabilities and other special needs groups must also be addressed.
Appearance of buildings	Improve the condition and appearance of buildings or structures which require upgrading, rehabilitation or redevelopment;		City of Thunder Bay Official Plan- May 30, 2005 Official Plan Section 2 Page 8.3 Community Improvement	Community Improvement is broadly defined as those activities, both public and private, which maintain, rehabilitate and redevelop the existing physical environment to accommodate the social and economic priorities within the community. In the past, the City has participated directly in senior government programs such as Urban Renewal, Downtown Redevelopment and Neighbourhood Improvement Programs, in its efforts toward community improvement. The City encourages eligible private property owners to maintain and improve their properties and participate in the various government rehabilitation and redevelopment programs made available from time to time. Maintenance of property standards is supported through the City's Property Standards By-law. The City also supports the establishment and maintenance of Business Improvement Areas (BIA's) and participates jointly in BIA endeavours to enhance the physical environment and the general promotion of these areas. City initiatives in community improvement contribute significantly towards strengthening the local tax base, economic development, job creation and the economic viability of the business community.
	Improve the presence of residential, commercial, industrial or institutional areas which require streetscape and/or facade improvement;		City of Thunder Bay Official Plan- May 30, 2005 Official Plan Section 2 Page 8.3 Community Improvement	
Residential Areas	Support the provision of services and amenities that enhance the quality of the residential environment.		City of Thunder Bay Official Plan- May 30, 2005 Official Plan Section 2 Page 17. Residential Areas	Lands designated for residential use, shown generally on Schedule "A" and more specifically on Schedule "C", are intended to provide for housing and other land uses that are integral to, and supportive of, a residential environment. Housing may take many forms ranging in density and scale from single detached dwellings to high-rise apartment structures. To provide opportunities for the development of a broad range of residential uses that will satisfy housing requirements, and a range of lifestyles, three residential land use designations are established in this Plan.
Urban Residential	Enhance compatibility between dwelling types at different densities and minimize potential conflict between incompatible land uses.		City of Thunder Bay Official Plan- May 30, 2005 Official Plan Section 2 Page 17 Residential Areas	Lands designated on Schedule "C" as "Urban Residential" are intended primarily for residential purposes, which include the full range of dwelling types and tenure, ranging from single detached dwellings to high-rise apartments. Non- residential uses permitted in "Urban Residential" areas include home occupations, neighbourhood commercial, minor institutional and recreational uses.
Urban Sprawl	Curb Thunder Bay's urban sprawl to reduce energy consumption and greenhouse gases		Earthwise Thunder Bay Annual Report 2009. p29	
Institutional Areas	Ensure that major institutional uses are located and designed in such a way as to adequately serve the needs of the residents; the provision of adequate outdoor amenity area; the provision of on-site landscaping, fencing, planting, and other measures to lessen any impact the proposed development may have on adjacent uses;		City of Thunder Bay Official Plan- May 30, 2005 Official Plan Section 2 Page 18.1. Institutional Areas	Lands designated on Schedule "A" as "Major Institutional" are intended to be used predominantly for public or quasi-public purposes of a city or region-wide nature, such as hospitals, colleges and universities, senior citizen homes, correctional institutions, fairgrounds, cemeteries, major cultural facilities such as theatres, auditoriums, and other public institutional facilities and buildings. Uses within this designation are generally characterized by large areas of open space.
Commercial Grounds	Minimize the impact of commercial development on adjacent land uses and on the traffic carrying capacity of adjacent roads; promote aesthetically pleasing forms of commercial development		City of Thunder Bay Official Plan- May 30, 2005 Official Plan Section 2 Page 19.1. Commercial Areas	Lands designated for commercial use, shown generally on Schedule "A" and more specifically on Schedule "D" are intended to be used for retail or wholesale activities, public and private office uses, service-related functions, cultural and entertainment facilities, as well as community service facilities. In an effort to provide for the efficient distribution of goods and services, five commercial designations are established in this Plan. Areas designated as "Downtown Core", "Regional Commercial", "Community Commercial", "Service Commercial" and "Mixed-Use Waterfront Commercial" are differentiated according to function, permitted uses, density and scale of development.
Downtown Core	Maintain and enhance the downtown areas as unique focal points of activity, interest and identity for residents and visitors through the provision of the fullest range of urban functions and amenities;		City of Thunder Bay Official Plan- May 30, 2005 Official Plan Section 2 Page 19.1 Commercial Areas	Lands designated as "Downtown Core" on Schedule "D" consist of the City's two traditional downtown cores and adjacent areas. It is intended that these two areas will continue to provide a full range of commercial, institutional, recreational, and residential uses. Generally, these areas shall function as places of symbolic and physical interest for all residents and visitors to the City and as focal points for entertainment, social and cultural pursuits. The traditional downtown core areas are viewed as significant assets, important to the City as a whole. The lands designated as "Downtown Core" include not only the downtown commercial cores, but also adjacent areas considered appropriate for the possible expansion of core area functions.

Prioritizing our Community's Goals

Goal Category		Goal Description	Priority	Sustainability Citation	Supplementary Explanatory Notes
	Industrial Areas	Co-ordinate development to minimize any potential conflicts between industrial and non-industrial land uses and between uses within industrial areas themselves;		City of Thunder Bay Official Plan-May 30, 2005 Official Plan Section 2 Page 20. Commercial Areas	Lands designated for industrial use shown generally on Schedule "A" and more specifically on Schedule "E" are intended to be used for a broad range of manufacturing uses, warehousing, assembly, fabricating, processing of goods and raw materials, public utility functions, transportation and communication facilities and uses ancillary to the foregoing. In addition, certain commercial, community and recreational uses, such as wholesale outlets, showrooms, banks, offices, restaurants, fraternal organizations and athletic clubs may be permitted in industrial areas, in accordance with the policies of this Plan. In order to recognize the needs of existing and future industry and to address concerns regarding land use compatibility; four industrial designations are established in this Plan. The "Heavy Industrial," "Light Industrial," "Business Park" and "Utilities" land use designations are differentiated on the basis of the range of permitted uses or industrial processes, the potential impacts these uses or processes have on adjacent areas, and the scale and intensity of development.
		Promote an aesthetically pleasing form of industrial development along major road entrances to the City		City of Thunder Bay Official Plan-May 30, 2005 Official Plan Section 2 Page 20. Commercial Areas	
ECONOMIC CAPITAL					
	Food	Increase the amount of food grown, hunted, gathered, processed, and consumed locally.		Earthwise Thunder Bay Annual Report 2009. p34	
		Reduce the transportation requirements and environmental impacts of the food system		Earthwise Thunder Bay Annual Report 2009. p35	
	Tourism	Attract and retain visitors to the community		2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008. p8	
		The establishment of the City as part of a strong network of communities and businesses which work together to promote and deliver quality tourism experiences in Northwestern Ontario will be promoted		City of Thunder Bay Official Plan-May 30, 2005 Official Plan Section 2 Page 7.1 Economic Development	
	Economic Development	Support the creation of a positive climate for business, institutions and employees, in order to develop a diversified, growing economy; City will rely more upon secondary and tertiary support industry, retail and service functions, and small business, rather than the traditional sources of employment.		City of Thunder Bay Official Plan-May 30, 2005 Official Plan Section 2 Page 7.1 Economic Development	Given its relative size and geographic location, the City functions as a regional centre for Northwestern Ontario. The City is also well situated to develop and capitalize on linkages with markets in the Midwest United States. Historically, the City's economy has been closely linked to transportation, the harvesting and processing of forest products and to tourism. However, in recent years there have been significant shifts in the City's employment base. Employment decline has been experienced in the manufacturing and grain handling sectors and employment growth in various service related industries has occurred. It is anticipated that the City's economy will continue to diversify. It is expected that the City will rely more upon secondary and tertiary support industry, retail and service functions, and small business, rather than the traditional sources of employment.
HUMAN CAPITAL					
Transportation					
	Active Transportation (AT)	Improved safety for people who are engaged in AT		Earthwise Thunder Bay Annual Report 2009. p11	
		Improve the number of people walking, biking, or travelling by other human-		Earthwise Thunder Bay Annual Report 2009. p11	
		Develop infrastructure that supports AT		Earthwise Thunder Bay Annual Report 2009. p13	
		Improve Active Transportation: A strategic priority for the City of Thunder Bay: Thunder Bay will have a High Quality of Life		2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008. p12	
		Encourage the use of energy efficient modes of travel such as public transit, car-pooling, bicycles and other non-motorized		City of Thunder Bay Official Plan-May 30, 2005 Official Plan Section 2 Page 10.1	
		The City will encourage linkages between the university, college, commercial, and open space areas.		City of Thunder Bay Official Plan-May 30, 2005 Official Plan Section 2 Page 10.58	
	Pedestrians	Provide a rationalized system of pedestrian walkways and corridors, which allow safe, effective, convenient and aesthetically		City of Thunder Bay Official Plan-May 30, 2005 Official Plan Section 2 Page 10.50	
	Transportation	Minimize the adverse effects of the transportation system on the natural and urban environments, especially in established residential neighbourhoods:		City of Thunder Bay Official Plan-May 30, 2005 Official Plan Section 2 Page 10.1 Transportation	The transportation policies of this Plan deal with the various elements of the transportation system in the City and the modes of travel it supports. The transportation system provides a framework for urban growth and development, and influences the function and compatibility of land uses and the quality of life in the City. The transportation system consists of many modes of travel, many types of travel routes, and various supporting facilities including roads, rail lines, sidewalks, bicycle paths, pedestrian trails, public transit, parking, harbour, and airport facilities. The Transportation Plan is illustrated on Figure 2. With the exception of the Airport, which is located within the "Airport" designation on Schedule "A", all other transportation facilities are permitted as complementary uses within all land use designations.
		Effect appropriate segregation of truck traffic, for environmental and safety reasons, while at the same time, minimizing the cost of movement expenditures.		City of Thunder Bay Official Plan-May 30, 2005 Official Plan Section 2 Page 10.32 Transportation	
	Traffic Calming	Council shall support the use of traffic calming techniques that help to slow down traffic, reduce through traffic in residential areas; promote pedestrian, bicycle and transit use; and improve the real and perceived safety of the City's streets		City of Thunder Bay Official Plan-May 30, 2005 Official Plan Section 2 Page 10.1 Transportation	
	Parking	Appropriate standards for off-street parking and loading facilities for all forms of land use activities shall be established in the implementing Zoning By-law. The intent of such standards shall be to achieve safe access, efficient usage, improved **aesthetics** and reduced impact on adjacent land uses.		City of Thunder Bay Official Plan-May 30, 2005 Official Plan Section 2 Page 10.1 Transportation	
Community Sustainability					
	Education	Using education and community awareness as a means to achieving a sustainable community		Community Environmental Action Plan	
		Increase public awareness of environmental issues and actions people can take by promoting environmental education and training, and participating in projects that promote water and energy conservation, waste reduction, pollution prevention and urban green-spaces		Statement of Environmental Principles: Environment and Conservation Corporate Policy (Pt 6)	
SOCIAL CAPITAL					
Safety					
	Crime	To reduce crime as indicated in Objective 1.0, 3.1 and 4.1, 4.9 of Thunder Bay Police Service Business Plan		Thunder Bay Police Services 2008-2010 Business Plan. P1-28	
	Speeding	To reduce speeding as indicated in Objective 4.5 of Thunder Bay Police Service [illegible]		Thunder Bay Police Services 2008-2010 Business Plan. P1-28	
	Safe Neighbourhoods	An over arching principle in the CTB Strategic Plan		2007-2010 Strategic Plan, CTB, Building on the New Foundation	
		Enhance Security at Parkades with better lighting - A strategic priority for the City of Thunder Bay: Thunder Bay will have a High Quality of Life		2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008.p11.	

Prioritizing our Community's Goals

Goal Category		Goal Description	Priority	Sustainability Citation	Supplementary Explanatory Notes
		Enhance Security at Transit Terminals - A strategic priority for the City of Thunder Bay: Thunder Bay will have a High Quality of Life		2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008 p11.	
	Informed and Involved Citizens	An over arching principle in the CTB Strategic Plan		2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008, p3	
Community Services					
	Needs of Special Groups	Encourage consideration of the needs of special groups, and in particular persons with disabilities, in the design and construction of buildings and other facilities		City of Thunder Bay Official Plan- May 30, 2005 Official Plan Section 4 Page 4.1 Community Services and Facilities	Land use decisions very often have significant social ramifications. This is particularly true where housing, institutional uses and cultural or recreational facilities are involved. The provision of adequate community services and facilities is essential for the enhancement of quality of life. While the City itself may not be directly involved in the provision of all community services and facilities, it can often play a supportive role. This Plan encourages the development of appropriate community facilities and the provision of appropriate community services. It is intended that these services and facilities be physically accessible, affordable, sustainable and continue to evolve to meet the changing needs of the community. 4.4 Access to Community Services and Facilities Accessibility will be considered in the design of all public buildings and facilities, and will be encouraged in private development initiatives to the fullest extent possible. The use of public transportation and the development of alternate transportation routes, such as pedestrian paths and bicycle commuting routes, will be supported so as to improve public access to facilities and services.
CULTURAL CAPITAL					
	Heritage Resources	1) conserve the historic, archaeological, architectural and cultural heritage resources of the City;		City of Thunder Bay Official Plan- May 30, 2005 Official Plan Section 3 Page 3.1 Heritage Resources	Buildings and sites of historic, architectural, archaeological or cultural significance serve as reminders of the past and constitute important cultural assets within the City. As development continues over time, buildings and sites of historic, architectural, archaeological or cultural significance, that are not protected in some way, become increasingly threatened by demolition or alteration. It is recognized that it is not always possible to preserve all buildings or sites of historic, architectural or archaeological value, but their significance should be assessed prior to demolition or alteration. The Ontario Heritage Act provides both legal and administrative mechanisms for municipalities seeking to pursue heritage conservation. The City has formally recognized the heritage value of approximately two dozen buildings and one area by designation under the Ontario Heritage Act. There are also numerous significant archaeological sites provincially registered under the Ontario Heritage Act as well as areas with archaeological potential within the City which can be further identified and inventoried for heritage conservation planning purposes. Many other buildings and several other areas within the City may be worthy of recognition through designation under this Act. (Summary: Official Plan Section 3 Page 3.1 Heritage Resources)
		2) preserve and enhance structures, buildings or sites deemed to have significant historic, archaeological, architectural or cultural significance and, where practical, preserve significant public views and cultural heritage landscapes		City of Thunder Bay Official Plan- May 30, 2005 Official Plan Section 3 Page 3.1 Heritage Resources	
	Increase Pride in Thunder Bay	A strategic priority for the City of Thunder Bay: Making Thunder Bay more beautiful		2007-2010 Strategic Plan, CTB, Building on the New Foundation 2008, p10.	
SUPPLEMENTARY SECTION					
A Call to Action: Ontario Professional Planners Institute (Feb. 10/09)					
	Planning for Children	Give priority to the needs of children and youth		[Guidelines 1-3]. These three guidelines are the most important in that they call for a focus on the needs of young people and indicate processes whereby this can be achieved. Report: Plan for the Needs of Children and Youth, Pg 2. Feb. 10, 2009	"If we can build a successful city for children we will have a successful city for all people." The guidelines have been endorsed by OPPI and thus represent OPPI's position on these matters, at least for urban and suburban communities. The guidelines are organized in six groups, set out here with brief comments and in full later in this Call to Action.
		Plan for children and youth as pedestrians		[Guidelines 4-7]. Walking is the most available mode of active transportation, and thus the most important. It can provide the maximum of exercise for the minimum financial outlay. Land uses should above all facilitate young people's walking. Report: Plan for the Needs of Children and Youth, Pg 2. Feb. 10, 2009	
		Plan for children and youth on bicycles (and other wheels)		[Guidelines 8-12]. Bicycling is the most common mode of mechanized, non-motorized transportation, and is available to most young people. It can be an important means of enhancing independence in youth; but, even more than adults, young people require a safe bicycling environment. Report: Plan for the Needs of Children and Youth, Pg 2. Feb. 10, 2009	
		Plan for children and youth as transit users		[Guidelines 13-15]. As with cycling, the availability of transit to young people can enhance their independence and social maturation. Young people will use transit if it is easy to use and particularly if they and their parents consider it to be safe. Report: Plan for the Needs of Children and Youth, Pg 2. Feb. 10, 2009	
		Focus on journeys to and from school.		[Guidelines 16-18]. During the school year, trips to and from school usually comprise the majority of young people's weekday travel. These trips should receive the highest priority when seeking to encourage active transportation (i.e., non-motorized transportation such as walking and bicycling). Report: Plan for the Needs of Children and Youth, Pg 2. Feb. 10, 2009	
		Reduce transport's adverse impacts on children and youth		[Guidelines 19-21]. Almost all of these impacts result from operation of the internal combustion engines that propel nearly all motorized vehicles. They are experienced mostly when travelling but also when near traffic. Report: Plan for the Needs of Children and Youth, Pg 2. Feb. 10, 2009	

Appendix IV - Ranked Goals Determined by Focus Group #2

Goal Category			Goal Description	Average	Std Dev.	Min.	Max.
ECONOMIC CAPITAL		Food	Increase the amount of food grown, hunted, gathered, processed, and consumed locally.	4.8	0.7	3	5
NATURAL CAPITAL	Lands and Water	Open Space Areas	Achieve a highly integrated system of recreational areas and trails throughout the City.	4.6	0.7	3	5
PHYSICAL CAPITAL	Beautification and Design	Intensification/Housing	Encourage efficient residential land use within the City by facilitating the creation of new residential accommodations within existing buildings or on previously developed and serviced land.	4.5	0.5	4	5
PHYSICAL CAPITAL	Beautification and Design	Urban Sprawl	Curb Thunder Bay's urban sprawl to reduce energy consumption and greenhouse gases.	4.5	0.5	4	5
HUMAN CAPITAL	Transportation	Active Transportation (AT)	The City will encourage linkages between the university, college, commercial, and open space areas.	4.5	0.8	3	5
SOCIAL CAPITAL	Safety	Crime	To reduce crime as indicated in Objective 1.0, 3.1 and 4.1, 4.9 of Thunder Bay Police Service Business Plan	4.4	0.9	3	5
PHYSICAL CAPITAL	Energy and Building	Energy	Reduce energy consumption at large City facilities. A strategic priority for the City of Thunder Bay: Making Thunder Bay greener	4.4	0.7	3	5
PHYSICAL CAPITAL	Beautification and Design	Downtown Core	Maintain and enhance the downtown areas as unique focal points of activity, interest and identity for residents and visitors through the provision of the fullest range of urban functions and amenities;	4.4	0.9	3	5
HUMAN CAPITAL	Transportation	Active Transportation (AT)	Improve the number of people walking, biking, or travelling by other human-powered means	4.4	0.5	4	5
HUMAN CAPITAL	Transportation	Active Transportation (AT)	Develop infrastructure that supports AT	4.4	0.7	3	5
SOCIAL CAPITAL	Safety	Safe Neighbourhoods	An over arching principle in the CTB Strategic Plan	4.3	0.8	3	5
NATURAL CAPITAL	Lands and Water	Natural Environment	1) maintain and improve, where possible, the diversity of natural heritage features within the City and **the natural connections between them**; 2) improve property owners' awareness of the value of natural heritage features and increase their understanding of their role in ensuring the protection of these features	4.3	0.9	3	5
PHYSICAL CAPITAL	Energy and Building	Energy	Reduce total energy usage by 35% within the CTB, and 10% within the community at large, below 2005 levels by 2017	4.3	0.9	3	5
HUMAN CAPITAL	Transportation	Active Transportation (AT)	Improved safety for people who are engaged in AT	4.3	0.9	3	5
HUMAN CAPITAL	Transportation	Active Transportation (AT)	Improve Active Transportation: A strategic priority for the City of Thunder Bay: Thunder Bay will have a High Quality of Life	4.3	0.7	3	5
CULTURAL CAPITAL		Heritage Resources	1) conserve the historic, archaeological, architectural and cultural heritage resources of the City;	4.3	0.9	3	5
CULTURAL CAPITAL			2) preserve and enhance structures, buildings or sites deemed to have significant historic, archaeological, architectural or cultural significance and, where practical, preserve significant public views and cultural heritage landscapes	4.3	0.9	3	5
SUPPLEMENTARY SECTION		Planning for Children	Reduce transport's adverse impacts on children and youth	4.3	0.7	3	5
NATURAL CAPITAL	Lands and Water	Protection of Wetlands	Protect provincially significant wetlands from any use or development that could result in a negative impact on those attributes for which the wetland has been identified.	4.1	1.0	3	5
ECONOMIC CAPITAL		Economic Development	Support the creation of a positive climate for business, institutions and employees, in order to develop a diversified, growing economy; City will rely more upon secondary and tertiary support industry, retail and service functions, and small business, rather than the traditional sources of employment.	4.1	1.0	3	5
HUMAN CAPITAL	Transportation	Pedestrians	Provide a rationalized system of pedestrian walkways and corridors, which allow safe, effective, convenient and aesthetically pleasing pedestrian movement.	4.1	0.6	3	5
HUMAN CAPITAL	Community Sustainability	Education	Using education and community awareness as a means to achieving a sustainable community	4.1	0.8	3	5
HUMAN CAPITAL	Community Sustainability	Education	Increase public awareness of environmental issues and actions people can take by promoting environmental education and training, and participating in projects that promote water and energy conservation, waste reduction, pollution prevention and urban green-spaces.	4.1	0.6	3	5
SOCIAL CAPITAL	Community Services	Needs of Special Groups	Encourage consideration of the needs of special groups, and in particular persons with disabilities, in the design and construction of buildings and other facilities.	4.1	0.8	3	5
SUPPLEMENTARY SECTION		Planning for Children	Focus on journeys to and from school.	4.1	1.0	2	5
NATURAL CAPITAL	Lands and Water	Water Habitat Protection	Preserve and enhance fish and wildlife habitat, as well as flora environs	4.0	0.8	3	5
NATURAL CAPITAL	Lands and Water	Water Quality	Policies will be developed to support the City's Pollution Prevention Control Plan and to protect the quality of water in the streams and rivers passing through the City and in Lake Superior.	4.0	1.1	2	5
PHYSICAL CAPITAL	Energy and Building	Green Building	Achieve long-term savings to the citizens of Thunder Bay through reduced operating and life-cycle costs of municipal and private facilities.	4.0	1.1	2	5
ECONOMIC CAPITAL		Food	Reduce the transportation requirements and environmental impacts of the food system	4.0	1.1	2	5
HUMAN CAPITAL	Transportation	Active Transportation (AT)	Encourage the use of energy efficient modes of travel such as public transit, car-pooling, bicycles and other non-motorized forms of transportation.	4.0	0.9	3	5
SUPPLEMENTARY SECTION		Planning for Children	Plan for children and youth as pedestrians	4.0	0.8	3	5
SUPPLEMENTARY SECTION		Planning for Children	Plan for children and youth on bicycles (and other wheels)	4.0	0.8	3	5
SUPPLEMENTARY SECTION		Planning for Children	Plan for children and youth as transit users	4.0	0.8	3	5
NATURAL CAPITAL	Lands and Water	ANSI's (Areas of Natural and Scientific Interest)	Ensure the preservation of "Areas of Natural and Scientific Interest" through the use of appropriate development controls	3.9	0.8	3	5
PHYSICAL CAPITAL	Energy and Building	Energy	Encourage the development and use of renewable energy technologies.	3.9	0.6	3	5
NATURAL CAPITAL	Lands and Water	Surface Drainage	Changes in peak runoff rates and the timing of peak flows are to be minimized so as to reduce downstream impacts and the associated threat to life, property and natural resources.	3.8	0.7	3	5
PHYSICAL CAPITAL	Beautification and Design	Revitalization	Revitalize Fort William Downtown. A strategic priority for the City of Thunder Bay: Thunder Bay will have a High Quality of Life	3.8	1.3	1	5
SOCIAL CAPITAL	Safety	Informed and Involved Citizens	An over arching principle in the CTB Strategic Plan	3.8	1.3	1	5
SUPPLEMENTARY SECTION		Planning for Children	Give priority to the needs of children and youth	3.8	1.0	2	5
NATURAL CAPITAL	Lands and Water	Water Discharge	In the case of new development, no surface water, ground water or building foundation drains will be discharged to the City's sanitary sewer system. To the fullest extent practical, this policy will also be applied to existing development.	3.6	0.7	3	5

Goal Category			Goal Description	Average	Std Dev.	Min.	Max.
NATURAL CAPITAL	Lands and Water	Surface Drainage	To the fullest extent practical, the quality and quantity of stormwater leaving a site shall be maintained or improved as a result of development.	3.6	1.3	2	5
PHYSICAL CAPITAL	Beautification and Design	Residential Areas	Support the provision of services and amenities that enhance the quality of the residential environment.	3.6	1.2	2	5
ECONOMIC CAPITAL		Tourism	Attract and retain visitors to the community	3.6	0.9	2	5
HUMAN CAPITAL	Transportation	Transportation	Minimize the adverse effects of the transportation system on the natural and urban environments, especially in established residential neighbourhoods;	3.6	1.3	2	5
CULTURAL CAPITAL		Increase Pride in Thunder Bay	A strategic priority for the City of Thunder Bay: Making Thunder Bay more beautiful	3.6	1.2	1	5
NATURAL CAPITAL	Lands and Water	Soil Contamination	Seek to ensure, in co-operation with the appropriate government authorities, if necessary, that contaminated soil and groundwater do not create a hazard for the health of natural ecosystems or the people who live, work or play within the City	3.5	0.9	2	5
HUMAN CAPITAL	Transportation	Traffic Calming	Council shall support the use of traffic calming techniques that help to slow down traffic; reduce through traffic in residential areas; promote pedestrian, bicycle and transit use; and improve the real and perceived safety of the City's streets.	3.5	1.2	2	5
NATURAL CAPITAL	Lands and Water	Water Conservation	Policies will be developed to encourage conservation in the use of treated water and to minimize the impact on the natural environment through the operation of the City's water system.	3.4	0.9	2	5
NATURAL CAPITAL	Lands and Water	Water Collection System	The collection of surface water and sanitary sewage shall be, to the fullest extent practical, achieved through two collection systems completely separate from each other.	3.4	1.1	2	5
NATURAL CAPITAL	Human and Environmental Health	Air Quality	To Improve outdoor and indoor air quality by reducing air pollutants and greenhouse has emissions.	3.4	1.2	2	5
PHYSICAL CAPITAL	Beautification and Design	Industrial Areas	Promote an aesthetically pleasing form of industrial development along major road entrances to the City	3.4	0.7	2	4
NATURAL CAPITAL	Lands and Water	Erosion and Slope Stability	Protect people and property from the risks associated with steep or unstable slopes, poor soil conditions, wave impacts, flooding and erosion.	3.3	1.0	2	5
NATURAL CAPITAL	Lands and Water	Soil Contamination	Improve the condition of soil contamination (selection criteria for Community Improvement Project Areas)	3.3	0.7	2	4
PHYSICAL CAPITAL	Beautification and Design	Beautification	**Improve image routes through Site Plan Control.** A strategic priority for the City of Thunder Bay: Making Thunder Bay more beautiful	3.3	1.2	2	5
PHYSICAL CAPITAL	Beautification and Design	Beautification	**Design and create Gateways to welcome people to the City.** A strategic priority for the City of Thunder Bay: Making Thunder Bay more beautiful	3.3	1.2	1	5
ECONOMIC CAPITAL		Tourism	The establishment of the City as part of a strong network of communities and businesses which work together to promote and deliver quality tourism experiences in Northwestern Ontario will be promoted.	3.3	0.5	3	4
SOCIAL CAPITAL	Safety	Speeding	To reduce speeding as indicated in Objective 4.5 of Thunder Bay Police Service Business Plan	3.2	1.0	2	5
NATURAL CAPITAL	Human and Environmental Health	Noise, Vibration and Emissions	Minimize or prevent, through the use of various abatement techniques and mitigation measures, the exposure of any person or property to adverse effects associated with noise, vibration or emissions; and encourage the implementation of appropriate mitigation measures to minimize existing compatibility problems;	3.1	1.1	2	5
PHYSICAL CAPITAL	Energy and Building	Energy	Reduce fossil fuel generation by adopting practices that reduce electricity demand during peak periods.	3.1	0.6	2	4
PHYSICAL CAPITAL	Beautification and Design	Appearance of buildings	Improve the presence of residential, commercial, industrial or institutional areas which require streetscape and/or facade improvement;	3.1	0.8	2	4
PHYSICAL CAPITAL	Beautification and Design	Institutional Areas	Ensure that major institutional uses are located and designed in such a way as to adequately serve the needs of the residents; the provision of adequate outdoor amenity area; the provision of on-site landscaping, fencing, planting, and other measures to lessen any impact the proposed development may have on adjacent uses;	3.1	0.8	2	4
PHYSICAL CAPITAL	Beautification and Design	Industrial Areas	Co-ordinate development to minimize any potential conflicts between industrial and non-industrial land uses and between uses within industrial areas themselves;	3.1	0.8	2	4
HUMAN CAPITAL	Transportation	Parking	Appropriate standards for off-street parking and loading facilities for all forms of land use activities shall be established in the implementing Zoning By-law. The intent of such standards shall be to achieve safe access, efficient usage, improved **aesthetics** and reduced impact on adjacent land uses.	3.1	1.0	2	5
SOCIAL CAPITAL	Safety	Safe Neighbourhoods	Enhance Security at Transit Terminals - A strategic priority for the City of Thunder Bay: Thunder Bay will have a High Quality of Life	3.1	1.3	1	5
PHYSICAL CAPITAL	Beautification and Design	Appearance of buildings	Improve the condition and appearance of buildings or structures which require upgrading, rehabilitation or redevelopment;	3.0	0.8	2	4
HUMAN CAPITAL	Transportation	Transportation	Effect appropriate segregation of truck traffic, for environmental and safety reasons, while at the same time, minimizing the cost of movement expenditures.	3.0	0.9	2	4
NATURAL CAPITAL	Human and Environmental Health	Pesticides	To protect the health and well-being of the environment and local citizens today, and ensure a sustainable future, by eliminating the use of pesticides on public and private property.	2.9	1.2	1	4
PHYSICAL CAPITAL	Beautification and Design	Commercial Grounds	Minimize the impact of commercial development on adjacent land uses and on the traffic carrying capacity of adjacent roads; promote aesthetically pleasing forms of commercial development	2.9	0.8	2	4
SOCIAL CAPITAL	Safety	Safe Neighbourhoods	Enhance Security at Parkades with better lighting - A strategic priority for the City of Thunder Bay: Thunder Bay will have a High Quality of Life	2.8	0.9	1	4
PHYSICAL CAPITAL	Beautification and Design	Urban Residential	Enhance compatibility between dwelling types at different densities and minimize potential conflict between incompatible land uses.	2.8	0.9	2	4
PHYSICAL CAPITAL	Beautification and Design	Beautification	**Improve appearance of Water Street Terminal.** A strategic priority for the City of Thunder Bay: Making Thunder Bay more beautiful	2.1	0.8	1	3

Appendix V - Link Table

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Appendix VI - Summary of Ranked Goals per Category Provided with Link Table to Focus Group Participants

Please review the following six categories. If you would recommend the model address another task please indicated this in the comments sections found in each category. In conclusion to your review please mark an X in the following box that pertains to you:

☐ I agree with recommendations
☐ recommendations and left
☐ Did not agree completely with the recommendations and have listed my recommendations/feedback in the comments section below.

ECONOMIC Capital

3 MANAGEMENT TASK TO CHOOSE FROM

					Score
Recommended for UFBM	ECONOMIC CAPITAL		Economic Development	Support the creation of a positive climate for business, institutions and employees, in order to develop a diversified, growing economy; City will rely more upon secondary and tertiary support industry, retail and service functions, and small business, rather than the traditional sources of employment.	0.85
	ECONOMIC CAPITAL		Food	Increase the amount of food grown, hunted, gathered, processed, and consumed locally.	0.37
	ECONOMIC CAPITAL		Food	Reduce the transportation requirements and environmental impacts of the food system	0.13

Comments:

PHYSICAL Capital

6 MANAGEMENT TASK TO CHOOSE FROM

					Score
Recommended for UFBM	PHYSICAL CAPITAL	Beautification and Design	Downtown Core	Maintain and enhance the downtown areas as unique focal points of activity, interest and identity for residents and visitors through the provision of the fullest range of urban functions and amenities;	0.67
	PHYSICAL CAPITAL	Energy and Building	Green Building	Achieve long-term savings to the citizens of Thunder Bay through reduced operating and life-cycle costs of municipal and private facilities.	0.54
	PHYSICAL CAPITAL	Beautification and Design	Intensification/Housing	Encourage efficient residential land use within the City by facilitating the creation of new residential accommodations within existing buildings or on previously developed and serviced land.	0.49
	PHYSICAL CAPITAL	Beautification and Design	Urban Sprawl	Curb Thunder Bay's urban sprawl to reduce energy consumption and greenhouse gases.	0.44
	PHYSICAL CAPITAL	Energy and Building	Energy	Reduce energy consumption at large City facilities. A strategic priority for the City of Thunder Bay: Making Thunder Bay greener	0.44
	PHYSICAL CAPITAL	Energy and Building	Energy	Reduce total energy usage by 35% within the CTB, and 10% within the community at large, below 2005 levels by 2017	0.36

Comments:

HUMAN Capital

13 MANAGEMENT TASK TO CHOOSE FROM

					Score
Recommended for UFBM	HUMAN CAPITAL -SUPPLEMENTARY SECTION	Community Sustainability/Transportation	Planning for Children	Reduce transport's adverse impacts on children and youth	0.63
Recommended for UFBM	HUMAN CAPITAL -SUPPLEMENTARY SECTION	Community Sustainability/Transportation	Planning for Children	Focus on journeys to and from school.	0.52
	HUMAN CAPITAL -SUPPLEMENTARY SECTION	Community Sustainability/Transportation	Planning for Children	Plan for children and youth as pedestrians	0.51
Recommended for UFBM	HUMAN CAPITAL -SUPPLEMENTARY SECTION	Community Sustainability/Transportation	Planning for Children	Plan for children and youth on bicycles (and other wheels)	0.51
	HUMAN CAPITAL	Transportation	Active Transportation (AT)	Improved safety for people who are engaged in AT	0.52
	HUMAN CAPITAL	Transportation	Active Transportation (AT)	The City will encourage linkages between the university, college, commercial, and open space areas.	0.50
	HUMAN CAPITAL	Transportation	Active Transportation (AT)	Improve the number of people walking, biking, or travelling by other human-powered means	0.46
	HUMAN CAPITAL	Transportation	Active Transportation (AT)	Develop infrastructure that supports AT	0.45
	HUMAN CAPITAL	Transportation	Pedestrians	Provide a rationalized system of pedestrian walkways and corridors, which allow safe, effective, convenient and aesthetically pleasing pedestrian movement.	0.44
	HUMAN CAPITAL	Transportation	Active Transportation (AT)	Improve Active Transportation; A strategic priority for the City of Thunder Bay: Thunder Bay will have a High Quality of Life	0.42
	HUMAN CAPITAL -SUPPLEMENTARY SECTION	Community Sustainability/Trans	Planning for Children	Plan for children and youth as transit users	0.30
	HUMAN CAPITAL	Transportation	Active Transportation (AT)	Encourage the use of energy efficient modes of travel such as public transit, car-pooling, bicycles and other non-motorized forms of transportation.	0.25
	HUMAN CAPITAL	Community Sustainability	Education	Increase public awareness of environmental issues and actions people can take by promoting environmental education and training, and participating in projects that promote water and energy conservation, waste reduction, pollution prevention and urban green-spaces.	0.01

Two overarching themes scored well in this category: Planning for Children and Active Transportation. Both themes are strongly interconnected and it is a recommended managament task to focus on Active Transportation for Children, focussing on journeys to and from school.

Comments:

NATURAL Capital

4 MANAGEMENT TASK TO CHOOSE FROM

					Score
Recommended for UFBM	NATURAL CAPITAL	Lands and Water	Water Quality	Policies will be developed to support the City's Pollution Prevention Control Plan and to protect the quality of water in the streams and rivers passing through the City and in Lake Superior.	0.57
Recommended for UFBM	NATURAL CAPITAL	Lands and Water	Water Habitat Protection	Preserve and enhance fish and wildlife habitat, as well as flora environs	0.45
	NATURAL CAPITAL	Lands and Water	Open Space Areas	Achieve a highly integrated system of recreational areas and trails throughout the City.	0.43
	NATURAL CAPITAL	Lands and Water	Protection of Wetlands	Protect provincially significant wetlands from any use or development that could result in a negative impact on those attributes for which the wetland has been identified.	0.40

The first and second Management Tasks are strongly interconnected and rank high. It is therefore recommended that the common theme of Protecting Water Quality (pollution loading, flora and fauna preservation) be chosen.

Comments:

SOCIAL Capital

3 MANAGEMENT TASK TO CHOOSE FROM

					Score
Recommended for UFBM	SOCIAL CAPITAL	Community Services	Needs of Special Groups	Encourage consideration of the needs of special groups, and in particular persons with disabilities, in the design and construction of buildings and other facilities.	0.45
	SOCIAL CAPITAL	Safety	Safe Neighbourhoods	An over arching principle in the CTB Strategic Plan	0.44
	SOCIAL CAPITAL	Safety	Crime	To reduce crime as indicated in Objective 1.0, 3.1 and 4.1, 4.9 of Thunder Bay Police Service Business Plan	0.39

Comments:

CULTURAL Capital

2 MANAGEMENT TASK TO CHOOSE FROM

					Score
Non Selected - See description	CULTURAL CAPITAL		Heritage Resources	1) conserve the historic, archaeological, architectural and cultural heritage resources of the City;	0.22
	CULTURAL CAPITAL			2) preserve and enhance structures, buildings or sites deemed to have significant historic, archaeological, architectural or cultural significance and, where practical, preserve significant public views and cultural heritage landscapes	0.22

It is recommended that neither of the Cultural Management Tasks be chosen due to their low priority ranking, low averages, and low final scores.

Comments:

Appendix VII - Script developed in Python Programming Language used for Determining the Proximity to School Variable in the School Travel Greening Index (Sapic, pers. comm. 2011).

```
import arcpy
from arcpy import env

arcpy.env.overwriteOutput = True

vgr_rows = arcpy.UpdateCursor("C:\\gis_temp\\special_needs\\vector_grid2.shp", "","","Grid_code; grid_score; Shape","")
# this is the vector grid source and adds a field called "grid_score"

schbuff = "C:\\gis_temp\\special_needs\\school_buff_ring.shp"
#pathway to school buffer
vector_grid = "C:\\gis_temp\\special_needs\\vector_grid2.shp"
#second pathway to vector grid
result_fold = "C:\\gis_temp\\special_needs\\result\\"
# create this new folder called "result"
n = 1

for vgr_row in vgr_rows:
    print vgr_row.Grid_code
    #print '"Grid_Code" = %s' %row.Grid_code
    cell_area = round(vgr_row.Shape.area, 0)
    #print cell_area
    arcpy.Select_analysis(vector_grid, result_fold + "cell.shp", '"Grid_code" = %s ' %vgr_row.Grid_code)
    arcpy.Clip_analysis(schbuff, result_fold + "cell.shp", result_fold + "schbuff_clip.shp", "")
    arcpy.AddField_management(result_fold + "schbuff_clip.shp", "buff_id", "SHORT", 3, "", "", "", "", "", "")
    arcpy.CalculateField_management(result_fold + "schbuff_clip.shp", "buff_id", "!FID! + 1", "PYTHON", "")
    schb_rows = arcpy.SearchCursor (result_fold + "schbuff_clip.shp", "", "", "NAME; BUFF_DIST; Shape; buff_id", "")

    sch_lst = []
    schbdist_lst = []
    schbarea_lst = []
    schb_id = 0
    schb_dict = {}
    na = 0
    for schb_row in schb_rows:
        schb_lst = []
        temp_lst = []
        arcpy.Select_analysis(result_fold + "schbuff_clip.shp", result_fold + "buff_temp.shp", '"buff_id" = %s ' %schb_row.buff_id)
        if na == 0:
            arcpy.Union_analysis([result_fold + "buff_temp.shp", result_fold + "cell.shp"], result_fold + "union_temp%s.shp" %na, "", "", "")
        arcpy.Union_analysis([result_fold + "buff_temp.shp", result_fold + "union_temp%s.shp" %na], result_fold + "union_temp%s.shp" %(na+1),
"", "", "")
        na = na + 1
    union_temp_rows = arcpy.SearchCursor (result_fold + "union_temp%s.shp" %na, "", "", "Shape", "")
    cell_score = 0
    for union_temp_row in union_temp_rows:
        schb_rows2 = arcpy.SearchCursor (result_fold + "schbuff_clip.shp", "", "", "NAME; BUFF_DIST; Shape; buff_id", "")
        part_score = 0
        for schb_row2 in schb_rows2:
            #print "tu sam 3"
            if union_temp_row.Shape.within(schb_row2.Shape):
                part_score = part_score + 0.25
        cell_score = ((union_temp_row.Shape.area / cell_area) * part_score) + cell_score
    del union_temp_row
    del union_temp_rows
    vgr_row.grid_score = cell_score
    vgr_rows.updateRow(vgr_row)
    print vgr_row.Grid_code
del vgr_row
del vgr_rows
```

Appendix VIII - Metadata

These pages contain metadata for the various GIS data layers used in developing the UFBM, particularly the source and contact information should additional information about the layers be required. The two tables below indicate the input spatial data used in the three standard and four link table management tasks. The details following present metadata for each theme or layer listed in these tables. Detailed contact information for individuals who provided and/or created these data are provided separately.

Shapefiles used in the seven management tasks:

Table VIII.1. The input data requirements for each standard task.

	Standard Tasks Theme Requirements			
Theme Description (Type)	Stormwater	PPI	EAB	Attributes Needed
public tree's existing (point)	✓	✓	✓	varied
private tree's existing (point)	✓	✓	✓	varied
road network (polyline)	✓	✓	✓	n/a
ortho SID 20cm Quad Aerial Images	✓	✓		n/a
dissemination areas (via census)		✓		population data
buildings (polygon)	✓			area
driveways (polygon)	✓	✓		area
lanes (polygon)	✓	✓		area
parking (polygon)	✓	✓		area
travelled roads (polygon)	✓	✓		road class
sidewalks (polygon)	✓	✓		area
neighbourhoods (polygon)	✓		✓	name and area
city study area (polygon)	✓		✓	n/a

Table VIII.2. The input data requirements for each link table task.

	Link Table Tasks Theme Requirements				
Theme Description (Type)	Economic Development	Downtown Core Development	School Travel	Special Needs	Attributes Needed
public tree's existing (point)	✓		✓	✓	varied
private tree's existing (point)	✓				varied
road network (polyline)	✓	✓	✓	✓	n/a
ortho SID 20cm Quad aerial images	✓				n/a
business (point)					location
neighbourhoods (polygon)	✓		✓	✓	name and area
city study area (polygon)	✓	✓	✓	✓	n/a
central business districts (polygon)		✓			n/a
school locations (points)			✓		location

Description of Shapefiles used: *(organized alphabetically)*

Buildings
Filename: *SDE_buildings.shp
Format: polygon shapefile
Data Current to: December 2008
Geographic extent: City of Thunder Bay
Source: City of Thunder Bay, Planning and Building Dept.
Contact: Janice Bonish (see details below)
Attributes used:
Area – building area

Business
Filename: business.shp
Format: point shapefile
Data Current to: 2002
Geographic extent: City of Thunder Bay
Source: City of Thunder Bay, Planning and Building Dept.
Contact: Janice Bonish (see details below)
Attributes used:
location

Central Business Districts
Filename: downtown_core_zones.shp
Format: polygon shapefile
Created: Central business districts were digitized during the summer of 2011 from the City of Thunder Bay's land use planning map from the 2005 Official Plan (see Figure 4.15)

Data Current to: September 2005
Geographic extent: Thunder Bay CMA (Census Metropolitan Area)
Source: City of Thunder Bay, Planning and Building Dept.
Contact: Janice Bonish (see details below)
Attributes used:
Cbd_zones

City study area
Filename: city_boundary_adjusted1.shp
Format: point shapefile
Created: The city study area was digitized during the Spring of 2011
Data Current to: December 2008
Geographic extent: Thunder Bay CMA (Census Metropolitan Area)
Source: City of Thunder Bay, Planning and Building Dept.
Contact: Janice Bonish (see details below)
Attributes used:
Area
Special Notes:
(1) The city study area incorporated most of the Thunder Bay CMA (Census Metropolitan Area) (see Figure 4.9).

Dissemination Areas (via census)
Filename: census_data_projctd.shp
Format: polygon shapefile
Data Current to: December 2001
Geographic extent: City of Thunder Bay
Source: Statistics Canada
Attributes used:
POP2001 – population per dissemination area

Driveways
Filename: driveways.shp
Format: polyline shapefile
Current to: December 2008
Geographic extent: City of Thunder Bay
Source: City of Thunder Bay, Planning and Building Dept.
Contact: Janice Bonish (see details below)
Attributes used:
Area – area of driveway

Lanes
Filename: lanes.shp
Format: polyline shapefile
Current to: December 2008
Geographic extent: City of Thunder Bay
Source: City of Thunder Bay, Planning and Building Dept.

Contact: Janice Bonish (see details below)
Attributes used:
Area – area of lanes

Neighbourhoods
Filename: *SDE_neighbourhoods.shp
Format: polygon shapefile
Geographic extent: Thunder Bay CMA (Census Metropolitan Area)
Current to: December 2008
Source: City of Thunder Bay, Planning and Building Dept.
Contact: Janice Bonish (see details below)
Attributes used:
NAME
SHAPE_Area – area of neighbourhood

Ortho SID 20cm Quad Aerial Images
Filename: SID_20cm_Quad.sid
Format: Raster
Data Current to: October 2008
Source: City of Thunder Bay, Parks Department
Contact: Shelley Vescio (see details below)

Parking
Filename: Parking.shp
Format: polygon shapefile
Geographic extent: Thunder Bay CMA (Census Metropolitan Area)
Current to: December 2008
Source: City of Thunder Bay, Planning and Building Dept.
Contact: Janice Bonish (see details below)
Attributes used:
Area – area of parking lots

Private Trees, Existing
Filename: private_trees.shp
Format: point shapefile
Created: Private tree locations were digitized during the summer of 2010 from the City of Thunder Bay's 'leaf on' imagery (i.e., the Ortho SID 20cm Quad Aerial Images) in conjunction with sections from other images (40 cm resolution near-infrared ADS40 imagery 'leaf-off' provided by the Ministry of Natural Resources). The SID 20cm imagery was flown in October 2008 capturing trees with their leaves on.
Data Current to: October 2008
Geographic extent: for a portion of the City of Thunder Bay as illustrated on Figure 3.9 (Private Tree Inventory Zone).
Source: Bradley Doff
Contact: Bradley Doff (see details below)
Attributes used:

Crown_Diam – Canopy width class

Special Notes:

(2) Other attributes within layer: There were additional attributes collected during summer 2010 including: {type; species; tr_height}. These additional attributes were collected for only a portion of the private tree inventory zone (as seen in Figure VIII.1 below).

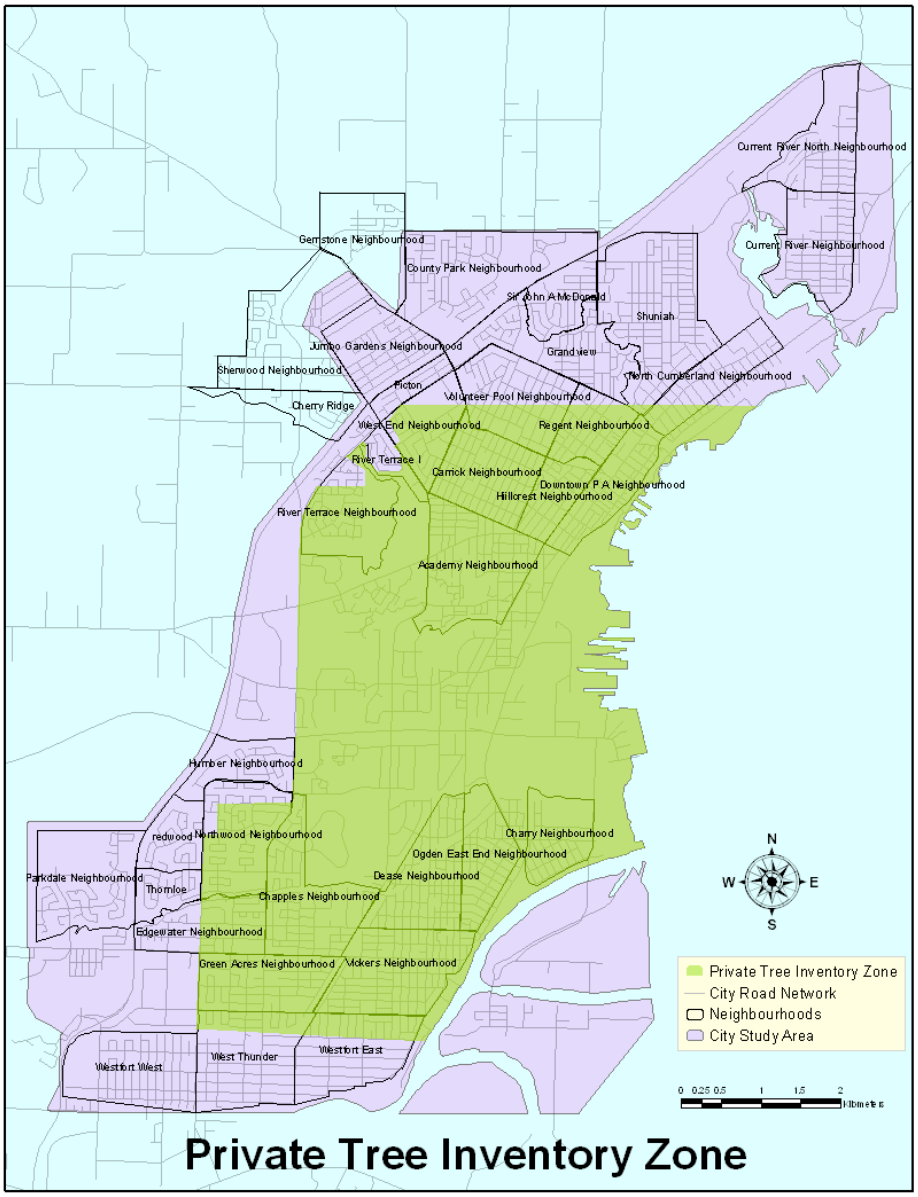

Figure VIII.1. A map displaying the extent of the private tree inventory that falls within the city study area of Thunder Bay, Ontario.

Public Trees, Existing
Filename: *SDE_trees.shp
Format: point shapefile
Data Current to: December 2010
Geographic extent: …
Source: City of Thunder Bay, Parks Department
Contact: Shelley Vescio (see details below)
Attributes used:
HT – Height

Road Network
Filename: city.shp
Format: polyline shapefile
Geographic extent: The City of Thunder Bay
Current to: December 2008
Source: City of Thunder Bay, Planning and Building Dept.
Contact: Janice Bonish (see details below)
Attributes used:
Rd_name

School Locations
Filename: schoolstbay_tojuly5.shp
Format: point shapefile
Geographic extent: The City of Thunder Bay
Current to: July 2009
Source: Lakehead University, Department of Geography
Contact: Todd Randall (see details below)
Attributes used:
Name
Location

Sidewalks
Filename: Sidewalks.shp
Format: polygon shapefile
Geographic extent: The City of Thunder Bay
Current to: December 2008
Source: City of Thunder Bay, Planning and Building Dept.
Contact: Janice Bonish (see details below)
Attributes used:
Area

Roads
Filename: Travelled_roads.shp
Format: polygon shapefile
Geographic extent: The City of Thunder Bay
Current to: December 2008

Source: City of Thunder Bay, Planning and Building Dept.
Contact: Janice Bonish (see details below)
Attributes used:
Area

Contact list:

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*SDE refers to the technology that manages spatial data in a relational database management system (RDBMS) and enables it to be accessed by multiple users. SDE is typically used in municipalities which have multiple users of the same ArcGIS projects.