DECISION SUPPORT FOR SUBURBAN RETROFITTING

By

TODD A. RANDALL, M.Sc.

A Thesis

Submitted to the School of Graduate Studies

in Partial Fulfilment of the Requirements

for the Degree

DOCTOR OF PHILOSOPHY

McMaster University

DECISION SUPPORT FOR SUBURBAN RETROFITTING

For Mira and Nicholas

DOCTOR OF PHILOSOPHY (2001) **McMASTER UNIVERSITY**
(Civil Engineering) Hamilton, Ontario

TITLE: Decision Support for Suburban Retrofitting

AUTHOR: Todd A. Randall, B.Sc. (University of British Columbia)

M.Sc. (McMaster University)

SUPERVISOR: Dr. Brian W. Baetz

NUMBER OF PAGES: x, 299, (CD enclosed)

ABSTRACT

Despite its popularity over the past 55 years, suburban sprawl development is widely criticized in the planning literature. Suburban sprawl is automobile dependent, socially segregating, and overly consumptive of raw materials, land and energy. Typically constructed at densities that do not support effective transit systems, suburban sprawl is often viewed as an unsustainable development form. Interest in urban sustainability evolved following the publication of *Our Common Future* in 1987, such that many communities now have vision statements and objectives for achieving sustainable community designs. There also has been a revival of neo-traditional planning concepts for the design and construction of new neighbourhoods to resemble those constructed prior to WWII (a period of lesser automobile dependence). Despite these efforts, there are many existing suburban areas surrounding cities in North America that need retrofitting, so that they may become increasingly sustainable.

This dissertation develops a conceptual model providing decision support for suburban retrofitting, with the intent that the retrofitted suburbs exhibit a greater degree of sustainability than existing conventional suburban developments. This model, applicable at the neighbourhood scale, represents a departure from current sustainable community planning which is more focussed on greenfield developments. The conceptual model provides retrofitting methodologies for nine aspects of conventional suburban development, including those for increased density, added commerce and employment components, and reduced water, energy and material consumption. Automobile dependence is, in part, addressed by enhancing pedestrian networks and the implementation of neighbourhood traffic calming measures.

Three prototype decision support tools have been created to assist a municipal planner or engineer in retrofitting a conventional suburban neighbourhood. These tools could be used at various stages within the planning process: 1) during the development or review of a community's Official Plan; 2) at the time of major street or utility reconstruction (to coincide with traffic calming installation); or 3) when more modest alterations to the neighbourhood are being considered (e.g., addition of street trees or pedestrian paths). The decision support tools can be used independently to model specific retrofitting aspects of neighbourhoods that may be of current interest to planners (e.g., traffic calming). When integrated with one another, they could be used to develop strategies for how a city might incorporate future population growth within existing built up areas, thereby maintaining a strict urban growth boundary.

The prototype decision support tools are compiled for use in ArcView GIS and allow the user to generate and evaluate retrofitting scenarios for pedestrian connectivity, neighbourhood traffic calming and neighbourhood greening. GIS is the most suitable framework for these tools as it is a primary component in neighbourhood and regional planning processes. Sample applications are provided for case study neighbourhoods in Hamilton, Ontario to demonstrate the use of these tools, particularly to illustrate the key benefits one can achieve by retrofitting conventional suburban areas.

ACKNOWLEDGEMENTS

I owe credit to a number of individuals in completing this work. First among these is my supervisor, Dr. Brian Baetz. He has been an exceptional friend and colleague, and I greatly appreciate all of his efforts in the development and preparation of this thesis. I would also like to thank my other supervisory committee members, Dr. Pavlos Kanaroglou and Dr. Bob Korol, for their guidance and support in this endeavour.

I am grateful for financial support received from the Natural Sciences and Engineering Research Council of Canada, the Imperial Order of the Daughters of the Empire, Ontario Graduate Scholarships in Science and Technology and McMaster University. I thank the Region of Hamilton-Wentworth who contributed spatial digital files for the numerous neighbourhoods used to demonstrate the use of the developed GIS tools.

Finally, I would like to thank my wife, Mira. Without her love and support, I would never have made it this far. I dedicate this work to you, my love, and to our boys, Nicholas and Fraser (woof, woof).

TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (continued)

[This page intentionally left blank.]

1. INTRODUCTION

This dissertation is concerned with the development of a conceptual model and related methodologies to address a number of problems identified in conventional suburban developments. Problems are generally related to the viewpoint that suburban sprawl is an unsustainable form of development (Van Vliet, 1994). The developed methodologies are intended to help provide solutions for retrofitting these conventional suburban areas so that they better fit models of sustainable communities. The generation and evaluation of suburban retrofitting alternatives will be facilitated by a series of decision support systems (DSSs). The DSSs are intended as a set of tools for the urban planner, municipal engineer or other individuals/groups involved in the planning of improvements for existing suburban areas. The material in this chapter is as follows. The first section of this chapter rationalizes the need for modifications to conventional suburban developments, including a discussion of suburbs and a definition of urban sustainability. The second section explores the broader significance of the research, including its key contributions and its key beneficiaries. The final section provides an overview of the research methodology and the nature of the associated GIS-based decision support tools.

Problem Definition

For much of the last century, and especially since World War II, most new residential development has occurred in patterns known as conventional suburbs or suburban sprawl (Hartshorn, 1992; Harris, 1996). Conventional suburbs typically consist of single-use zoned areas of single family detached homes, each with a garage and driveway. These developments may contain a convenience store, but shopping amenities and workplaces are typically located some distance from the home. The segregation of the workplace and home developed early in the 20th Century for North American cities, as efficient transportation systems (e.g., streetcars) were developed to provide means for workers to commute long distances (Harris, 1996). Automobiles and the construction of extensive road and highway networks replaced streetcars from the 1920's onward, as the population demanded the freedom of movement provided by the automobile. The automobile has encouraged suburban sprawl, producing a population now largely dependent upon automobile transportation. Moreover, the automobile has allowed urban planners to maintain segregated land uses, leaving residential development separate from commercial and light industrial activities. Segregation of land uses has led to an abundance of freeways and arterial roads, requiring the majority of people to commute to work or shopping each day by automobile.

From the time ideas relating to "carrying capacity" were developed, societies have begun to realize that resources and space available for human development are finite (Rees, 1990). Well-defined ideas about the unsustainability of human population levels and the need for "sustainable development" were described in the book *Our Common Future* (WCED, 1987). Since then, issues concerning sustainability have been applied to many disciplines, including urban development and community design (Hill, 1992; Maclaren, 1992; Roseland, 1992; Gurstein and Curry, 1993; Alexander and Tomalty, 1994; Tomalty *et al.*, 1994; Van Vliet, 1994), and the documentation of the ecological footprint that societies have on their surrounding environment (Wackernagel and Rees, 1996). The ecological footprint analysis of Wackernagel and Rees (1996) has shown that, on average, each Canadian requires 4.3 ha of land to support their consumption of food and resources. When these per capita land requirements are applied to the global population, we quickly run out of land area to sustain current and future populations.

Sustainability addresses social and economic issues, in addition to environmental ones. It is often viewed as a three-legged stool, with each leg representing one of these three dimensions (Tomalty *et al.*, 1994). By definition, if one leg of the stool (e.g., the environment) is neglected, then this neglect can "topple" the stool, as the social and economic factors cannot sustain the integrity of the stool over the long term. The design of sustainable communities aims to minimize resource and energy consumption for buildings, transportation and municipal infrastructure elements. This process will also recognize the importance of the natural environment within the human-modified environment, while acknowledging the need for continued economic development (Tomalty *et al.*, 1994).

Suburban sprawl has been identified as an issue to which these sustainability principles could be applied. Various authors have critiqued suburban sprawl. Alexander and Tomalty (1994) list the following among the "costs" of urban sprawl:

- Land consumption;
- Energy consumption;
- Destruction of habitat and farmland;
- Groundwater pollution;
- Stormwater runoff;
- Wetland destruction.

In addition to these costs, suburban developments are criticized because they lack healthy civic environments (Duany and Plater-Zyberk, 1992), are socially segregating and overly reliant on the automobile (Christoforidis, 1994; Adler, 1995). It also seems that some citizens are frustrated with the conventional suburb and want something else. From a community development recently proposed near Victoria, the general public expressed a frustration with current suburban design, disliking its dependence on the car and wanting some mix of land uses and protection of the environment (Young, 1995). Other authors have recognized the need to address issues of urban unsustainability, of which suburban sprawl is a large component. Objectives for the planning of sustainable communities are described, for example, in Regional Municipality of Hamilton-Wentworth (1992), Sustainable Seattle (1993), British Columbia RTEE (1994) and City of Calgary (1995).

Despite growing awareness of sustainable community concepts, suburban growth in North America continues to increase. For example, Phoenix sprawls over the surrounding desert at a rate of an acre per hour (approximately 8770 acres per year), and the suburbs around New York City stretch all the way through New Jersey to eastern Pennsylvania, a commuting distance of approximately 100 miles to downtown New York (Adler, 1995). Air pollution associated with excessive commuting is receiving increasing media coverage because of its potential impacts on human health (Bates, 1994; The Hamilton Spectator, 2001a,b). Clearly the continued expansion of conventional suburban sprawl cannot be sustained indefinitely. Future suburban development must have a different form if we expect to maintain a certain quality of life and achieve some form of sustainability. This dissertation aims to address some of the deficiencies of conventional sprawl through the development of a conceptual model to retrofit suburban sprawl neighbourhoods. In developing this conceptual model, the following research questions have been addressed:

- How can principles for urban sustainability be applied to conventional suburban development?
- What physical characteristics of an urban or suburban area are viewed as more sustainable, and therefore more desirable to have within community plans?
- How can these characteristics be integrated within a suburban neighbourhood (if currently absent)? These augmentations or alterations are encapsulated by the term "retrofitting".
- How can retrofitting activities be co-ordinated (within an integrated framework or conceptual model), due to the interrelated nature of these activities?
- How can these retrofitting activities be coded into workable decision support tools for use by interested planners or municipal engineers?

- What other issues for the implementation of suburban retrofitting will need to be addressed?

The significance of the development of a conceptual model for suburban retrofitting is now considered.

Significance of the Research

The main problems with conventional suburban development include automobile dependence and high rates of land and energy consumption. Air pollution, in large part the result of high rates of automobile usage, has developed into a human health issue in many cities across North America (e.g., Vancouver, Los Angeles, Toronto). In these and other cities, people with respiratory and circulatory ailments are recommended to remain indoors or limit their strenuous activities on "poor" air quality days. As well as air pollution, new suburban development has long consumed land rendered "easy to build upon", particularly farmland. Canada contains a very small percentage of class 'A' farmland, located in portions of southern Ontario and in BC's Lower Fraser Valley. These areas are relied upon for the production of domestic fruit and vegetable produce, and it is not surprising that two of Canada's largest urban centres have developed in close proximity to them. However, the consumption of one vital land use (agriculture) by another (residential development), is a problem for the self-sufficiency of the country. Long term sustainability could be achieved by the preservation and enhancement of local food production areas (Regional Municipality of Hamilton-Wentworth, 1992), rather than the continued import of food from Florida or California.

New suburban development should encourage the reduction of individual automobile transportation and support mass transit. Rees and Roseland (1991) write that land use planning and controls must be strengthened. "Sprawl should be attacked by setting maximum expansion limits (i.e., *urban growth boundaries*) and favouring growth near transit stations" (Rees and Roseland, 1991). Recent planning directives provide green field designs which consume less land (per resident) (e.g., Neo-Traditional Developments; see Duany and Plater-Zyberk, 1992) and those designed around new and existing rapid transit corridors (e.gs., Transit-Oriented-Developments or Pedestrian Pockets; see Calthorpe, 1993; Atash, 1994). A recent study at UBC, in co-operation with the Fraser Valley Real Estate Board, suggests that allowing smaller lots and changing infrastructure standards could result in community developments that are more ecologically sustainable, affordable and fiscally sound (REM, 1998).

There is a need to modify existing conventional suburbs to make them less automobile dependent and more sustainable from a variety of other perspectives. The building of new suburbs (e.g., green field developments), even in a more sustainable fashion, does not deal with the existing built stock of unsustainable suburbs (Van Vliet, 1994; Hess, 1997; Southworth, 1997). Considering the size of the suburban rings around many North American cities, there is a huge stock of already-built-upon land that will require retrofitting at some point in the future. Many aspects of suburbs could be modified to reduce energy consumption, and to protect more of the natural landscape for recreation, preservation or agriculture. Van Vliet (1994) writes that "as development is redirected to reconstruction, renovation of the urban area through intensification measures, and overhauling suburbia, there will be a shift in focus from new subdivisions to subdivision redesign and restructuring, intensification, and redevelopment".

The research in this dissertation addresses the need, stated by many researchers (e.g., Van Vliet, 1994; Adler, 1995), that work needs to be done to improve existing conventional suburban developments. Current work aims to: improve suburban neighbourhoods by the installation of traffic calming devices (City of Toronto, 1994; City of Portland, 1999); better connect suburban areas to downtown areas with retrofitted light rail systems (e.g., in Calgary and Dallas); and reduce per capita energy and water consumption. As well, urban growth boundaries such as those implemented in Portland, have taken the focus of development away from sprawl and refocused it to the existing urban and suburban areas.

What is missing, from a review of the academic and planning practice literature, is research on the coordination of a number of these different retrofit measures. Retrofit measures are typically applied in isolation from each other, not co-ordinating activities to address some of the larger issues of suburban sustainability. As well, no one has developed a decision support system (DSS) to generate or evaluate suburban retrofit solutions, since most DSSs (in the urban planning field) have been used primarily for new development (Sussman and Hall, 1993; Churchill, 1997; Timmermans, 1997). The contribution of this research will be the development of an integrated methodological framework within which municipalities can retrofit existing suburbs to achieve a number of the goals of sustainability.

Overview of Research Methodology

This dissertation research has identified and consolidated aspects of a conventional suburban neighbourhood that could be changed to improve the state of "suburban un̲sustainability". These include things such as reducing water and energy consumption, increasing the natural landscape component in suburban areas, and reducing automobile dependence. The nine aspects identified to improve a suburban neighbourhood are shown in Table 1.1. These are primarily physical features of the neighbourhood that can be added or altered to achieve a particular goal. Changes to land use allocations are promoted to diversify land use in suburban neighbourhoods, so that opportunities for local employment and shopping become available. Changes to the road network are suggested to facilitate more sustainable modes of transportation. These include the installation of traffic calming devices to reduce vehicle speeds, the addition of bike lanes and pedestrian facilities to stimulate these modes, and the increase of residential density to support viable transit service. Other changes include the adoption of more naturalized landscaping techniques and the management of water and wastewater. Both of these aspects can provide a quantifiable reduction in energy, water and material use, achieving a condition of greater sustainability. Issues of neighbourhood aesthetics are also important, such as street trees, street furniture and light standards, as more attractive neighbourhoods encourage pedestrian activity and social interaction amongst residents.

Table 1.1: Aspects of suburban neighbourhoods to be retrofitted

PRIMARY	• Pedestrian Connectivity • Neighbourhood Greening • Street Re-design for Traffic Calming and Multi-Modal Use
SECONDARY	• Local Commercial Development • Local Employment • Local Food Production • Residential Density and Housing Mix • Street Re-design for Aesthetics and Safety • Water Consumption and Wastewater Generation and Treatment

Aspects have been divided into primary and secondary categories, as a means of indicating the emphasis placed on each aspect in this dissertation. For the three primary aspects, a more detailed methodology is developed and an operational ArcView extension has been created (see chapters 3, 4, 5 and 6). Methodological development of the remaining "secondary" aspects is discussed in chapter 3, but these methodologies have not been coded as individual ArcView extensions. The division in no way elevates the importance of the primary aspects over the secondary aspects, but reflects the author's decision to focus on a subset of issues that are of particular current interest to North American municipalities. Ultimately, extensions are to be written for all nine aspects, linked in an umbrella decision support tool for suburban retrofitting.

The treatment of three retrofitting aspects in individual decision support tools, rather than in an integrated decision support system with nine aspects, is viewed as a reasonable assumption to make in the development of prototype versions of the tools. That is, these three primary aspects will be considered in this research as largely independent of one another. However, there are interdependencies between the nine aspects that will become crucial once the remaining six ArcView extensions are developed. At that time, it will no longer be possible to model retrofits to any one aspect without considering downstream implications to other aspects. This is especially true of increased density, which has impacts on many other aspects. The nature of these impacts and interdependencies are explored in detail in chapter 3.

The methodologies for suburban retrofitting are intended for use at the neighbourhood scale. The neighbourhood is a common planning unit for many communities and often resources are allocated to neighbourhoods on a one-per-neighbourhood basis (e.g., a school, a park). Furthermore, planning departments have generated zoning and land use maps at this scale, as well as digital database files for use in GISs, and neighbourhood associations have formed corresponding to neighbourhood boundaries and names. In addition, the retrofitting aspects considered in Table 1.1 are best-suited to a neighbourhood scale, particularly traffic calming. Use of any larger scale (e.g., regional scale) would involve additional parties and numbers of residents that might make advancement of retrofitting initiatives more difficult. The regional scale, however, is appropriate for certain activities such as transportation planning and wildlife corridor management. Smaller scales (the individual household or street) represent too fine a resolution to make substantive changes to a neighbourhood other than just piecemeal efforts. Smaller scales are well-suited to the development of a DSS to retrofit a home for the adoption of a number of sustainability features. Because of its suitability, the neighbourhood has been used as the planning and implementation unit for suburban retrofitting. Sample applications at this scale are provided in chapters 4, 5 and 6.

As stated earlier, the developed decision support tools will be useful and instructive tools for urban planners and municipal engineers considering the possibility of retrofitting existing suburban areas. They are intended to model incremental positive changes that would make conventional suburban neighbourhoods more sustainable. These tools could be used at various stages within the planning process. Firstly, they could be used during the development or review of a community's Official Plan. Changes to the chosen neighbourhood, such as the introduction of commercial or employment land uses, could be modelled and evaluated, with the best scenario selected according to established criteria. This would also apply when new development is planned for vacant land in an existing suburb. A second application would be at the time of major street or utility re-construction. Costs for retrofit options such as roadway narrowing, sidewalk additions and certain traffic calming measures are reduced when coincident with street re-constructions. A third application could be done when more modest alterations to the neighbourhood are considered, such as the addition of street trees or pedestrian paths. Again, a number of scenarios could be generated and evaluated by the tool, allowing the user to select the preferred alternative.

The modification or retrofitting of conventional suburban neighbourhoods will not necessarily occur quickly. It is a process that may take decades to achieve, determined by financial constraints, the existing stock of buildings, and public resistance to change. Retrofits to suburban streets, such as the addition of sidewalks or traffic calming measures, could be implemented relatively quickly coincident with periodic maintenance done on municipal roads. Other retrofits, such as increasing the residential density or the addition of viable commerce and employment activities to neighbourhoods, may only be feasible to do in the intermediate to long term, since much of the land may already be built up. A methodology for determining the optimal staging of the retrofit measures will not be part of this dissertation. The scenarios (or "snapshots") generated by the decision support tools are only meant to illustrate, to the user, what the neighbourhood could look like if the retrofitting measures were implemented. Determination of the optimal staging is a logical addition for future research.

Concluding Remarks

This dissertation identifies aspects within conventional suburban neighbourhoods that are amenable to retrofitting, and provides decision support tools to generate and evaluate possible retrofitting alternatives. The need to retrofit these aspects is based upon an objective to have suburban neighbourhoods become more sustainable. Users of the developed tools would have the opportunity to modify neighbourhood aspects, and then evaluate the expected improvements to the neighbourhood. For the prototype versions, three retrofit measures (pedestrian connectivity, neighbourhood traffic calming, and neighbourhood greening) will be examined in significant detail. Other aspects are considered to a degree, but their associated methodologies have not been coded into individual ArcView extensions.

These tools provide planners and engineers with an approach capable of weighing vast amounts of neighbourhood information, incorporating sustainability criteria, and suggesting retrofit measures to solve specific problems or enhance specific neighbourhood characteristics. No such methodology to provide conventional suburban retrofitting solutions currently exists. With the extensive areas of suburban sprawl surrounding many cities in North America, there will be a great deal of future work in retrofitting these areas to more sustainable forms. It is hoped that this research provides insights into potential solutions and the development of prototype systems to generate and evaluate suburban retrofitting alternatives.

The dissertation begins with an examination of the literature on conventional suburban development in North America (chapter 2). Particular interest is paid to growing criticism that conventional suburban sprawl is an unsustainable urban form and to some attempts at sustainable community designs. A conceptual model to retrofit conventional suburban neighbourhoods is presented in chapter 3. The model framework is accompanied by a comprehensive discussion of the developed suburban retrofitting methodology for each of the aspects shown in Table 1.1. Material relating to how each aspect can be modified to achieve the overall objective of creating more sustainable communities is provided, and the interrelationships with other aspects are considered. Of the nine aspects to be retrofitted, three have been formulated into ArcView GIS-based decision support tools: pedestrian connectivity, neighbourhood traffic calming and neighbourhood greening. Their methodological development and application to sample neighbourhoods are discussed in chapters 4, 5 and 6 respectively. The final chapter addresses the major contributions of the research and potential areas for further research.

2. LITERATURE REVIEW

This chapter provides a discussion of the background literature relating to the development of retrofitting solutions for conventional suburban neighbourhoods. The need for retrofitting is based on the desire to have these neighbourhoods better fit models of more sustainable communities. The first section sets the context for the research problem described in chapter 1, outlining the evolution of North American residential developments over the last two centuries. The characteristics of the conventional suburban neighbourhood are then fully described, followed by a critique of its commonly cited deficiencies. The second section describes the key evaluation framework used to suggest improvements in the design of suburban neighbourhoods. This framework relates to the concept of sustainability. The history of the term sustainability is described, as are its applications to community and neighbourhood planning. Included in this review are discussions of what is meant by the term sustainable community design (SCD), and how SCD is currently being implemented. These designs are evaluated using urban sustainability indicators that have been developed to measure how these designs are more sustainable than others. The third section describes the use and need for decision support systems and explores the use of geographic information systems in the context of urban planning problems. A final section reviews some of the community retrofitting activities currently taking place across North America. Many of these activities, applied in relative isolation at present, have been incorporated into the integrated suburban retrofitting methodologies developed in subsequent chapters.

2.1 Suburban Development in North America

2.1.1 Historical Evolution of Suburban Development

The characteristics of North American communities, observed over the last two centuries, have depended very much on mobility within these communities. With technological advances in transportation came segregation of land uses and the increasing demand for commuting to and from work or other destinations. Researchers describe four major eras in the historical development of suburbs, based primarily on transportation modes.

Walking/Horsecar Suburbs (1800 to 1890)

Prior to mechanized transportation, people and goods were moved (as they had been for many centuries before) by rudimentary water transportation, horse-drawn vehicles and walking (Hartshorn, 1992). Lack of mobility, in comparison to modern standards, led to compact city forms. Land uses were mixed, so that employees would be located within "commuting" distance of their workplaces or their daily shopping needs. The wealthy and upper classes of society, with the means of private carriages, were not limited to the central portions of cities, and thus could live some distance away from the city.

During the middle half of the nineteenth century (starting in the 1830's), public transit opportunities began to develop. Horse-drawn cars on iron rails flourished initially, prior to the development of mechanized transportation (e.g., the cable car in 1873 in San Francisco) (Hartshorn, 1992). Both modes had operating speeds in the order of 4 to 5 mph. Horsecar lines thrived in eastern North America, with as many as 39 horsecar companies operating in Philadelphia in the 1850's. Horsecar networks were more commonly developed, since their costs were considerably less than cable car networks. Both horse and cable cars led to the early concentration of commercial activities.

Streetcar Suburbs (1890 to 1920)

The development of the "electric traction motor" provided the means to mechanize the previously developed horsecar networks. The electric streetcar provided higher travel speeds (10 mph), longer network lengths and lower fares, with which earlier forms of transit could not compete. It strongly influenced the geography of development (Warner, 1978), as it provided mass transit at a more affordable price than previously available (Hartshorn, 1992).

Streetcar technology had several major impacts on the growth of cities, which were experiencing massive growth due to the migration of workers (needed for the developing factories of the Industrial Revolution) from rural areas to cities. Transit companies extended their lines to undeveloped tracts of land, and then sold lots and houses to would-be transit users. The resulting urban development followed the transit routes. The streetcar also provided the means for populations to decentralize, driven by the desire for people to escape the increased congestion and greater pollution levels in the central portions of the city (Hartshorn and Muller, 1986). Workers were willing to commute upwards of one-hour by streetcar, to escape living in the central city (Harris, 1996).

Streetcar suburbs, when originally developed, were much like conventional suburban development in that they were located seemingly long distances from workplaces, and they encouraged segregated land uses (Southworth, 1997). They differ, however, in that travel within neighbourhoods was still pedestrian based only, which meant that development attempted to minimize the pedestrian travel distances to the local streetcar stop. Houses are located closer together than in conventional suburbs, with smaller setbacks from the street. Streetcar suburbs have been compared favourably to both the current trend towards Neo-Traditional Designs and conventional suburban development (Southworth, 1997). The heyday for the electric streetcar was during the 1880-1910 period, with 94 percent of all urban passenger trips occurring on streetcars in 1907 (Saltzman, 1979). The automobile, however, was soon to take over from the streetcar.

Mass Automobile Production/Recreation Auto Suburbs Era (1920 to 1950)

Ownership of a private automobile was initially limited to the wealthy. As well, poor quality roads and bad weather also limited automobile use (Hartshorn, 1992). Prior to 1920, vehicles were used primarily for weekend outings, and nearly all of urban commuting in 1920 still occurred by streetcar or rail transit (Hartshorn, 1992). The automobile did provide opportunities for development away from streetcar lines, as commuters began to travel to streetcar stations by car.

Engineering advances in car design during the 1920's assisted the growing popularity of vehicles. Car ownership nearly tripled in the US during the 1920's to 23 million vehicles (Hartshorn, 1992). Improvements in road design and traffic controls accompanied the growth of ownership, and cars began to compete very seriously with the streetcars.

The decentralized form of development encouraged by the streetcar and rail transit systems, produced an environment in such cities as Los Angeles that was very suitable to automobile transportation (Hartshorn, 1992). Accordingly, it is not surprising that four-lane controlled-access roadways (the modern freeway) were first developed in southern California in 1940 (Hartshorn, 1992). However, widespread building of controlled-access roadways did not occur until following World War II.

Sprawl/Freeway/Conventional Suburbs (1950 to present)

The conventional suburb began to develop following World War II, coincident with the Interstate Highway System legislation in 1956 in the United States (Hartshorn, 1992). The development of these road and freeway networks has extensively altered many metropolitan areas in North America.

The initial intention of freeways was to provide more convenient travel (shorter commuting times) to the Central Business Districts (CBDs) of cities (Hartshorn, 1992). It is ironic, therefore, that the improved access provided by freeways is to blame for the demise of the CBDs of many cities. Improved access to cheaper land in the surrounding suburbs has refocused the majority of residential and employment activity there (Hartshorn, 1992), creating what are now identified as "edge cities" (Garreau, 1991). Most large metropolitan areas in North America have a number of these edge communities along radial and circumferential highways.

It is no surprise that conventional suburban development is closely linked to the most effective means of "mass transit" at this point in history: the automobile. The automobile remains affordable to the masses and, together with its associated road networks, has provided the mobility for millions of North Americans to complete their daily transportation requirements. The character of suburbs, like the streetcar suburbs of nearly 100 years ago, reflects the current primary means of transportation. Rather than the compact, high-density and pedestrian-friendly suburbs of the streetcar era (Warner, 1978), current suburbs are spread out, have low densities and do not encourage pedestrians. The next section discusses the characteristics of these conventional suburbs in detail, since it is these sprawling suburbs that pose the greatest challenge to achieve a reasonable degree of urban sustainability.

2.1.2 Characteristics of Conventional Suburban Development

The outcome of the automobile-dominated society (in North America) during the latter half of the twentieth century is the post-war (or conventional) suburb. As stated earlier, prior to the widespread affordability of the automobile, cities were more compact and had mixed land uses in close proximity to each other. The development of the automobile provided affordable means for individual travel over large distances, and industrial and commercial activities re-located to the suburbs to take advantage of lower cost land and proximity to the labour force (Des Rosiers, 1992). There is debate as to whether or not this land and its associated services are actually cheaper, since many feel that high land and infrastructure costs for suburban development are subsidized by the urban core tax base, and are therefore artificially low (Rees and Roseland, 1991; Litman, 1998). Cheap individualized transportation has resulted in the segregation of land uses in cities, and the development of what is commonly known as “urban sprawl”. The following paragraphs contain a generalized description of conventional suburbs.

Land Use

Land use in the conventional suburb is segregated, zoned primarily for residential land uses (Van Vliet, 1994). Historically, when most industrial facilities were heavy polluters, there was a significant desire to locate residential districts away from industrial areas. Initially, in streetcar suburbs, public transportation services provided the means to segregate land uses (Southworth, 1997), and ultimately, the automobile has exacerbated the segregated sprawl across much of North America. Non-residential land uses in suburbs typically include school buildings, churches, green spaces, and commerce. Commercial enterprises are commonly located in suburban neighbourhoods in varying amounts. Typically, a neighbourhood will have a corner convenience store. Some neighbourhoods contain small strip malls or plazas or are located adjacent to large regional shopping centres. Few conventional neighbourhoods are close to significant employment generators.

The provision of school space has long been a priority in neighbourhood design, as suburban neighbourhoods were generally touted as the best place to raise a family. Therefore, many suburban neighbourhoods have an elementary school, a key benefit being that children are able to walk to school without crossing any busy streets. Neighbourhood populations, however, are dynamic. As a suburb ages, the average age of the residents increases and often, the neighbourhood no longer has enough children to support the local school. Many schools are beginning to close in these older neighbourhoods, meaning that any remaining children will be bused to school in a distant neighbourhood. Loss of the school may make it difficult to attract young families to the neighbourhood when houses eventually come up for sale, so the neighbourhood may have trouble rejuvenating itself.

Conventional suburban neighbourhoods are commonly a homogeneous collection of single family homes, built at low density, geared to specific income levels and age groups. Houses are generally built to their fullest extent in today's suburbs, covering the maximum allowable proportion of the lot, with minimum frontage and side yards, and with the greatest allowable heights. This has given the appearance in many neighbourhoods, of "monster homes" with the newer, larger homes dwarfing the more conservative and smaller bungalows of yesteryear. Commonly, home frontages are dominated by a 2-car garage and driveway. As suggested above, any attempt at including mixed economic housing (e.g., apartments and townhouses) with single family dwellings is usually met with opposition. This has meant that these medium-density housing types are relegated to the periphery of housing developments or neighbourhoods, usually in close proximity to arterial and collector roads. Such sites are the most undesirable since they may have higher traffic volumes and can be close to commercial land use zones.

Shifts in population demographics have been occurring for much of the last century with smaller family sizes and improved health and life span of human populations. Once a couple's family has grown and left the family home, couples remain in their neighbourhoods as they are comfortable with their neighbours, homes and local community. Many are reluctant to move to newer communities, since they might be in their mid- to late- fifties and may not want to re-establish themselves in a new community or neighbourhood. However reluctant they might be, they may be forced to move as the single family house becomes too large and too much responsibility to care for lawns, gardens, housing cleaning and other maintenance. Current suburban development is not set up to allow people to remain in the same neighbourhood, in a variety of housing types, for their whole lives.

Many planners, architects and engineers have recognized that integrated - rather than segregated - land uses will produce more sustainable communities and cities (Fowler, 1991; Calthorpe, 1993; City of Calgary, 1995). Integrated land uses means that home is close to work, shopping, and community and social needs. Such urban forms will reduce the transportation demands of the population, and lead to the use of more sustainable forms of transportation such as walking, cycling and transit.

Density

Low-density urban sprawl is a reflection of the desire of North Americans to have their own "space" (Knack, 1991a) and a result of the affordability of the automobile and its associated costs (Gordon and Richardson, 1997). Low densities for suburban sprawl are commonly in the range of 2 to 4 dwelling units per acre (De Chiara and Koppleman, 1975), and there is consensus that suburban sprawl is built at unsustainable densities (Tomalty *et al.*, 1994; Van Vliet, 1994). It is widely reported that current suburban densities of North American cities are too low and have perpetuated their dependence on the automobile (Newman and Kenworthy, 1989; Ewing, 1997). Such densities will not support extensive public transportation systems such as those in Europe. For example, Pushkarev and Zupan (1982) report that a density of 12 dwelling units per residential acre (30 d.u./ha) is required to support rail transit. Although communities in Canada have by-laws permitting such densities, they are rarely achieved over a built-out neighbourhood. In fact, designing a community at a density to achieve transit viability is not currently promoted in suburban planning (Moore, 1998). The Huntington neighbourhood in Hamilton, described later in chapters 5 and 6, has a neighbourhood residential density of 6.8 du/acre (Table 2.1). The neighbourhood density measure, as defined by Alexander (1993), includes total neighbourhood land allocated to residential, street and non-residential (e.g., shopping, recreation, religion) uses.

Table 2.1: Neighbourhood density of Huntington neighbourhood, Hamilton, ON, achieved at buildout

House Type	Number of Dwelling Units	Total Neighbourhood Area	Neighbourhood Density
Single Family	1404	317.5 acre 127.0 ha	6.8 du/acre 16.9 du/hectare
Duplex	14		
Apartment	733		
Total	2151	n/a	n/a

Street Layouts and Connectivity

The conventional suburb has a three-class road hierarchy: arterial, collector, and local roads. Arterial roads are the major "arteries" of the city, facilitating rapid and convenient access from one part of the city to another. Collector roads collect and feed traffic from the local roads in neighbourhoods to the arterials. Local roads are the streets, avenues, drives, crescents, and cul-de-sacs along which most low-density residential development occurs. Collector and arterial roads are busier and are generally home to higher density residential and commercial development (City of Stoney Creek, 1997).

Early suburbs, built prior to WWII, were laid out in a recti-linear grid pattern. This minimized travel distance from the home to a destination, whether that be a streetcar stop or shopping. Arguably, these patterns produced undesirable through-traffic once automobile ownership became widespread, but they are thought to have lower overall fuel consumption per household (Curtis *et al.*, 1984). Following 1950 or so, the curvi-linear pattern for suburban development took root and the cul-de-sac became particularly popular, since it provided quiet suburban streets that were safe for children and families.

What the grid network provided to the neighbourhood or district was a number of linkages between home and any particular destination. Rather than being required to walk the same path to the corner store, for example, a home owner in a grid neighbourhood might be able to walk to the same store by 5 different routes, all of the same distance. Such a connected network also provided these same 5 routes to all forms of transportation, including cyclists and cars. These linkages, between residence and the desired destination, are a measure of the connectedness of the neighbourhood (Hess, 1997). They are afforded by a grid pattern of short blocks, key elements of a successful neighbourhood identified by Jacobs (1961). In contrast, the curvi-linear neighbourhood design (with cul-de-sacs) has often produced street patterns where it becomes difficult to travel from home to the nearby "convenience" store without having to take a surprisingly convoluted route.

Transportation

Current neighbourhood design pays homage to the car (Van Vliet, 1994). Streets are wide and double garages are plentiful in most neighbourhoods. Shopping and employment centres are surrounded by expansive parking lots, necessary for a society heavily dependent on the car. As mentioned earlier, segregated land use in suburban neighbourhoods perpetuates the demand for mechanized travel, since distances very often exceed the distance people would be willing to walk or cycle. The distance North Americans would willingly walk, rather than choose to drive their vehicles, is approximately 400 m or 5 minutes travel time (Atash, 1994).

Low suburban density, common in the conventional suburb, also impacts an individual's transportation choice. Low density development does not typically meet the 9 to 12 dwelling units per residential acre threshold for viable rail transit operations, nor are densities maintained at thresholds across a large enough built up corridor (Table 2.2). Rather, suburban areas are usually serviced by bus transit at service levels determined by the density (Table 2.2). Lower levels of bus service discourage the choice of transit over the automobile, and typically only those unable to afford a car use public transit. The personal mobility provided by the car is sought, albeit at higher cost, especially in the absence of any realistic transportation alternative.

Table 2.2: Density thresholds for the viability of public transit (Pushkarev and Zupan, 1982)

Service Levels	Density Threshold
Bus: minimum service, ½ mile between routes, 20 buses/day	4 du/residential acre
Bus: intermediate service, ½ mile between routes, 40 buses/day	7 du/residential acre
Bus: frequent service, ½ mile between routes, 120 buses/day	15 du/residential acre
Light rail: 5-minute peak headways	9 du/residential acre; 25-100 square mile corridor
Rapid rail: 5-minute peak headways	12 du/residential acre; 100-150 square mile corridor

Transportation use is shown in Table 2.3, with the percentage of trips in a variety of transport types. The dependence of U.S. and Australian cities on the automobile is in stark contrast to the transit- and pedestrian-dependent cities of Europe and southeast Asia. Reducing the fraction of individual mechanized travel should provide a significant reduction in a Canadian's ecological footprint. Currently, personal motorized transportation (i.e., the car) accounts for 14.1% of the average Canadian's ecological footprint (see Wackernagel and Rees, 1996). The ecological footprint is "the land (and water) area that would be required to support a defined human population and material standard indefinitely" (Wackernagel and Rees, 1996).

Table 2.3: Transportation use in world cities in 1980 (Newman and Kenworthy, 1989)

Form of Transport	**Toronto**	**U.S. Cities**	**Australian Cities**	**European Cities**	**Asian Cities**
Annual car use per capita	9850 km	12507 km	10680 km	5595 km	1799 km
Annual transit use per capita	1976 km	522 km	856 km	1791 km	3059 km
Percentage of workers using private transport	63.0	82.9	75.9	44.2	14.7
Percentage of workers using public transport	31.2	11.8	19.0	34.5	60.3
Percentage of workers walking and cycling	5.8	5.3	5.2	21.3	25.1

Green Spaces and Greenways

The provision of green space and greenways has long been important in community and neighbourhood design. The Garden City concept of Howard (1945) was based on the provision of village greens and green belts in close proximity to residential dwellings (Christoforidis, 1994). Large city parks, such as Central and Prospect Parks in New York, Golden Gate Park in San Francisco, and Stanley Park in Vancouver, developed during the late 19th Century (Hodge, 1991; Levy, 1991) and are highly valued by residents and tourists. Innumerable small city parks are present in nearly every neighbourhood and are often important gathering places for community events, social interaction and recreation.

So desirable have become green space and greenways that their presence within a neighbourhood has become a primary draw for prospective homeowners, and has helped to elevate property values in these areas (Arendt, 1994). Planners and developers have responded to peoples' preferences "to live, work, shop and recreate in communities or neighbourhoods having an abundance of trees, open spaces, and uncluttered pedestrian ways" (Brabec, 1994). Most new conventional neighbourhood plans have at least one park, and provision for more if townhouses and apartments are extensive (Moore, 1998). Concepts of the New Urbanism (discussed in section 2.2.3) also incorporate people's desire for more open space in their urban environment.

However pleasing to look at, city and neighbourhood parks often do not attract significant diversity of uses to make them viable (and hospitable) spaces in the long term (Jacobs, 1961). Diverse cross-uses are required so that parks and greenways are used throughout the day and hence are safe places for children to play and individuals to walk (Jacobs, 1961). The incorporation of green space and greenways in neighbourhood plans requires careful design parameters to address social and safety issues and not just the provision of more natural landscape.

This section has reviewed the major characteristics of conventional suburban developments. The next sections explore the problems for these developments as identified in the literature.

2.1.3 Problems with Conventional Suburban Development

There is no shortage of criticism of the conventional suburb. Current suburban and urban development is described as unsustainable (Rees and Roseland, 1991), lacking healthy civic environments (Duany and Plater-Zyberk, 1992), socially segregating and overly reliant on the automobile (Christoforidis, 1994). Public input on a recently proposed housing development at Bamberton (near Victoria, BC) also showed the public's general frustration with current suburb design (Young, 1995). In particular, they disliked dependence on the car, and wanted some mix of land uses and protection of the environment (Young, 1995). It is generally thought that suburban sprawl is subsidized by the urban core with regards to the provision of infrastructure services, such as roads and utilities (Rees and Roseland, 1991; Litman, 1998). It is therefore ironic that suburban development, whose success was initially determined by the economic vitality of the urban core, is causing the weakening of these urban cores by attracting residents and companies out to the suburbs (Des Rosiers, 1992). Major consequences of the sprawled land use pattern of North American cities are: congestion; urban air pollution; job-housing location imbalance; and longer commuting times (Rees and Roseland, 1991). A summary of the major criticisms of conventional suburban development is shown in Table 2.4, which are briefly discussed below.

Table 2.4: Major criticisms of conventional suburban development and urban sprawl

Des Rosiers (1992)	**Christoforidis (1994)**
• Over-consumption of agricultural land; • Rising pollution and congestion problems; • Growing imbalance between home and job distribution; • Increasing costs of public services and amenities; • Weakening of inner cities;	• Lack of transportation choice; • Limited housing opportunities for low-income families; • Inefficient use of infrastructure services; • Separation of land uses from other land uses; • Deprivation of a sense of community among residents; • Physical environment is designed to serve the needs of the automobile.

North American communities are currently unsustainable because they developed using technologies that assumed abundant and cheap energy and land would always be available (Rees and Roseland, 1991). These communities grew quickly and inefficiently, and thus became dependent on lengthy distribution systems to move goods, services and labour. The provision of cheap energy in Canada and the U.S., following World War II, led to the construction of spacious home and buildings, fostered automobile addiction and increased the separation of our workplaces from our homes (Environmental Council of Alberta, 1988). Current per capita gasoline consumption in Canada and the U.S. is four times higher than in Europe and ten times higher than in southeast Asian cities (Newman and Kenworthy, 1989). Replogle (1990) attributes this difference to the increased efficiency and compactness of land-use in European and southeast Asian cities, and not to the size of the cars or the cost of fuel. Segregation of land uses perpetuates the need for motorized transportation, either by car or public transit. If work and shopping were made closer to home, alternative transportation (such as cycling, walking and transit) would become more viable because the distances would be acceptable (Seneviratne, 1985; Atash, 1994).

Canadians are among the highest consumers of energy in the world, to meet demands for transportation and heating/cooling (World Resources Institute, 1997). The burning of fossil fuels and excessive car use have caused deteriorating air quality and traffic congestion in many cities. For example, in Greater Vancouver, more than 60% of the air pollution is due to automobile use (Steyn *et al.*, 1997; AirCare, 2001). Growth of sprawl around cities has caused increases in traffic congestion, so that traffic reports on the radio become as or more important (to the travelling public) than the news or weather.

North Americans have come to desire the suburban lifestyle of spacious suburban lots and excess consumption. The provision of new suburbs at the edges of the modern city has caused the exodus of residents from higher density older neighbourhoods in the city core. The conventional neighbourhood is commonly comprised of homogeneous dwellings, attracting residents from middle and high-income families. Lower cost housing may be provided at the periphery of such neighbourhoods, although these sites are generally less attractive because of their proximity to major roads and commercial land uses. Most new development occurs on farmland around cities, as has occurred extensively in southern Ontario and many other parts of Canada. Streetscapes are dominated by the automobile (e.g., excessively wide roads, large setbacks, imposing house designs with front-garages, large parking lots; Adler, 1995), and few destinations are available within reasonable walking and cycling distance. These patterns have kept several groups of suburban residents (e.g., children, elderly, the handicapped) "in an unnaturally extended state of isolation and dependence because they live in places designed for cars rather than people" (Duany and Plater-Zyberk, 1992).

According to Jacobs (1961), there are four indispensable conditions required to generate exuberant diversity in a city's streets and districts, each of which is not provided in conventional suburban development. These are: 1) the need for mixed primary uses; 2) the need for small blocks; 3) the need for a mix of new and older buildings; and 4) the need for concentration (i.e., higher density). Jacobs' personal preference of a higher-density urban lifestyle is clearly evident, but the character of successful neighbourhoods and districts, about which she writes, is clearly a large step towards more sustainable suburbs than is provided in the conventional suburban model. In a similar vein, Adler (1995) suggests the provision of a town centre, mixed housing types, street trees, alleys for rear garages and smaller parking lots to improve the character of suburbs and make them more pleasing to residents.

Solutions to the suburban crisis, provided by Adler (1995), involve the adoption of urban growth boundaries, the abandonment of “big lawns”, and "thinking green" by reducing energy consumption, and preserving farmland and natural landscapes. Cities, such as Portland, have taken a leading role in demonstrating the effectiveness of urban growth boundaries and it is one of many communities encouraging residents to lower energy and water consumption. It is no longer possible to think of ourselves as distinct from natural ecosystems; rather, it is a requirement of sustainable development that we operate within the Earth’s carrying capacity (Rees, 1992). This concept of sustainable development (or "sustainability") and its relevance to urban environments are discussed in the next section.

2.2 Sustainability and Sustainable Community Design (SCD)

The concept of sustainability embraces one of the very basic of human needs: the need for the continued existence of humans as a species. The concept gained wide notoriety following the publication of *Our Common Future* by the Brundtland Commission (WCED, 1987). In this book, the term "sustainable development" was defined as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (p.8). Many researchers are not satisfied with this term because it emphasizes *development* or *growth* (Rees and Roseland, 1991; Maclaren, 1996) and its intended meaning is sometimes ambiguous (Richardson, 1996). Rees and Roseland (1991) criticized that any concept implying "we can eat our developmental cake and have the environment too is bound to have popular appeal". Having such a loosely defined term allowed individual researchers to interpret sustainable development as it suited them. Some researchers also felt that the social component was missing in a term focused on either the environment or on development (Yiftachel and Hedgecock, 1993). An earlier document (IUCN, 1980) elaborated more fully that sustainability has economic, environmental, and social aspects. These aspects are analogized to the concept of a "three-legged stool" in which treatment of all three aspects is required to make the best stool. An imbalance towards one aspect would result in a toppled stool (i.e., a condition of unsustainability).

2.2.1 Urban Sustainability and SCD

Since 1987, there has been a great deal of thought and publication about sustainable development. Early literature on sustainable development, such as ICUN (1980) and WCED (1987), was largely focused on non-urban systems and resource and overpopulation issues (Tomalty *et al.*, 1994). These early works clearly ignored a large portion of the world's population, that of the *developed* countries, whose urban populations consume the majority of the world's resources (Rees, 1990). Tomalty *et al.* (1994) wrote "in one of the most highly urbanized societies in the world, we could hardly achieve sustainable development without dealing with urban areas". In response, government, industry and university researchers have created a substantial body of literature to define urban sustainability and to outline how it might be achieved (Rees and Roseland, 1991; Beavis and Patterson, 1992; Maclaren, 1992; Roseland, 1992). A variety of terms have been introduced during the decade since the Brundtland Report, including "sustainable urban development" and "sustainable community". It is widely accepted that these consist of the integration of the following three aspects (Tomalty *et al.*, 1994):

- **Ecological component**: stressing the importance of environmentally sound policies and practices;
- **Economic component**: concerned with development activities and fiscal issues; and
- **Social Equity component**: concerned with the fair distribution of resources and the distributive effects of environmental or economic policies.

The question of the current state of sustainability is briefly considered. Current urban development is not sustainable from an ecological standpoint (Rees, 1990; Van Vliet, 1994). Global carrying capacity is eroded each year, with more of the natural capital lost to growing populations in the developing world and the ravenous consumption of resources by the developed world. The economic aspects of sustainability are threatened by the diminishing supply of the world's resources, particularly fossil fuels. These are heavily depended upon for transportation and the generation of electricity (World Resources Institute, 1997). As well, global development, which implies further population expansion, will be limited by the amounts of water and land. Assessment of social equity clearly finds an imbalance of food and wealth both within nations and internationally.

What is meant by a sustainable community is a very important - although elusive - question. Richardson (1996), in attempting to answer it, states that “at present we are still a long way even from being sure we know what all the components are, let alone how they interact to produce something distinctive we can identify specifically as urban sustainability”. An earlier definition from Richardson (1989) recognized the inseparability of the urban environment from the region of which it is a part. Sustainable urban development, he wrote, is “a process of change in the built environment that fosters economic development while conserving resources and promoting the health of the individual, the community and the ecosystem”.

Meeting the objectives for "strong" sustainability has "serious implications for urban form, for the material basis of urban life, and for community social relationships" (Rees and Roseland, 1991). Strong sustainability requires that humans must live off the interest generated by the remaining natural capital; the remaining natural capital must be kept intact for future generations (Rees and Roseland, 1991). There is general consensus that meeting urban sustainability objectives is a large undertaking, requiring considerable changes to the ways our economy and society currently function. Paraphrasing Rees and Roseland (1991), Hardoy *et al.* (1992), and Alexander and Tomalty (1994), the main objectives of a sustainable community should be the following:

1) Use urban space effectively;
2) Reduce consumption of material and energy resources, minimizing the use of non-renewable resources while using renewable resources in a sustainable manner;
3) Increase community and regional self-reliance while reducing dependence on imports;
4) Reduce the dependence on extensive transportation systems;
5) Protect the remaining natural environment, and in particular, biodiversity;
6) Improve community living;
7) Organize administrative and planning processes that can deal sensitively and comprehensively with the attendant socio-economic and ecological complexities.

The first five statements are aimed at the environmental side of sustainability, reducing the consumption of natural capital (i.e., land and resources). The sixth addresses the social aspects of community building, and would include social equity and educational issues amongst others. The final statement may be the most important, suggesting there needs to be a planning process and administrative framework capable of carrying out a desired sustainability plan. Any plan that intends to change the lifestyle of each resident clearly needs the support of all players in the society, especially the general public.

Not all researchers agree that sustainability is a balance of the three-legged stool discussed earlier. Bill Rees is among the strongest advocates stressing ecological preservation above economic development (Rees, 1990), and is a harsh critic of current land use patterns in North America. Hardoy *et al.* (1992) argue that sustainability should be interpreted in terms of ecological sustainability alone. Their four-point plan includes the following objectives:

1. minimize the use of non-renewable resources;
2. minimize impacts on the natural environment;

3. protect biodiversity; and
4. use renewable resources in a sustainable manner.

Platt *et al.* (1994) discuss two senses of the term urban sustainability. One concerns the protection and restoration of the remaining biological phenomena and processes within the urban community itself. For example this might refer to the protection of existing parkland, farmland and wetlands within the urban boundary of a city. Their second sense of urban sustainability refers to the impact of cities upon the larger terrestrial, aquatic, and atmospheric resources of the biosphere. This emphasizes concern for the consumption of resources and pollution of surrounding ecosystems (air, water and land). It may be correct that these researchers emphasize ecological concerns, over the socio-economic concerns of sustainability, since an unhealthy natural environment and depleted resource supply will ultimately reduce the carrying capacity of the planet.

Few researchers doubt the benefits of more sustainable communities. "Sustainable communities will be cleaner, healthier and less expensive; they will have greater accessibility and cohesion; and they will be more self-reliant in energy, food and economic security than our communities now are" (Rees and Roseland, 1991). Sustainable communities will also have a smaller, more compact urban pattern interspersed with productive areas to collect energy, grow crops and recycle wastes, and will have reduced energy and resource consumption (Van der Ryn and Calthorpe, 1986). Because of their projected benefits, it is not surprising that urban sustainability is being touted as a principal goal of planning in many Canadian and American communities (Regional Municipality of Hamilton-Wentworth, 1992; Sustainable Seattle, 1993; British Columbia RTEE, 1994). The success of such plans still remains to be seen, since the means to measure this success are still under development (Maclaren, 1996).

2.2.2 Urban Sustainability Criteria

Changes in urban form over approximately the last one-hundred years - from small, compact, walkable communities to sprawled, automobile-dependent metropolises - have resulted in less sustainable communities now than in the nineteenth century, despite vast technological advances. The basic question about urban sustainability is in deciding when a condition of sustainability is reached. There are pessimists who think that society's consumptive habits for energy and resources are unlikely to be curbed, while optimists choose instead to consider society in a constantly evolving position, gradually moving towards more sustainable conditions. This latter viewpoint allows constant re-thinking and refinement of sustainability objectives. Rather than large leaps, sustainability goals are reached in small steps, the sum of which achieve a sustainable state, given enough time. Many researchers agree, however, that achieving sustainability will be difficult, and equally as difficult to measure.

There are a large number of indicators used to measure urban sustainability. A sustainability indicator generally "reflects something basic and fundamental to the long term economic, social and environmental health of a community over generations" (Sustainability Seattle, 1993). Moreover, sustainability indicators must include linkages among these three domains in the form of “integrating” and “composite” indicators (Maclaren, 1996). For example, the amount of “brownfield” in an urban setting is an integrating indicator, since it indicates both industrial activity loss (economic) and environmental constraints on redevelopment if the lands are contaminated (environmental) (Maclaren, 1996). Indicators must also be “forward-looking”. Maclaren (1996) divides forward-looking indicators into three categories: trend, predictive and conditional indicators. A trend indicator describes some historical trend and then “provides indirect information about future sustainability”. A predictive indicator relies on mathematical models to describe the future state. A conditional indicator is one where a scenario development is specified and the question is posed: “If a given indicator achieves or is set at a certain level, what will the level of an associated indicator be in the future?”.

Maclaren (1996) summarizes a large list of urban sustainability criteria from the City of Seattle, the Province of BC, and the Region of Hamilton-Wentworth. Each geographic entity has used slightly differing criteria to select its respective urban sustainability indicators. According to work published by these jurisdictions, a sustainability indicator should:

- reflect something fundamental to the long term economic, social, or environmental health of a community over generations;
- be easily understood by members of the community and generally agreed upon to be a valid sign of sustainability;
- be appealing for use by the local media;
- be statistically measurable for a geographic area and a practical form of data collection should either exist or be possible;
- preferably be comparable to indicators that would be available for other communities;
- be potentially useful for affecting change; and
- be reliable, responsive and valid.

Present efforts have resulted in long lists of urban sustainability indicators, each addressing aspects of urban sustainability. The numbers of possible urban sustainability indicators in the following publications are as follows: 107 in Murdie *et al.* (1992); 26 in Sustainability Seattle (1993); 90 in British Columbia RTEE (1994); and 59 in Regional Municipality of Hamilton-Wentworth (1995).

Given the large number of possible urban sustainability indicators, it is unimaginable that one could hope to design communities able to meet all of these criteria in the first design phase, let alone to finance the costs of monitoring each at an appropriate geographic and temporal scale. Rather, it is more conceivable to select the most appropriate urban sustainability criteria initially, and include means within the planning process to change indicators over time as necessary. For example, the British Columbia RTEE (1994) reported the current conditions of a number of sustainability indicators in the 5 most populous communities in the Province (Table 2.5). It is interesting to note the poor condition and continuing negative trend for the "settlement and population" theme areas. These include: population growth, urban sprawl and mobility; all three received a failing grade for the current situation, and show continued negative trends, at least for the short term. This report card provides planners with an indication of what might need to be looked at or corrected in the continued striving for urban sustainability.

Table 2.5: Report card on urban sustainability in British Columbia

Theme	**Topic**	**Condition**	**Trend**
Settlements and Population	Population Growth	Poor	Negative
	Urban Sprawl	Poor	Negative
	Mobility	Poor	Negative
Urban Environment	Natural Habitats	Poor	Negative
	Resource Use	Fair	Positive
Urban Economy	Vibrancy	Good	Neutral
	Equity	Fair	Neutral
	Diversity	Poor	Neutral
	Cost of Growth	Poor	Neutral
Social Well-being	Health	Good	Positive
	Education	Fair	Neutral
Governance and Citizenship	Process	Poor	Positive
	Participation and Citizenship	Fair	Positive

This dissertation aims to provide retrofitting methodologies for existing suburban areas that may reverse some of the negative trends highlighted in Table 2.5. In particular, it is hoped that this work can provide more natural habitat within urban environments and reduce the current dependency on the automobile, of which urban sprawl and poor mobility are symptoms.

2.2.3 Current Attempts at SCD

Current attempts at sustainable community design address the above items, albeit to varying degrees. There is general recognition that something has to be done to wean the North American (and potentially global) appetite for personal motorized transit and consumption in general. As well, current suburbs in North America are impersonal and lack a real “sense of community”. It is a difficult task to design and implement a community plan to create this sense of community, and to reduce the ever-growing isolation of members of society. Rees and Roseland (1991) provide a comprehensive list of initiatives required to achieve more sustainable urban communities listed in Table 2.6. In particular, they call for efficient use of urban space, reduction of resource consumption and improved community living. Several of these initiatives have already been undertaken in some communities, to a degree, such as the development of bike facilities and traffic calming programs, municipal energy and water conservation campaigns, and waste reduction through recycling and composting programs. Other initiatives suggested by Rees and Roseland (1991) require strong government leadership. In particular, governments will be needed to implement automobile restrictions and road pricing, and to support transit. Government leadership is also needed to introduce and evaluate the relatively new technologies such as "constructed wetlands for sewage treatment" and "district heating" amongst others, and to develop ordinances that would lead to "energy efficient neighbourhoods" (Table 2.6). Energy-efficient neighbourhoods include the following suggested actions: 1) solar orientation of streets; 2) cluster development; 3) neighbourhood-level services and facilities; 4) increased densities; 5) natural drainage; 6) narrow roads; and 7) energy conservation programs.

Table 2.6: Initiatives to achieve sustainable urban communities (Rees and Roseland, 1991).

EFFICIENT USE OF URBAN SPACE	
Transportation Planning and Traffic Management Initiatives:	Land Use Planning
• trip reduction by-laws; • automobile restrictions; • road pricing; • parking measures • free or inexpensive transit; • bicycle transportation (car-free routes); • street re-design and traffic calming; • telecommuting.	• proximity planning; • residential intensification; • co-housing; • community land trusts; • rural area protection; • co-management agreements.
REDUCING CONSUMPTION OF RESOURCES	
Energy Conservation and Efficiency Initiatives	Waste Reduction, Recycling and Wastewater Management Initiatives
• energy efficiency targets; • district heating and co-generation; • municipal energy conservation campaign; • energy conservation retrofit ordinances; • energy-efficient neighbourhoods.	• waste reduction goals; • packaging restrictions; • "precycling" campaigns; • municipal composting; • polystyrene plastic foam bans and restrictions; • integrated reclamation / recycling centres; • constructed wetlands for sewage treatment; • solar aquatics waste treatment facility.
IMPROVING COMMUNITY LIVABILITY	
• citizen participation; • North-South partnerships; • gender equity;	• public-community partnerships; • healthy community projects.

Recent developments in community and neighbourhood planning are starting to address some of the sustainability criteria discussed earlier. Much attention has been focused on the need for the re-integration of land use in cities, calling for "compact cities" (Alexander and Tomalty, 1994), "eco-cities" (Register, 1987), and less reliance on the automobile (Nelessen and Howe, 1995). Mixed-use developments have been proposed by many of the New

Urbanists, where the main objectives are reduced land consumption, lower dependence on the automobile and the encouragement of more social interaction in neighbourhoods. A number of these attempts at sustainable community design are discussed in the following sections.

Neo-Traditional Developments

Neo-Traditional Development (NTD) - also known as the New Urbanism - is a movement determined to reform American urbanism by offering alternatives to conventional suburban sprawl. According to its leading practitioners, "the principles underlying the New Urbanism are straightforward: the built environment must be diverse in use and population, scaled for the pedestrian, and capable of accommodating the automobile and mass transit. It must have a well-defined public realm supported by an architecture reflecting the ecology and culture of the region" (Taylor, 1994). Its general characteristics are summarized in Table 2.7.

Table 2.7: General characteristics of NTDs as summarized in Christoforidis (1994).

- A mixed-use core;
- The establishment of employment and civic centres;
- Fostering a sense of community;
- Street patterns that allow drivers and pedestrians a variety of path options;
- The encouragement of socio-economic diversification by providing housing for all income levels;
- A balanced land use mix for all people to walk between residences, businesses, and employment centres;
- Higher than typical suburban density as a result of locating various uses within walking distance;
- Streets that are designed to encourage street life;
- A common open space located and designed for public intensive use, often modelled after an historic village square or town green;
- A distinctive architectural character, often modelled on the traditional architecture of the region.

Many of the design concepts of NTD are not new to planning. In fact, many of the physical planning characteristics (such as grid streets, mixed land use, green and civic spaces, and designs to support public transit and to foster community interaction) are borrowed from neighbourhood planning of the early 20th Century and from Howard's Garden City concept. Neo-Traditional Developments simply represent a revival, and in parts a revision, of North American streetcar suburbs from the 1920's and many neighbourhood-planning concepts long practised in Europe.

Neo-Traditional Developments have five distinct development types (Christoforidis, 1994). These and their lead proponents (in brackets) are: Traditional Neighbourhood Developments (Duany and Plater-Zyberk); Transit-Oriented Developments (TOD) (Calthorpe, 1993; Atash, 1994); Hamlets (Nelessen); Metropolitan Purlieus (MacBurnie, 1992); and the revitalization of existing traditional towns (Herr, 1993). The intended benefits of NTDs are shown in Table 2.8.

Of the five models, Traditional Neighbourhood Development (TND) is the most controlled and comprehensive (Christoforidis, 1994). Usually this relates to detailed requirements of building types and materials implemented by the designing architect. Town growth is limited by providing a greenbelt around the entire community. The desired socio-economic mix is encouraged by the provision of a variety of owner-occupied and rental housing types. These include the single family home, townhouses, condominiums, apartments over stores, and "granny flats" located over garages in alleys (Christoforidis, 1994). Many examples of TND are currently under construction in North America (Ont. MMAH, 1997; New Urban News, 1998; 2001).

As the name implies, Transit-Oriented Developments (also known as Pedestrian Pockets) are compact developments containing a mix of housing, offices and stores centred around a mass transit stop (Christoforidis, 1994). The primary proponent of TOD is Peter Calthorpe, an architect operating in the San Francisco area. His work is intended to "encourage walking, provide easy access to regional mass transit, and make the town's streets and plazas a source of civic pride" (Christoforidis, 1994). Different from TND, Calthorpe's designs provide for access to a larger region, via "regional mass transit", rather than isolated self-sufficient communities of less than 30,000 people. This is viewed as an advantage, since many North Americans work in larger communities and may wish to extend their activities beyond their own "small town". In addition, in many larger cities, regional rail transit systems are already built, along which these TODs could be implemented.

Table 2.8: Major design characteristics of NTDs and their intended benefits

Character	**Intended Benefit**
Grid layout for streets	More interconnected pattern of streets; provides variety of auto and pedestrian paths to every destination (LL '92); lowers congestion of traffic (DPZ '92; M&C '95)
Narrower streets and ROW	To slow traffic and provide a safer atmosphere for children, pedestrian and cyclists (M&C '95)
Back alleys	Eliminates need for front-drive garages and improves street aesthetics
Higher densities	To meet required densities necessary to support public transit (Cal '93)
Mixed land uses	Work and shopping opportunities close at hand (G&L '97), reducing auto use
Provision of public transit	To reduce dependence on the automobile
Accommodation of the pedestrian and the cyclist	Grid layout facilitates pedestrians and alternatives (to auto) transportation
Open space for parks, playing fields, water bodies, etc...	With higher residential densities (smaller lot sizes), more open space required to foster community interaction and recreation
On-street parking	"Safety" buffer between pedestrians on sidewalk and cars on the street (LL '92)
Size limits for buildings (max. number of stories)	To keep building design at a human scale; building height-street width ratios should not exceed 1:6 (DPZ '92)
Squares that form the public common	Around these form public commons, around which are larger shops and offices, as well as apartments (LL '92)
Civic buildings are given central locations	Important buildings receive important locations, visible and accessible to the community (LL '92)
Mixed housing stock	To encourage a mixed socio-economic composition to the neighbourhood (DPZ '92)
Low curb radius at intersections	Reduce crossing distances for pedestrians and calm traffic (DPZ '92; M&C '95)
Buildings, street trees and on-street parking on major streets	Encourages pedestrian traffic by making street aesthetics appealing (DPZ '92)

Author Notes: Cal '93: Calthorpe (1993); DPZ '92: Duany and Plater-Zyberk (1992); G&L '97: Gabor and Lewinberg (1997); LL '92: Lerner-Lam *et al.* (1992); M&C '95: MacDonald and Clark (1995); S '97: Southworth (1997).

Hamlets, metropolitan purlieus, and the revitalization of existing traditional towns are the lesser known of the NTDs. Different from TND designs, Anton Nelessen's hamlet designs emphasize the participation of citizens and public officials in the design process (Christoforidis, 1994). He uses a visual preference technique called "imagineering", which "accommodates direct citizen input into the design of a specific community, allowing community leaders and politicians to find out what their constituents want" (Christoforidis, 1994). Hamlets are based on the traditional eastern US small town having a common town green and 50 to 100 closely spaced single family homes. Community facilities, such as churches, day care and shops are located around the town green. Designs do not include apartments over shops since residents showed no desire for them (Knack, 1991b).

MacBurnie (1992) envisions metropolitan purlieus covering approximately 150 acres, and providing residences for 7000 persons and employment for 3000 to 4000. Designs include a wide variety of housing types (single family to high-density garden apartments), and like hamlets, are less restrictive than TNDs or TODs on building use. Rather, MacBurnie's guidelines focus on building design and placement (Christoforidis, 1994). Similar to TODs, metropolitan purlieus are transit-oriented and therefore regionally based. Individual purlieus are isolated from each other by large linear green belts, which aim to limit community size (Christoforidis, 1994).

Herr (1993) is concerned with the revitalization of current traditional towns. As has been implied earlier, both Canada and the US have numerous historical towns that developed during periods of lower (or no) dependence on the automobile. Therefore, many of these towns have characteristics that the New Urbanists are attempting to emulate in their new developments. Herr highlights the importance of the preservation of existing "good development" rather than the constant push to discard the old and build new neighbourhoods.

Compact Cities and Eco-Cities

The five described NTD models embrace a number of urban sustainability principles. They represent concrete models of sustainable community designs since they have numerous examples of built or planned projects. Other SCD models, less tangible and more visionary in nature, include the concepts of compact cities and eco-cities.

The compact city, called a "utopian vision" by Neuman (1991), has been reviewed in detail by Alexander and Tomalty (1994). Compact cities have two optimal forms: multiple centres, and radial corridors (Preston, 1977). With the multiple centres model, one might envision a pattern of self-sufficient urban sub-units of 10,000 to 30,000 people (Owens, 1986). With a radial corridor model, development patterns occur in a small number of routes along which transit and communal heat and power systems could be delivered (Owens, 1986). These patterns, envisioned by Owens (1986), are not dissimilar from the TND models developed by the New Urbanists. The radial corridor idea is clearly analogous to the TOD concept of Calthorpe (1993). Alexander and Tomalty (1994) cite the following advantages of compact urban forms:

- reduce the need for motorized transportation, and may actually reduce air pollution from autos by 20 to 30 percent (Downing and Gustely, 1977) and the annual auto mileage on a per capita basis also by 20-30 percent (Holtzclaw, 1991);
- higher densities enhance the potential for walking and cycling (Patterson, 1992);
- smaller living units and multiple dwellings are more efficient in terms of energy and materials use (Downing and Gustely, 1977; Owens, 1986);
- more dense cities may also allow for more efficient district heating systems;
- reduce energy and materials used in the provision of infrastructure and utilities (Ontario MMAH, 1982; Rybczynski, 1991);
- enables more viable public transit (Newman and Kenworthy, 1989).

There is uncertainty, however, in many of the benefits of the compact city. Several authors comment that the energy and land benefits of compact cities may be over-estimated (Altshuler, 1977; Troy, 1992), and that compact cities may produce serious environmental problems. For example, "high-density, core-oriented cities" have higher levels of mobile and source pollutants than do dispersed cities (Naroff and Ostro, 1982), potentially related to their higher congestion (La Barra and Rickaby, 1987). As well, low-density segregated land use patterns for residential development achieves better urban air quality than do mixed-use patterns (US Department of Housing and Urban Development, 1980). Further research is needed to consider the appropriate level of compactness for cities. There is surely an intermediate density that could achieve some of the advantages of compact cities listed above. If much of urban air pollution is due to mobile light duty vehicles, as suggested by Steyn *et al.* (1997) and AirCare (2001), any significant reduction in per capita emissions (that might be achieved through greater transit use) could provide significant air quality benefits. Higher density European cities (e.g., Copenhagen and Amsterdam) function largely on excellent transit and cycling facilities (Newman and Kenworthy, 1989) and appear not to have the air quality problems noted in lower density sprawled cities of the US (e.g., Los Angeles, Phoenix, Chicago). European cities, on average, have better use of transit and lower automobile dependence (Table 2.3).

The eco-city model is a second utopian vision of the sustainable community. The eco-city term is credited to the Urban Ecology movement at Berkeley, founded by Richard Register and others in 1975 (Roseland, 1997), and becoming more widely known following the publication of *Eco-city Berkeley* (Register, 1987). The book envisioned ecological retrofits to the City of Berkeley over the next several decades, with a population reliant only on its local environment and a lifestyle promoting voluntary simplicity and discouraging excessive consumption of material goods. Other principles include the support of mixed use communities and local agriculture, emphasis on access by proximity (not by transportation), and restoration of damaged urban environments (Urban Ecology, 1996).

Like the compact city model, there are considerable obstacles to the eco-city vision. Foremost among these would be voluntary reduction in consumption, abandonment of the automobile by society, and a willingness to adopt a more simple lifestyle. These are not main stream values in the current North American culture. Despite these obstacles, the eco-city model provides a useful vision of where the development of sustainable communities could possibly go.

2.2.4 Success of Current Attempts at SCD

As defined earlier, sustainable community designs address the social and economic needs of a neighbourhood's population in addition to the ecological needs of the supporting ecosystems. These designs must provide employment, commercial, cultural and recreational opportunities within walking or cycling distance, or an effective transit system to reach these destinations in a nearby community or neighbourhood, if automobile dependence is to be reduced. In the following paragraphs, current trends in community planning will be evaluated for the presence or lack of sustainability criteria. Specifically, neo-traditional designs are compared to streetcar suburbs of the early 20th century and conventional suburban development.

The design objectives of Neo-Traditional Developments (NTDs) seem aligned to many of those of sustainable community planning. Design objectives of NTDs encourage neighbourhoods which: 1) consume less land; 2) provide for a streetscape more friendly to pedestrians and cycling; 3) provide local shops and employment; 4) provide a mix of housing types for various income levels and family types; 5) provide more open space; and, 6) are built at densities supportive of local and regional transit systems. As with previous experiments in urban planning, the success of these ventures can only be measured after projects are fully built out, likely to be 15 to 20 years for some NTD projects (Christoforidis, 1994). Thus it is difficult to fully appreciate the success or failure of NTDs meeting their design objectives, but preliminary work to this end has been completed by Southworth (1997).

Streetcar suburbs could be viewed as more sustainable than conventional suburbs, because of their reliance on public transit and pedestrian traffic rather than on automobiles. Southworth (1997) compared two of the most widely described NTDs (Kentlands and Laguna West) with a streetcar suburb in Berkeley, CA. Neighbourhood density in the streetcar suburb (Elmwood) is over two times as high as either of the NTDs (Table 2.9). The higher density in Elmwood is due, in part, to its having comparatively little open space (Southworth, 1997). Conventional suburban development fares no better in comparison to the Elmwood streetcar suburb. Estimated density for a study neighbourhood in Hamilton is 6.8 d.u./acre and the amount of open space is less than 3 percent (Table 2.9). The Huntington neighbourhood is more dense than other conventional suburbs reported by De Chiara and Koppleman (1975), due to its 773 apartment and townhouse units. From Southworth's analysis, NTDs achieve a slight increase in residential density and substantial increase in open space in comparison to conventional suburban development. However, both NTDs and conventional suburbs are not replicating densities as high as Elmwood. It does not appear that these lower densities will support effective public transit (see Table 2.2).

Table 2.9: Data comparing density and open space for streetcar suburbs, NTDs and conventional suburbs

Development Type and Approximate Construction Date	Neighbourhood Density*^{1} (d.u./acre)	Open Space*^{2} (percent)
Streetcar Suburb:		
Elmwood, CA (1905)*^{3}	10.22	little
Neo-Traditional Development:		
Kentlands, MD (1989)*^{3}	4.78	28%
Laguna West, CA (1990's)*^{3}	3.24	20%
Conventional Suburb:		
Huntington Neighbourhood Hamilton, ON (1960's)	6.8	3 %
Suburban Sprawl*^{4}	2 to 4	n/a

*1: Neighbourhood density includes all neighbourhood area, regardless of land use;
*2: Open space is reported as a percentage of the overall development size;
*3: Data from Southworth (1997);
*4: Data from De Chiara and Koppleman (1975).

Many advocate that NTDs are a step towards more sustainable communities because they contain design strategies to reduce automobile dependence and to encourage community interaction and socially responsible development. As a critic of NTD, Dr. Frank Clayton (a Canadian housing economist) is concerned that “people see it as a panacea ('cure-all') for many of society’s malaises: pollution, traffic congestion, lack of neighbourliness, and inefficient and costly land use patterns” (Wight, 1995). Rather than being a saviour to the unsustainable suburb, NTD proponents argue that while NTDs may not replace suburbs, they can at least become viable alternatives to them (Christoforidis, 1994). Clearly, this is quite possible as there seems to be sufficient demand for new urbanism greenfield projects, with many projects underway in Canada and the U.S. which are selling quite well (New Urban News, 1998; 2001).

From marketing and planning points-of-view, there are a number of barriers to NTDs (Christoforidis, 1994):

- unproven investment security;
- rezoning and project approval requirement; and
- the opposition of no-growth interests to higher-density development in metropolitan areas.

Firstly, with regards to its investment security, NTD projects include building a commercial or "old town" centre that requires large amounts of investment capital without the security of knowing that commercial tenants will be viable. They face stiff competition from regional malls and "big box commercial" developments. Christoforidis (1994) writes that "given the choice of a five-minute walk to a pedestrian-oriented commercial centre a half mile away or a three-minute drive to a traditional strip centre a mile away, developers argue that people will choose the three-minute drive - leaving the economic viability of pedestrian-oriented commercial areas in question". Secondly, current zoning by-laws are geared towards conventional suburban development and require substantial changes to permit NTD design features, such as narrower ROWs, rear-alleys, mixed land uses and smaller building set-backs. Thirdly, there is likely to be significant resistance to densification, since most North Americans do not aspire to higher density lifestyles (Gordon and Richardson, 1997).

Many people think that NTD is simply another form of suburbia (only at higher densities). It is still consuming greenfields, and does not address the problems of what to do with existing suburban development. Furthermore, the automobile is still likely to remain the major transportation mode in NTDs (Lerner-Lam *et al.*, 1992). However, compared with "conventional suburbs, NTDs, at least on the drawing board, are characterized by somewhat higher densities, mixed uses, provision of public transit, accommodation of the pedestrian and the cyclist, and a more interconnected pattern of streets" (Southworth, 1997). As well, NTD has a stronger sense of public structure and more interesting and cohesive landscapes than conventional suburbia (Southworth, 1997). But neither NTD nor conventional suburban development adequately achieves the following: 1) ease of access to retail/office uses; 2) mix of housing types; 3) pedestrian access to daily needs; and 4) overall connectedness found in many small towns or in early 20th Century streetcar suburbs (Southworth, 1997). Southworth states that suburban development in the early part of the 20th Century (streetcar suburbs) is superior to that of NTD. NTD, he admits, is a step towards more transit- and pedestrian-friendly communities and therefore, could be viewed as a step towards more sustainable communities.

A significant uncertainty exists with NTD and the general push towards higher residential densities in suburbs - do North Americans really want this? The "suburban dream" of the 1950's has been ingrained so long on the North American lifestyle, it seems unlikely that this desire (for a large suburban home with a large lot and peaceful surroundings, isolated from work and especially from industrial and high traffic commercial areas) will be discontinued any time soon. North Americans, if given the choice between low-density suburban living and high-density urban living, will overwhelmingly choose the former (Gordon and Richardson, 1997; Ewing, 1997). What may be most encouraging for proponents of NTD is that conventional suburban developments seem increasingly more expensive, such that town- and row houses (key elements of NTDs) may become the desired affordable housing type. Thus, it seems that the fiscal situation of the North American house consumer may be encouraging NTD. In addition, anecdotal evidence also suggests that consumers are changing their opinions of conventional suburban development. The outcome of a public input process for a proposed NTD suggested that the public wanted "a return to the old way of doing things: to create towns the way they used to be designed" (Young, 1995; see Table 2.10).

Table 2.10: Responses of the public input process for a proposed NTD at Bamberton, near Victoria, BC (From Young, 1995)

- They complained that the car had taken over their communities; that their lives revolved around the car.
- They wanted a community designed for people first, with the car accommodated afterward.
- They wanted to see people of varying incomes brought back together and mixed uses to facilitate walking.
- The majority wanted to live in a town that presented opportunities for interaction and happenstance contact with their neighbours.
- They wanted a local economy.
- They wanted protection of the environment.

Housing choice is commonly based on social and economic factors, such as those suggested above and in Table 2.10. By contrast, the choice of housing by the average North American is usually not based on ecological or environmental considerations. It is unlikely that NTD is popular because of its "environmental appeal": consuming less land and lessening automobile dependence. Polls, according to Rees and Roseland (1991), "do suggest that the public is willing to make some sacrifice to achieve ecological stability", but the degree of sacrifice is unknown due to concerns of the employment impacts of such sustainable policies. The initiatives to achieve sustainable communities (see Table 2.6) can be viewed as economically costly and socially disruptive (Rees and Roseland, 1991). This is a valid concern, because it is quite probable that drastic changes in consumer behaviour will have to occur if true urban sustainability is to be realized. And because of its implications to the public, the planning of sustainable communities requires public participation. Moreover, the success of sustainable community development "depends upon widespread understanding of the critical relationship between people and their environment and the **will** (emphasis added) to make the necessary changes" (Regional Municipality of Hamilton-Wentworth, 1992).

This section (2.2) has described the concepts of urban sustainability and sustainable community design (SCD). SCD has been discussed in the context of the promotion of ideas relating to NTD, compact cities and eco-cities, and examples have been shown of what is currently being done to create more sustainable communities. Several of these ideas are to be incorporated in the conceptual model for retrofitting suburban neighbourhoods discussed in chapter 3. The next section in this chapter explores the use of computer tools in urban planning and SCD.

2.3 Computer Tools

Previous sections discussed the need for the generation of alternative configurations for current suburban neighbourhoods to make them more sustainable. Because of the complexity of these neighbourhood configurations (e.g., altering a number of neighbourhood characteristics at any given time), computerized approaches are an efficient means to generate and assess the alternative configurations. This section provides an overview of the use of decision support systems and geographic information systems in urban planning applications.

2.3.1 Decision Support Systems

Information systems are used to convert large volumes of data into meaningful information (Van Order, 1993). When they are designed to convey information to managers, they are called Management Information Systems (MIS) and have three main functions (Van Order, 1993): 1) problem detection; 2) problem analysis; and 3) decision-making. The first two functions are logical uses of an MIS, since computer algorithms can be written to search for a problem (from a *known* set of problems) and to provide some analysis. However, to have the computer *making* a decision about urban problems, as suggested by the third function, is not correct. Rather, the user of the MIS is still required to make the final decision; it is the role of the MIS to provide only support to that decision. Hence the term decision support system (DSS) is more commonly used when the role of the information system is to provide support to a decision-maker.

More formally, Bonczek *et al.* (1984) have defined a decision support system as "a computerized system that helps the user solve ill-structured problems through the use of knowledge in that particular area". It is composed of three sub-systems: 1) a Language System (LS); 2) a Problem-Processing System; and 3) a Knowledge System (KS). A DSS must possess knowledge about the problem area (in a KS) and must be able to accept requests made of it by the user of the system (via a LS). Then, in order to satisfy the user's stated request, the problem-processing system must possess at least one of the seven abilities involved in decision-making (Bonczek, *et al.*, 1984):

- to collect information;
- to formulate models;
- to govern;
- to analyze;
- to evaluate;
- to recognize problems; and
- to implement.

The knowledge system of a DSS includes the large volume of facts that a user "has neither the time, capacity, inclination, nor opportunity to absorb into her/his own memory" (Bonczek, *et al.*, 1984). The heart of a DSS is its problem-processing system, which consists of software capable of controlling the actions taken by the DSS (Bonczek, *et al.*, 1984). Problem-processing systems have been commonly built with the traditional programming languages (e.g., FORTRAN and APL) and more recently using C and C++ (Churchill, 1997) and GIS

(Negahban *et al.*, 1996).

Decision support systems have been used in a wide variety of planning applications including: environmental planning (Frysinger *et al.*, 1996; Negahban *et al.*, 1996); greenfield development (Churchill, 1997); and urban planning (Timmermans, 1997; Criterion, 1998). Van Order (1993) writes that the four most important uses for planners for any computerized information system are:

1) to manage complex and diverse data;
2) to facilitate analysis of alternatives;
3) to facilitate sharing of information; and
4) to facilitate communication of designs (or alternatives) and their impacts (e.g., modelling).

The design of effective DSSs for urban planning would clearly be beneficial, with the increasing complexity of planning and incorporation of issues surrounding urban sustainability. Such DSSs are particularly useful, when coupled with CAD tools and GIS, to provide two- and three-dimensional computer-generated views of proposed developments, allowing urban design and site plan control concerns to be assessed (Sussman and Hall, 1993).

2.3.2 Geographic Information Systems

A Geographic Information System, or GIS, is a powerful tool used for the analysis of spatially distributed data. A GIS is defined by ESRI (1994) as “an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information”. A GIS has innumerable applications, since any variable with a spatial component can be mapped and then analyzed with a GIS. Not surprising is the fact that a GIS can be a key component for urban planning and decision support systems. Data within a GIS “can be interrogated and analyzed, and the relevant data, needed for decision-making and planning, extracted" (Van Order, 1993).

Spatial data within a GIS is typically organized into a number of layers. For illustration, consider that land use data for the Hamilton area are stored within sixteen such layers. There might be 8 layers representing the various land uses (e.g., residential, industrial, commercial, forest, agricultural, institutional, roads, etc) and 8 other layers for the base map information (e.g., streams, lakes, wetlands, soils, geology). Once the data are available to the GIS, the GIS allows a number of operations for spatial analysis (Table 2.11). Data queries and manipulations can be done either on single or multiple layers.

Table 2.11: GIS usage in spatial analysis (From Chou, 1997)

Operation	**Description**
single layer operations	GIS procedures corresponding to attribute queries, spatial queries and alterations of data that operate on a single data layer
multiple-layer operation	Manipulation of spatial data on multiple data layers
spatial modelling	Involves the construction of explanatory and predictive models for statistical testing
point pattern analysis	Deals with the examination and evaluation of spatial patterns and the processes of point features
network analysis	Designed specifically for line features organized in connected networks, typically applies to transportation problems and location analysis
surface analysis	Deals with the spatial distribution of surface information in terms of a three-dimensional structure
grid analysis	Involves the processing of spatial data in a special, regularly spaced form

Further to the manipulations and analyses provided by the GIS package, many GISs support customization. One of the most commonly used GISs is ArcView (ESRI, 1998) because of its ease of use and lower purchase cost. Other ESRI products (e.g., ARCINFO) provide more analytical power, although they are more difficult to use and are more costly. In versions of ArcView up to and including version 3.2, customizations (known as "extensions") are created by coding in ArcView's programming language Avenue. Numerous ArcView extensions have been created by users all over the world and are generally available (free of charge) on ESRI's web sites. Future versions of ArcView (8.1 and beyond) are to be programmed using Visual Basic for Applications. The impact of this change on existing ArcView extensions and related project files is unknown at this time.

ArcView GIS (version 3.1) is used in this dissertation to develop decision support extensions for investigating and evaluating retrofitting alternatives to conventional suburban developments. A conceptual model for suburban retrofitting and its associated GIS extensions are fully described in subsequent chapters. A final section of this chapter will provide an overview of retrofitting activities already occurring in conventional suburban developments.

2.4 Retrofitting for the Unsustainable Conventional Suburb

The concept of sustainable communities, covered in section 2.2, has largely been applied to greenfield developments. Researchers provide "to do" lists of initiatives to be implemented, if sustainable community designs are to be realized (e.g., see Table 2.6). Some have taken these listings the next step, and provide means to generate and evaluate more sustainable designs. Decision support tools having these objectives have been developed by Churchill (1997) and Meyn (1999). Another facet of the work on sustainable communities is to take these "to do" lists and to consider their application to the existing built environment. In this research, ideas on more sustainable communities are being incorporated into the methodologies for retrofitting conventional suburban neighbourhoods.

Retrofits to neighbourhoods, to address *some* of the items on these "to do" lists, are currently taking place. These include a range of activities from transportation and traffic, ecological, and energy and water consumption, amongst others. By and large, these activities are implemented in relative isolation from one another, lacking a cohesive or comprehensive approach involving numerous aspects. This section will provide a broad overview of some of the retrofitting activities currently being done to improve conventional suburban communities. The integration of some of these techniques into comprehensive retrofitting methodologies for the conventional suburb is addressed in the next chapter.

One of the more common retrofits to suburban neighbourhoods is traffic calming. Traffic calming has the general objective of slowing down traffic speeds and reducing volumes to make streets safer for residents, particularly pedestrians. There exists an extensive (and growing) literature on the implementation of neighbourhood traffic calming, and it is certainly a popular topic in transportation engineering. Two publications provide engineers and planners with comprehensive descriptions of traffic calming measures (TAC and CITE, 1998; Ewing, 1999). Traffic calming is a key component of the methodologies developed in this dissertation for suburban retrofitting, and is described at length in chapter 5.

In addition to traffic calming, other transportation objectives are being undertaken. Several medium-to-large cities in North America are retrofitting regional transit systems to relieve pressure on congested roads and freeways. In particular, Los Angeles has finally begun to re-embrace rapid transit, through the development of a subway system, light rail systems have or are being installed in Calgary, Dallas and Portland, and commuter rail links have been established in Greater Vancouver. In addition to these large capital-intensive projects, there have been cheaper alterations such as the designation of traffic lanes as HOV (high-occupancy vehicle) lanes for carpool and transit vehicles (e.g., Seattle, Vancouver). The installation of these lanes and transit systems are beyond the scale of suburban retrofitting considered in this study, although they are attempts to address the general problems of automobile dependence of urban areas. Further activities, such as road pricing or tolls (Rees and Roseland, 1991), may become more commonplace in the future as more aggressive measures to get motorists out of their cars. The use of tolls is not yet widespread in Canada.

A second area of retrofits is to make suburban neighbourhoods more ecologically sound. Several researchers, including Hough (1995), Katz (1995), and Hudson (2000), describe the benefits of the re-introduction of ecological principles in suburban landscape development. Hough (1995) reviews a number of projects in Toronto and Ottawa that have led to more naturalized landscapes and innovative techniques to manage stormwater in urban areas. Naturalization projects may utilize vegetation native to a particular geographic area, and rely less on manufactured pesticides and fertilizers. The Evergreen Foundation actively promotes schoolyard naturalization projects in Canada. Another major field of activity is the development of greenways along natural and manmade landscape elements (Little, 1990). Greenways have been introduced on former rail beds and on utility right-of-ways, as well as along natural linear elements such as streams and waterfronts. Greenways incorporate a wide variety of users, with some for human recreation and access, while others promote nature and its associated biodiversity. Many cities are now revitalizing their waterfronts to provide recreational access (e.g., Milwaukee, Portland, Hamilton), and others have developed greenways to provide pedestrian and cycling access between neighbourhoods (e.g., Hamilton-Brantford and Escarpment rail trails in Hamilton). Other activities in greening neighbourhoods are efforts to reduce reliance on fertilizers and pesticides through alternative garden types (CHMC, 2000a), and the development of community gardening facilities (Knack, 1994;

Malakoff, 2000; City of Vancouver, 2000b). There are efforts underway to reestablish systematic street tree planting programs in cities because of their significant benefits in terms of cooling and pollution amelioration (Hudson, 2000). Where municipal governments have been reluctant to take up the cause directly, non-profit groups have led the way, such as Green Venture in Hamilton. Alternative garden types and increased planting of street trees are components of a neighbourhood greening methodology developed in this dissertation. This methodology is fully described in chapter 6.

A third area of retrofitting to create more sustainable communities has been the creation of urban growth boundaries. The concept of urban growth boundaries, to contain urban development, was first implemented by the City of Portland in 1973. The concept has been slow to catch on in the rest of North America, although several jurisdictions have tried to establish regulations to limit urban growth, particularly where it impacts prime farmland. Regulations developed in BC (Agricultural Land Reserve in 1973) and in Ontario (urban boundaries for Niagara Region in 1981) have both fared well under sympathetic governments, while restrictions have been lapsed and weakened under more right-wing governments (Krueger, 2000). A similar relaxation of urban growth boundaries has recently occurred in Hamilton (in spring 2001), a city claiming itself as a visionary for urban sustainability (Regional Municipality of Hamilton-Wentworth, 1992).

And finally, in addition to a municipality-sponsored tree planting program, many municipalities and utility companies in North America sponsor a wide range of programs geared to helping individual households reduce energy and water consumption and the generation of wastes. In particular, programs are available to encourage the use of low-flow plumbing fixtures, and reduce energy consumption through the use of lower watt fixtures, high efficiency furnaces, and added insulation. Furthermore, blue box recycling programs, which evolved in the late 1980's, have flourished across much of North America, although there is still room for considerable diversion of wastes, particularly compost and recyclable materials. A very recent development has occurred in Portland, Oregon, where the approval has been granted to collect and use rainwater for a variety of uses around the home (City of Portland, 2001). This has exciting potential for reducing the demand on water distribution systems and diversion of collected roof water away from treatment plants, when used for yard and garden applications.

2.5 Concluding Remarks

In this chapter, conventional suburban developments have been described and shown to have a number of "unsustainable" traits. These are predominantly high rates of energy, water and resource consumption, and are related to their development patterns. The conventional suburban form has been criticized largely because of its fostering of automobile dependence through segregated land uses, and its discouragement of other forms of transportation because of low residential densities. Unfortunately, suburban sprawl continues to grow around cities in North America, and new developments are repeating many of the mistakes of conventional suburban development.

As suggested in section 2.2.3, there are initiatives being undertaken to try to improve the ways in which suburban neighbourhoods are constructed, attempting to plan and build communities that reflect a condition of greater urban sustainability. These include neighbourhood designs promoted by the New Urbanism movement, and designs which contain elements of ideas taken from the more abstract concepts of the compact city and eco-city models. But these initiatives are aimed primarily at new development and there is still no concrete model for incorporating sustainability principles into existing suburban neighbourhoods. In addressing existing developments, there are numerous retrofitting activities taking place in municipalities across Canada and the US, tackling certain aspects of these neighbourhoods, such as neighbourhood traffic calming, ecological retrofits, and measures to reduce home water and energy usage. By and large, these have been applied piecemeal rather than as integrated efforts to attack the identified deficiencies of the conventional suburb.

This dissertation presents a conceptual model and associated GIS-based methodologies to retrofit the conventional suburban neighbourhoods described in this chapter. This work embraces the principles of sustainability and sustainable community designs, as well as the numerous initiatives already underway in communities across North America. The conceptual model is not unlike the compact city or eco-city models, in that it contains a vision of what the future shape of suburban developments will have. The model provides a framework to retrofit a number of key aspects (nine in total) of the conventional suburb. Some of these aspects can be retrofitted right away, while others will have a longer timeline for their implementation. This conceptual model for suburban retrofitting is discussed in the next chapter. Three computer tools have been created in an ArcView GIS environment to automate specific retrofitting components as decision support systems. The development of these tools and their application to case studies are discussed in chapters 4, 5 and 6.

3. CONCEPTUAL MODEL DEVELOPMENT

3.1 Introduction

The previous chapter has set the scene for why suburban neighbourhoods are in need of retrofitting. This need applies particularly to conventional suburban neighbourhoods that developed road networks and segregated land uses which have perpetuated automobile dependence. The need to retrofit these suburban neighbourhoods is founded on the desire to create communities that are more sustainable.

The conceptual model discussed in this chapter is related to a set of methodologies to address many of the deficiencies of conventional suburban development. Several aspects were identified in chapter 1 that are steps toward the goal of more sustainable suburban neighbourhoods. The methodologies discussed here focus on the environmental component of suburban neighbourhood design. Reduced automobile dependence, reduced water use, and enhanced pedestrian and cycling facilities are all intended to reduce overall energy and material consumption. This work does not specifically address retrofitting neighbourhoods to promote the other "legs" of sustainability, namely economic and social components. Clearly society needs to be actively and gainfully employed, and there are social inequities to be addressed if societies are to become fully sustainable. But the proposed conceptual model and its associated decision support methodologies do incorporate a number of socio-economic issues. Retrofitting the conventional suburban neighbourhood addresses, to some degree, the provision of:

- Affordable housing;
- Meaningful employment;
- Vibrant, liveable communities;
- Access to the greater region; and a
- Healthy environment.

A total of nine aspects have been identified which could be retrofitted to improve a conventional suburban neighbourhood (Table 1.1). How each of these aspects is incorporated into the overall scheme of more sustainable suburban neighbourhoods is explored in section 3.2 below.

The scale for suburban retrofitting was discussed earlier in chapter 1. The selection of this scale has implications for what has been included and excluded within the individual methodologies. At regional scales, urban sustainability is largely focussed on the viability and efficiency of regional transportation systems as real alternatives to the automobile. Concepts of Transit-Oriented-Developments, high speed commuter trains and light-rail systems are regional-scale planning objectives. Other issues best planned at the regional scale include conservation of agricultural land, connectivity of open spaces for wildlife and biodiversity, and integration of hydrological system elements. At a smaller scale, there are many options to enhance and promote sustainability concepts. These include energy consumption and conservation techniques available at the scale of the individual home or building. Numerous technologies are available now for use in creating green building designs, such as high efficiency furnaces and windows, solar photovoltaics to generate electricity, building materials which absorb and retain heat, and in-house grey water recycling systems.

For the most part, the discussion of suburban retrofitting in this research does not make explicit reference to either the regional or home/building scales. However, it is impossible to consider changes at one scale in the hierarchy (e.g., the neighbourhood) without some evaluation of the implications for other scales. The discussion of neighbourhood concentrations of commercial and employment activity in a "neighbourhood hub", centered on a transit station, presumes the development of similar hubs across a greater metropolitan region. At the home scale, a key component of neighbourhood greening was identified as the yards and gardens of individual properties, since they comprise much of the current land available for greening. In addition, one aspect (water and wastewater) was definitely focussed on the scale of the home in terms of practices a homeowner may follow to reduce water usage. Individual reductions in water use and wastewater generation have direct impacts on neighbourhood scale planning such as pipe sizing for sewers and water mains. However, the details on sustainable or "green" building and housing technologies are largely beyond the scope of this dissertation. Examples of sustainable building technologies are provided by Kirnbauer and McCaig (2000) and CMHC (2000b), and these remain as viable topics for future research.

This chapter begins with an overview of the conceptual model of suburban retrofitting that integrates the nine identified aspects to be retrofitted (section 3.2), followed by a description of the methodologies for each aspect (sections 3.2.1 to 3.2.9). The selection and use of GIS for creating computer-based decision support tools for suburban retrofitting is explained in section 3.3. A final section (3.4) provides an overview of data requirements necessary to use the developed tools.

3.2 Overview of a Conceptual Model for Suburban Retrofitting

The conceptual model for suburban retrofitting incorporates improvements for nine key aspects (Table 1.1). In this section, a prescribed methodology for each aspect is discussed. Although presented in individual sub-sections, the nine aspects are clearly interconnected, possessing a number of linkages and interdependencies between them, as shown in Figure 3.1.

Of the nine aspects, increasing residential density may be the most fundamentally important, if many of the other aspects' objectives are to be realized. Increasing density of

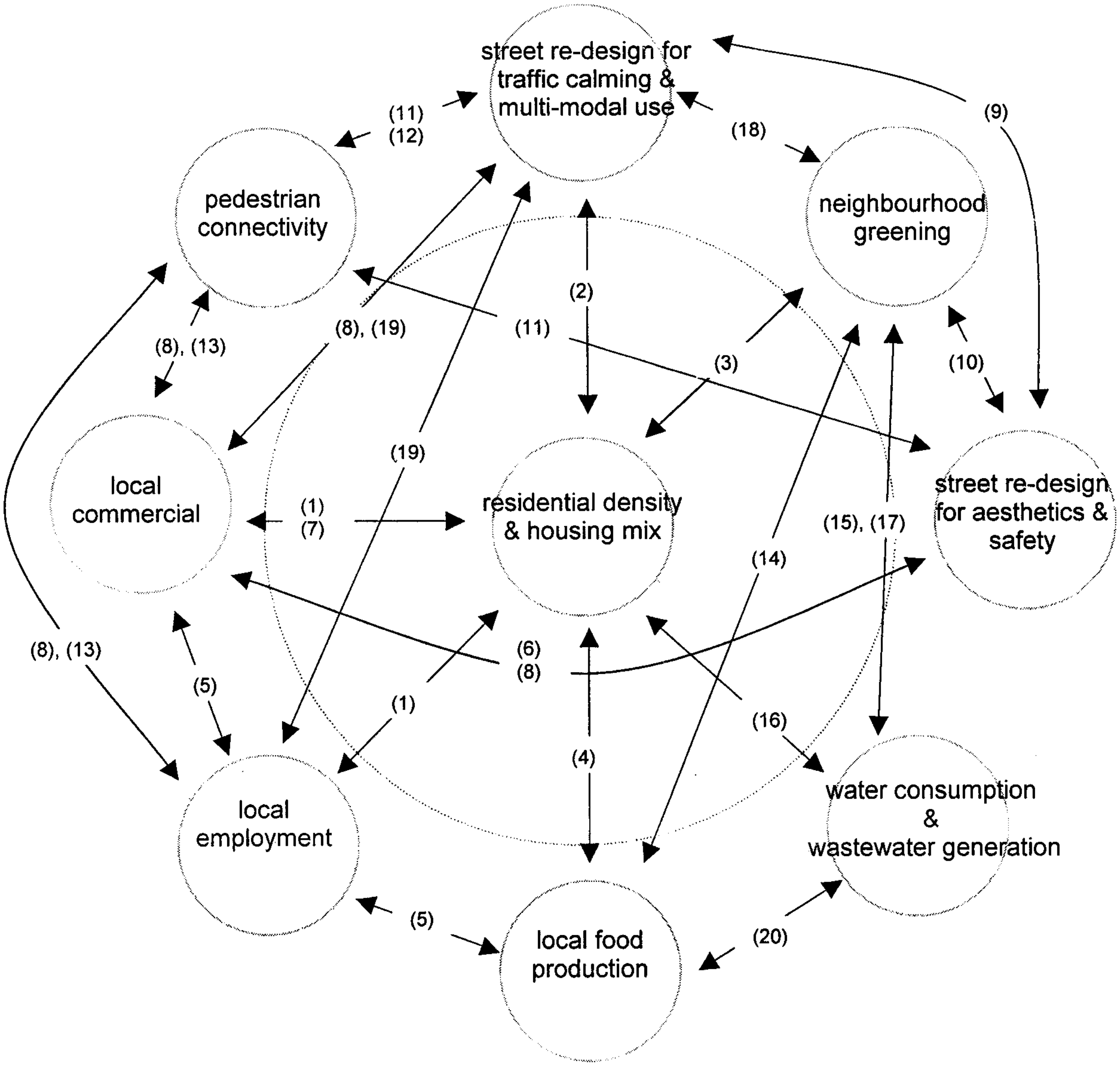


Figure 3.1: A conceptual model for suburban retrofitting with interdependencies and linkages amongst the nine proposed retrofitting aspects (*Note:* numbered arrows correspond to descriptions in Table 3.1 on the following page)

Table 3.1: Brief description of linkages shown in Figure 3.1. A complete description is provided where the appropriate retrofitting aspect is discussed in the text.

---

(1) higher density in buildings with apartments over shops and offices;

(2) higher density increases the viability of transit services;

(3) multi-unit dwelling residents are the target group for neighbourhood community gardens;

(4) higher density frees up adjacent lands for agriculture (and relieves pressure of land speculation);

(5) local commercial and food production activities provide local employment;

(6) improvements to streetscape aesthetics are often done to attract businesses to a commercial district;

(7) an increased number of potential patrons for local commerce is achieved through increased density, and may increase the diversity of potentially viable businesses;

(8) re-designing commercial buildings and districts (with regards to setbacks, parking, traffic calming, and aesthetics) will stimulate increased pedestrian traffic;

(9) a key objective of traffic calming is to increase safety on suburban streets;

(10) many greening techniques, especially street trees, enhance neighbourhood aesthetics;

(11) pedestrian activity is stimulated by a more aesthetically pleasing street environment, as well as one with slower vehicle speeds;

(12) increased pedestrian travel means that some modal shift has occurred (likely away from auto);

(13) planned neighbourhood hubs need to be well-connected for pedestrians, cyclists and automobiles to access demand points;

(14) the addition of community garden plots and fruit and nut trees in neighbourhoods provide a local food source;

(15) naturalized green spaces consume less water and other materials than existing suburban lawns and garden types;

(16) increased density will have increased demand for water and wastewater services, potentially balanced by diminished per capita water consumption;

(17) diversion of runoff from storm sewers, through rain and snowmelt collection in cisterns and the use of porous driveway materials, will reduce volumes directed to wastewater infrastructure;

(18) several traffic calming measures employ landscaping techniques; low maintenance options such as "quasi-naturalization" would be useful to reduce costs and to increase aesthetics and acceptability of measures;

(19) reduced automobile dependence through the provision of local commerce and employment activities could reduce volume on neighbourhood arterial streets, making their calming and narrowing more realistic and acceptable to the transportation and planning professions;

(20) stormwater diverted by use of swales and cisterns would be available for use in local food production initiatives (e.g., community gardens, fruit trees)

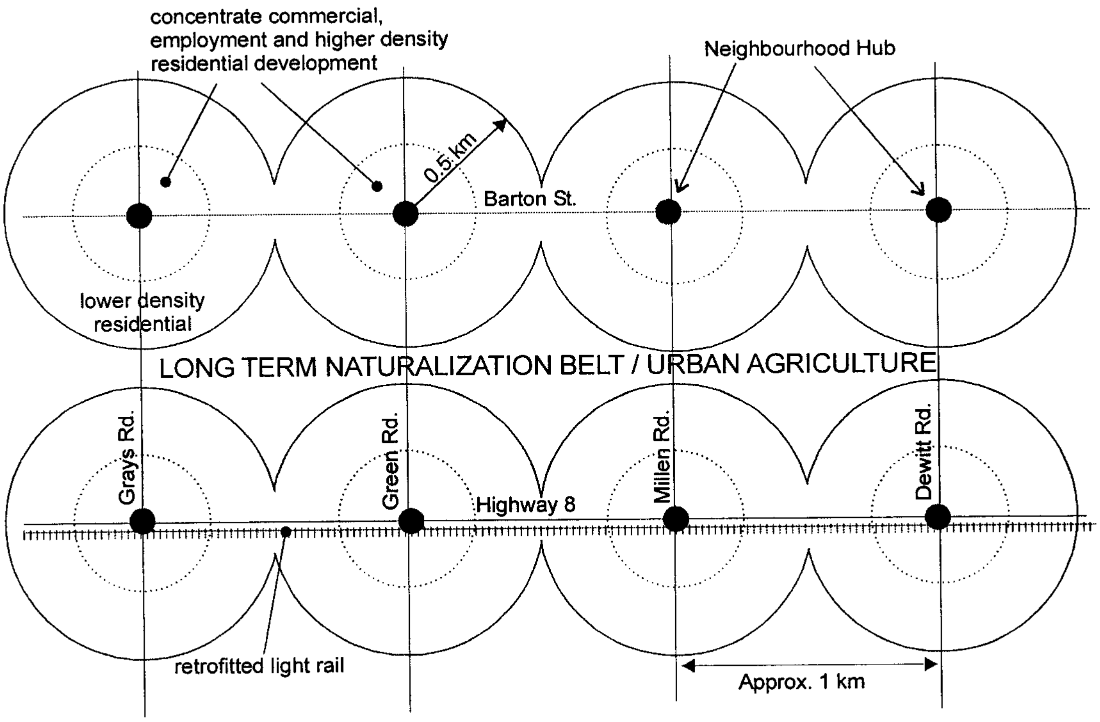


Figure 3.2: Sketch showing the regional application of proposed transit-oriented hubs

suburban neighbourhoods will presumably make transit systems more economically viable (by providing potential riders) and more effective (more frequent service that attracts more riders). Therefore, the location for increased density within a suburban neighbourhood depends, in large part, on where a regional transit system is planned to operate. The Transit-Oriented Development (TOD) and "metropolitan purlieu" concepts, of Calthorpe (1993) and MacBurnie (1992) respectively, identify high activity nodes in a regional setting. The nodes (or hubs) are centred on a transit station providing a link to a regional transit system, and are generously-spaced (> 1 km apart) to make travel within the region by light rail or high speed bus more effective than by car. In addition, commercial and employment activities are concentrated around nodes and residential density is increased through the provision of residences above shops and offices in three and four storey structures. Such an example of how a TOD network might be planned for an existing suburban region is shown in Figure 3.2 for East Hamilton and Stoney Creek, Ontario. Adequate spacing of hubs is encouraged so that businesses are able to have a sufficiently large customer base to remain economically viable. Pedestrian and cycling access from the surrounding neighbourhood to its nearest hub is facilitated through various means. Access is intended to be as direct as possible and may require the addition of sidewalks and pedestrian pathways linking isolated cul-de-sacs, and the provision of effective and safe cycling routes, while maintaining automobile circulation within the neighbourhood.

A description of the methodology for retrofitting each aspect is discussed in the following sub-sections. For each aspect, the objectives and benefits of retrofitting are discussed, including an explanation of how these relate to the overall objective of creating more sustainable communities. Current conditions are discussed for each aspect, followed by an illustration of what changes could be implemented to achieve a more sustainable form and of any links or interdependencies to other aspects. Each sub-section concludes by reviewing the time frame for any alterations and expected hurdles in realizing the overall objectives.

3.2.1 Pedestrian Connectivity

This section is an overview of the methodology used to retrofit improvements for pedestrian connectivity in suburban neighbourhoods. The complete descriptions of this methodology and its associated ArcView GIS-based decision support tool are provided in chapter 4.

Pedestrian connectivity is a term introduced to measure how accessible a neighbourhood's destinations are to its residents. Potential destinations include schools, local commercial businesses, bus stops and neighbourhood parks. A decision is made by a resident to walk, cycle or drive to a particular destination based on the expected trip distance, trip directness, the availability of the destination in the neighbourhood and an individual's personal health and fitness.

By measuring the route distance to be travelled to a selected destination, we can comment on the environment or network available for pedestrian travel within a neighbourhood. Exceptional neighbourhoods are those which have pedestrian networks with numerous short and direct routes to reach a selected destination. The literature commonly cites a value of approximately 400m travel distance as being the threshold between walking and driving to reach a particular destination. For those less-than-exceptional neighbourhoods, retrofits to the pedestrian network such as sidewalks or pedestrian paths, are suggested to improve pedestrian connectivity and encourage walking rather than driving to local destinations. By improving the pedestrian network (shortening and straightening of routes to reach neighbourhood destinations), residents may access local neighbourhood destinations by walking rather than driving, thereby reducing automobile dependence. As discussed earlier, lessening automobile usage will reduce energy consumption and air pollution, while less-quantified benefits, such as improved community interaction achieved through walking, may also result.

The quintessential conventional suburban neighbourhood is designed for automobile access first, and pedestrian issues second. Road networks are commonly constructed in a curvilinear pattern, with frequent use of cul-de-sacs to discourage cut-through traffic and speeding, thereby providing quiet residential streets safe for children to play on. Sidewalks are often a missing component in many of these neighbourhoods. These features are in contrast to those of earlier traditional neighbourhoods which utilize an urban grid street pattern, characterized by short blocks and abundant sidewalks.

The methodology for pedestrian connectivity assesses the current layout of a particular suburban neighbourhood by calculating route distance and route directness values for home-destination pairings. A route directness ratio (called the PRD) developed by Hess (1997), is used to express a neighbourhood's evaluated connectivity using four connectivity cases, representing the spectrum from acceptable to unacceptable connectivity. In the initial analysis, a map showing those areas poorly connected to a destination is created. To evaluate potential improvements to pedestrian connectivity, the user is prompted to add sidewalk or pedestrian path segments to the pedestrian network. Pedestrian connectivity on the updated network is then evaluated and the improvement over the initial configuration is shown on another map.

Improving pedestrian connectivity has numerous links to other retrofitting aspects as shown in Figure 3.1. Increased pedestrian travel will be stimulated through the provision of a safe and aesthetically pleasing streetscape (link 11), as well as through the provision of more neighbourhood destinations such as retrofitted commerce or employment (link 8). Increased safety for pedestrians is a key outcome of neighbourhood traffic calming programs (link 11), and may encourage more pedestrian activity. The number of neighbourhood destinations, available within walking distance, is increased through the retrofitted additions of commercial and employment activities discussed below. These activities are located at to-be-identified transportation hubs, and it is important that routes to these hubs be both short and direct to encourage walking (link 13).

Retrofits to the pedestrian network are relatively simple to make, especially when compared to other aspects of suburban retrofitting. Adding sidewalks on a city-owned right-of-way is only restricted by cost. However, the addition of pedestrian paths linking isolated cul-de-sacs may meet resistance from residents who lose portions of their back and side yards. As well, a number of safety, loitering and vandalism issues need to be addressed before installation of paths. In the end, the tool may be capable of identifying the best paths to be retrofitted, leaving their implementation to the politicians.

3.2.2 Street Re-Design for Neighbourhood Traffic Calming and Multi-Modal Use

The following is a brief overview of the objectives and methodology used to consider street re-design for neighbourhood traffic calming and multi-modal use. The complete descriptions of this particular methodology and its associated ArcView GIS-based decision support tool are provided in chapter 5.

This particular aspect has two primary aims. The first aim is to address problems associated with high speed and volume on a neighbourhood's street network, as these impact the safety of residents, cyclists and pedestrians. Traffic impacts of these types are increasingly being addressed using devices known as traffic calming measures. There is a growing body of work discussing the design, merits, and effectiveness of such devices. A key goal of traffic calming is to reduce the negative effects of the automobile (Lockwood, 1997). Comprehensive summaries of available traffic calming measures are provided by TAC and CITE (1998) and Ewing (1999). The second aim is to re-design streets to include specific facilities that encourage the use of other modes of travel. These modes include pedestrian, cycling and public transit, and are more sustainable (than the automobile) in terms of their overall impact on the environment.

Our current neighbourhoods, both urban and suburban, are experiencing traffic problems, albeit of differing types. Many urban neighbourhoods in the older cores of larger cities developed with residential densities much higher than the current suburban neighbourhoods during the periods prior to widespread cultural dependence on the car. These neighbourhoods have grid street patterns, high demands for on-street parking facilities, and tend to be well serviced by transit. Often located in city centres, these neighbourhoods are victims to cut-through commuter traffic trying to find optimal routes to and from work. Transportation engineers have developed calming measures, attempting to mitigate cut-through traffic while retaining automobile circulation for the neighbourhood's residents. Drastic measures including road obstructions, closures and diverters have been successful for these types of neighbourhoods in both Vancouver (Zein *et al.*, 1997) and Seattle (Ewing, 1999).

Conventional suburban neighbourhoods have different problems, typically associated with elevated speeds, rather than cut-through traffic volumes, on local and collector streets. It is not surprising that elevated speeds have become problematic here, since design speeds for local streets often exceed 60 km/h and the street designs include generous allotments for on-street parking, despite the need for it. Each house is typically adorned with a double garage and accompanying driveway with enough parking for three or more cars. Generally, the neighbourhood layouts consist of curvilinear streets with only a few access and egress points to the bordering arterial street network. Thus any of the drastic measures employed in urban neighbourhoods, such as closures or diverters, are not feasible in these street patterns, as there are limited routes for drivers. Successful traffic calming measures in these areas include horizontal and vertical deflections of the roadway to encourage slower speeds (Ewing, 1999).

Arterial streets in conventional suburban neighbourhoods have few houses facing them, because they are designed for higher traffic speeds and four or more lanes of traffic. They are commonly lined with commercial enterprises and associated expansive parking lots, and are inhospitable to pedestrians and cyclists for aesthetic, health and safety reasons. Calming arterial streets presents a different problem than local or collector streets *within* a neighbourhood. Traffic calming on these streets has occurred, with some success, on a limited basis in the U.S. and Canada (Macbeth, 1998a; Skene, 1999; West, 2000), but such calming efforts are not without their critics (see Robinson, 1999). There are numerous techniques available to calm arterial streets such as lane width reductions and lane allocations to transit, carpool vehicles, and bikes. Calming arterial streets successfully is clearly related to achieving goals of modal shift away from auto to bike and transit.

The first step in implementing neighbourhood traffic calming and promoting alternative modes of transportation is to evaluate the current suburban neighbourhood and reveal the traffic problems currently inflicting the study area. A map will be given showing road segments with measured speeds and volumes in excess of user-defined thresholds or those repeatedly requested for calming by a neighbourhood's residents. Based on the particular problems and the street type, a list of traffic calming options is provided to the user. For each traffic calming measure, the relevant benefits (i.e., effectiveness in speed or volume reduction) are provided, as well as implementation guidelines. The final step involves the actual selection and placement of a measure (or group of measures) to generate a neighbourhood traffic calming plan on a map. A preliminary estimated cost for the plan is provided using data available from current sources.

It is important to note that retrofits to all three levels of the road hierarchy used in suburban neighbourhoods are considered, although calming measures used on each vary.

Traffic calming measures for local and collector streets are based on existing experiences in North America, and are summarized in TAC and CITE (1998) and Ewing (1999). Measures for arterial streets are not widely implemented in North America (see earlier citations), although Europe has some experience installing calming treatments to these higher activity roadways (Ewing, 1999). A toolbox of measures to calm arterial streets is a key contribution of this dissertation.

The re-design of streets for traffic calming and multi-modal use has a number of linkages to other aspects considered in the overall suburban retrofitting process, as shown on Figure 3.1. An implemented neighbourhood traffic calming program has benefits for enhanced safety in a neighbourhood (link 9). As well, the success of neighbourhood traffic calming is commonly related to both an effective and aesthetically attractive design, integrated with the streetscape. Several measures including curb extensions, traffic circles and median islands, have a complementary landscaping component. Landscaping techniques that minimize maintenance and material inputs are linked to the neighbourhood greening discussion (link 18).

Higher residential densities suggested for suburban retrofitting will increase traffic while providing greater potential ridership for transit services (link 2). Street designs that prioritize transit, pedestrian and cycling, may encourage these as viable modal choices over the automobile (link 11). The viability of commercial districts or neighbourhood hubs, located on arterial streets, is aided by their being calmed (i.e., addition of on-street parking, roadway narrowing and aesthetic treatments) (link 8). And finally, any reduced automobile dependence through the provision of local commerce and employment could provide some reduction in current auto commuting habits. If so, volume reductions on arterial streets may them be sufficient to make their calming and narrowing more acceptable to transportation engineers and planners (link 19).

Neighbourhood traffic calming measures for local and collector streets are commonly retrofitted on a reactionary basis to observed problems. Some planners and developers, recognizing the benefits of calmed neighbourhoods, now include strategies for calming at the time of initial construction, such as street designs with lower design speeds. Neighbourhood traffic calming programs provide clear benefits to neighbourhoods, with only slight impacts on overall automobile access throughout the region. Regional networks of arterials, highways and freeways are ever-expanding in capacity, counteracting efforts to reduce or diminish automobile dependence at the neighbourhood level. Retrofits to arterial streets - an element of the proposed NTC methodology - are not widely considered by many in the transportation profession. It may be difficult to convince engineers and planners to do so when their mandate has largely been in improving the Level of Service (LOS) to motorists, by adding lanes to arterial streets and reducing traffic congestion.

Although planning and implementation of traffic calming may be at the neighbourhood scale, it is important to consider the broader regional implications. To this point in the dissertation, two neighbourhood scale retrofits have been proposed to reduce automobile dependence (e.g., pedestrian connectivity, traffic calming). However, if automobile dependence is really to be challenged, regional plans must include strategies to address required changes to land use zoning and transportation networks beyond the neighbourhood. It is unclear whether society is willing to make the necessary changes to achieve reduced auto usage.

3.2.3 Neighbourhood Greening

The following is a brief overview of the objectives and methodology used to consider neighbourhood greening alternatives. The complete descriptions of this particular methodology and its associated ArcView GIS-based decision support tool are provided in chapter 6.

This aspect of suburban retrofitting incorporates strategies for the creation and change in the management of neighbourhood green spaces. These green spaces (both public and private) serve a number of purposes, whether it be for active recreation (e.g., soccer, baseball) or more passive pursuits (e.g., walking, bird watching). Suburban developments commonly have more green space per capita than urban neighbourhoods. But these green spaces have associated costs. Many of our suburban green spaces are highly manicured with the use of fertilizers, pesticides, and water and frequent mowing. Suburban homeowners feel compelled to do regular upkeep around their property. There exists a certain pride in ownership by having the greenest lawn or the most beautiful collection of exotic flowers. Water demands to irrigate lawns and non-indigenous plants unfortunately occurs in the summer when water is typically in shorter supply and municipal reservoirs are most taxed.

The overall objective in greening a neighbourhood under the premise of sustainability principles is to foster green space management that utilizes "naturalization" techniques, such as those discussed in Hough (1995). These kinds of activities consume less material resources (fertilizer, pesticide, gas, water), while relieving a homeowner or municipal parks department from the time and associated costs of maintaining the manicured suburban landscape. Generally, naturalization is a return to the use of indigenous plantings native to the soil and climatic conditions of a particular area. The decision support methodology proposed here has the overall aim of re-thinking our neighbourhood green spaces. While there will always be a need for the well-groomed soccer pitch or the little league ball diamond in our neighbourhoods, there are means to incorporate more natural landscaping techniques. Options are considered for both the public and private realm. The public realm consists of parks, school yards and the network of street trees occupying the city-owned right-of-ways, whereas the private realm includes suggestions for homeowners on how they might naturalize their own yards and gardens.

Neighbourhood greening involving greater use of naturalized landscaping techniques, providing a number of benefits for the overall cause of sustainability. Firstly, the inclusion of nature in neighbourhoods facilitates frequent recreation opportunities and may reinforce the important connection (and interdependence) between humans and their environment. Secondly, increasing areas of green space in neighbourhoods, particularly trees, provides significant air quality and energy benefits. Trees are net producers of oxygen and net consumers of carbon dioxide, a benefit alleviating global warming attributed to the increasing concentrations of CO_2 and other greenhouse gases in the atmosphere. In addition, increasing the vegetative cover alters the surface albedo and may counter the urban heat island effect commonly observed in cities (Oke, 1987). Street trees will cool suburban streets as well as improve aesthetics. Energy effects include the benefits of appropriately-sited trees for providing shade in summer and a shield from harsh winter winds, thus reducing building air conditioning and heating costs respectively (Kirnbauer and McCaig, 2000). A third key benefit of naturalization techniques is in the reduction of the use of materials (energy, water, fertilizer, pesticide) and the savings in terms of time and cost. A report by CMHC (2000a) demonstrates quantitatively some of these expected reductions and savings. Fourthly, some might argue that natural landscaping might be an aesthetic improvement over current practices, although this is debatable since practices of lawn care and gardening are well entrenched in current culture. A final point concerns the overall dollar value of green space to a city. Studies have shown that property with mature landscaping, including street trees, have higher retail values (Arendt, 1994), which also benefit a municipality via increased taxes based on assessment values (City of Vancouver, 2000a). A report by the Vancouver Parks Board showed that the estimated value of all the city-owned street trees was $500 million, and represented one of a few assets the City could expect to increase in value over time (City of Vancouver, 2000a).

The decision support methodology for neighbourhood greening provides four key options for a potential user: 1) investigate greening features and create a map depicting a neighbourhood greening program; 2) determine the best locations for neighbourhood greening features; 3) quantify the benefits of alternative landscaping techniques; and 4) generate a street tree planting schedule. In the first option, various landscaping features for neighbourhood greening are presented to the user (see Table 3.2). Descriptive information concerning their respective benefits, recommended locations, and maintenance issues, is presented to the user in a series of dialog boxes and illustrations. The user is prompted to create a map displaying a neighbourhood greening program, comprised of features selected from Table 3.2. In the second option, an algorithm has been developed to help the user select the best location for community gardens and playgrounds in a neighbourhood. The algorithm is a simplified version of a p-median location-allocation model (Ghosh and Ruston, 1987), where the best configuration of potential facilities is determined from all available facilities. The best facility is defined as the one closest to the demand points (e.g., residents of multi-unit dwellings) while satisfying constraints related to the size and number of garden plots desired.

Table 3.2: Neighbourhood greening features considered

- Natural Areas - Quasi-Natural Areas - Greenways	- Greened Streetscape - Community Gardens - Yard, Garden and Driveway Options

The third option allows the user to investigate potential impacts of neighbourhood greening. Potential impacts are evaluated when a conventionally-manicured landscape is altered to one of the types shown in Table 3.3. These include changes in the use of materials such as, water, gasoline, fertilizer and pesticides, and the allotments needed in terms of time and cost. Estimated consumption rates of the various materials for garden types, except for vegetable gardens and greenhouses, is provided in CMHC (2000a). Vegetable gardens and greenhouses have been added as garden types because of their benefit of providing residents with the ability to grow food, although data on the consumption of material resources, time or cost for these features are presently unavailable.

Table 3.3: Home garden types as discussed in CMHC (2000a)

- xeriscaping - woodland shade garden - wildflower meadow - conventional lawns - low maintenance lawns	- ornamental trees and shrubs - ornamental flowerbeds - vegetable gardens[1] - greenhouses[1]

Note: 1) Not discussed in CMHC (2000a).

The fourth and final option allows the user to investigate the required number and placement of street trees in a particular neighbourhood. Deciding on where and what types of trees to plant, is subject to a number of constraints. One might, for example, desire to place a tree in front of every home along a street and at similar spacings for larger buildings (Figure 3.3). Following planting, tree care becomes the responsibility of the property owner (e.g., watering, leaf collecting). Hence, the owner should be well-informed on the importance of the tree program, and should contact the city if a problem with the tree develops (disease, accident, scar, vandalism). Selected tree types should be tolerant of urban conditions (e.g., air pollution, salt splash). Since one objective for planting street trees is to benefit pedestrians (in terms of shade and separation from vehicular traffic), they should be planted sufficiently close to sidewalks or within boulevards and be uniformly spaced (Figure 3.3). Their ultimate placement is also dependent on the location of under- and above-ground utilities which could be affected by tree roots and branches, respectively.

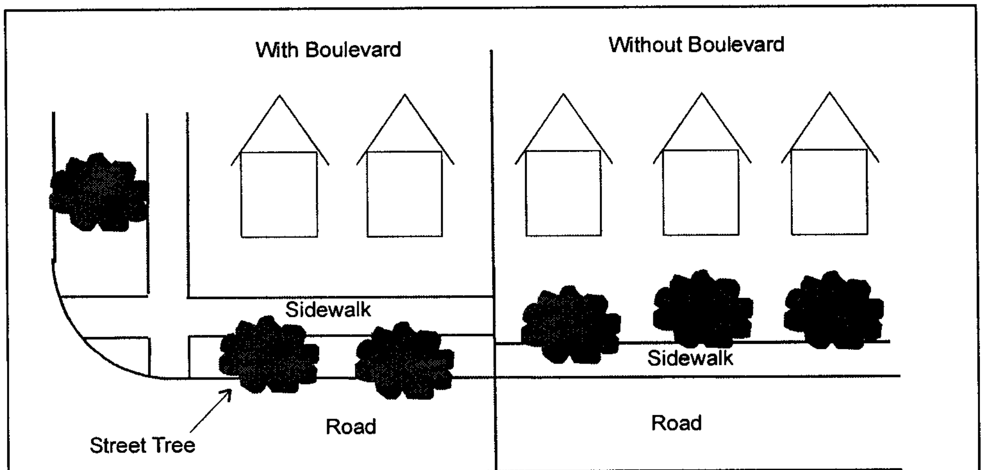


Figure 3.3: Potential street tree locations along streets with and without a boulevard

Retrofits to achieve neighbourhood greening have links to other retrofitting aspects, as shown in Figure 3.1. The key links are those related to water consumption for landscaping in the neighbourhood. Naturalized landscaping alternatives consume less water than conventional, manicured suburban landscapes (link 15). In addition, garden and yard options around the home such as "greened driveways", the collection of rainwater in cisterns for irrigation, and other water conservation measures discussed later, will reduce the overall impact of the home on wastewater treatment infrastructure (link 17). Furthermore, increased residential density through the construction of more multi-unit buildings will provide increased demand for community garden facilities and possibly for playground facilities (link 3). Community gardens provide the opportunity for local food production, as does adding fruit and nut trees in parks (link 14). And finally, street tree additions are a fundamental component of enhancing the streetscape aesthetic, which could lead to greater community pride and increased pedestrian activity (link 10).

The methodologies considered thus far in sections 3.2.1 to 3.2.3 are for the three primary retrofitting aspects identified earlier (Table 1.1). Further description of their methodologies is provided in chapters 4, 5 and 6 in which ArcView GIS extensions are described and applied to case study neighbourhoods. The remaining sections (3.2.4 to 3.2.9) describe preliminary retrofitting methodologies for the secondary aspects. The development of ArcView GIS extensions for these aspects will be covered in future research.

3.2.4 Residential Density and Housing Mix

As stated earlier, the increase in residential density is viewed by many as a key step in making communities more sustainable. A sustainable community is defined by having a mix of land uses and socio-economic groups, and fostering a shift away from automobile dependence to more sustainable transportation modes. Each of these points is facilitated by an increase in residential density or through the provision of a variety of housing choices in suburban neighbourhoods.

A number of benefits are possible through an increase in residential density. First and foremost, from a land accounting point of view, increasing residential density means less land is ultimately consumed for dwellings, freed up for other equally important activities such as open space preservation, agriculture, and forestry. By increasing density in our neighbourhoods, pressure on adjacent farmlands is less severe allowing more to remain in active production. A second benefit is in support of commercial activities within a neighbourhood. Threshold populations exist for the economic viability of a corner store, pharmacy, or restaurant in a neighbourhood (Berry and Garrison, 1958; Noble *et al.*, 1976). In developing neighbourhood hubs, as shown in Figure 3.2, densities need to be increased to make services viable at the neighbourhood level. This concept is discussed further in section 3.2.5 below. A third benefit is the support of an effective and economically viable public transit system. Effective transit means convenient and frequent service, providing access to the entire region. Pushkarev and Zupan (1982) determined levels of density required to support a variety of transit services. For example, a density of 9 dwelling units/acre would support light rail transit with 5-minute peak headways. Cities in which transit systems are presently being retrofitted (light rail in Dallas and Calgary) project future densities to ensure routes remain economically viable. The final benefit is the provision of a range of housing types within a suburban neighbourhood. A holistic view envisions a community with representation from a diverse socio-economic profiling, not segregation by ethnicity, age or wealth. This will also permit residents to stay in a particular neighbourhood, allowing them to increase or decrease living space as necessary.

Current suburban neighbourhoods are primarily bedroom communities built at densities believed to be unsustainable (Tomalty *et al.*, 1994; Van Vliet, 1994). Most daily amenities (shopping and workplace related) are beyond reasonable walking distances, with densities too low to support effective transit service. Housing in most conventional suburban neighbourhoods is primarily single family, with a clustering of multi-unit dwellings located on the peripheral arterial roadways. Typically, once a couple has had their family, no longer needing a large single family house, they remain there for lack of a nearby opportunity to move into a smaller home or condominium. The densities of many cities in Europe far exceed those in North America, part of the reason for their lower automobile dependence (Newman and Kenworthy, 1989). The cultural acceptance of higher density in Europe may be due to effective public transportation facilities, and the priority placed on preservation of agricultural activities in proximity to major cities.

The proposal for increasing residential density and broadening the range of housing types is a recognition that the current make up of neighbourhoods needs to be altered. Changes are not going to occur overnight as most neighbourhoods are fully built out and many buildings in these are many years from reaching the end of their design lives. The housing types that should be permitted and encouraged in suburban neighbourhoods are as follows, requiring some changes to existing zoning regulations:

- Permit apartments and condos over retail, with a maximum of 4 to 5 storeys;
- Build retail buildings with little or no setback, having parking at the rear or in an underground parking structure;
- Legalize "granny flats" over garages and in basements, to provide low cost housing for students and singles;
- Allow for mixed types of housing - single family houses integrated with rowhouses, small 3-storey apartment and seniors homes.

Figures 3.4 and 3.5 present a simplified look at the proposed composition of residential and commercial streetscapes. Composition along a residential streetscape should not consist of one type, but rather a mix of types as shown in Figure 3.4. On this figure, all dwellings face the public street, not as a separate "complex" of townhouses or apartments behind a gated or fenced area. Buildings with shorter setbacks and smaller side yards would promote smaller lots and increased density. The use of high- or medium-rise apartments is not recommended, despite their dramatic increase in density, since they remove a person's connection with the landscape. Buildings and streetscapes should be at the human scale as advocated by proponents of New Urbanist principles (CNU, 1998). The proposed commercial streetscape resembles traditional main street planning, with residential dwellings located above main street shops and businesses. Many of these active commercial strips become desirable places to live and work such as those found in Toronto's Beaches and Vancouver's Kitsilano areas.

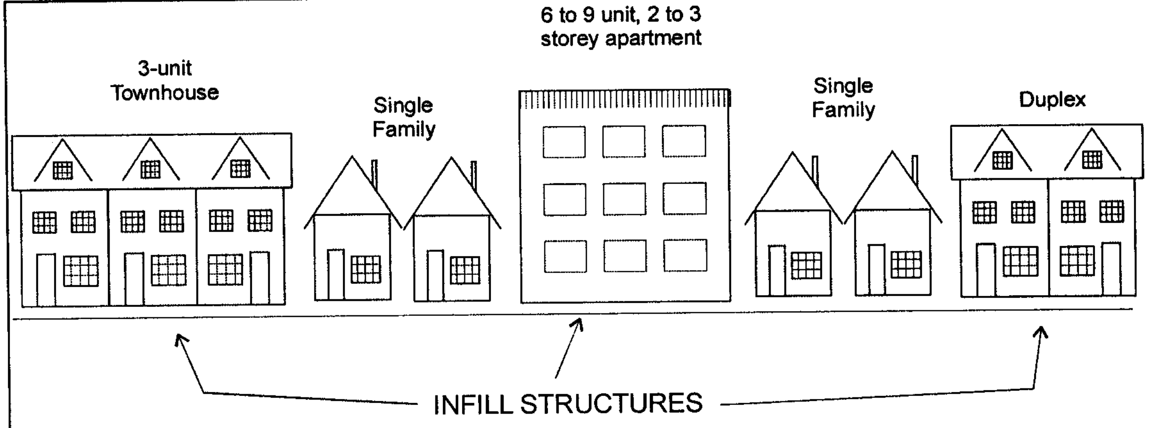


Figure 3.4: Proposed residential streetscape with a mixture of dwelling types. Note the human scale is maintained.

As suggested earlier, residential density is undoubtedly a key underpinning to the success of a long term suburban retrofitting process. It has numerous links to other retrofitting aspects as shown in Figure 3.1. For example, higher density can lead to commercial and employment activities becoming viable in suburban neighbourhoods, as well as an effective transit system (links 1 and 2). In a link to neighbourhood greening, residents of a multi-unit building would be the target group for the implementation of community gardens (link 3). Promoting infill development, through densification, would relieve some pressure on farmland adjacent to city boundaries. This land could then remain in production, providing local

Figure 3.5: An example of the envisioned commercial streetscape from King Street, Dundas, Ontario

agricultural products, another key part of the sustainable community or region (link 4). An increased number of residents will impart a greater demand on existing water and wastewater treatment infrastructure and may warrant an increase in service to the neighbourhood (link 16), with pipe size requirements to be investigated for projected population increases.

The timing for densification will vary for differing neighbourhoods. Some neighbourhoods, not yet fully built out, could set aside some areas for increased density. Others nearing buildout, with a relatively young stock of buildings, would have to wait before significant increases in density are achieved. The key to increasing density over the long term is to identify neighbourhood hubs where commercial and employment activities are centred around a regional transit station. Incremental and adaptive planning will be needed to build structures that meet the overall goals when land becomes available. The more immediate options are those involving zoning changes to allow secondary suites in basements and granny flats above garages.

The biggest challenge of densification, like any broad sweeping government sponsored change, is NIMBYism. The idea of bringing density to suburbs, known as an escape from all things urban, would be repugnant to many suburbanites. The mixing of housing types to provide continuous and affordable housing may also meet considerable resistance. The success in realizing the necessary changes is in doing them incrementally and universally across a metropolitan area. Small, subtle increases in density, by the addition of a small apartment or trio of row houses, will be met with less resistance than plans for a multi-block complex of townhomes. Universality aims to create unique neighbourhoods across a region; it demonstrates the importance of having all neighbourhoods participating in the creation of a sustainable region.

3.2.5 Local Commercial Development

Current suburban zoning segregates land use types into residential, commercial and industrial. Zoning was developed largely to keep dirty, unhealthy industrial practices and commercial development away from residential dwellings (Levy, 1991; Harris, 1996). The implication of zoning, however, is that it has slowly embraced the principle of excluding anything "non-housing" from residential neighbourhoods. No longer is it the norm that neighbourhoods are built with enough shopping facilities for the expected population. Rather, developers and planners presume residents will have a car and be able drive to some distant shopping centre. In addition, although less common, is a neighbourhood constructed without a school building. The expectation is that children will be bussed to an existing school some "unwalkable" distance away. The dependence of suburban residents on motorized transportation as the means to access their daily activities is widespread.

Commercial activity in neighbourhoods is a principle that many neighbourhood and community planners are beginning to revisit, under the guise of neo-traditional planning (CNU, 1998). Commercial activity was an integral component of streetcar suburbs built during the 1910's and 1920's (Warner, 1978). The benefit of introducing commercial activities into conventional suburban neighbourhoods is to provide local commercial destinations within walking and cycling distance. The aim is not to create homogenous commercial developments in suburban neighbourhoods across a region, but rather that they develop some distinct character. Distinctiveness can be based on such differences as physiographic setting, historical context and ethnic compositions.

Some may view these changes as returning to a previous era, no longer acceptable to the modern consumer. Principles such as human scale commercial enterprises, production and consumption of durable goods, repair and recycle of goods rather than disposal, and loyalty to the small local retailer who employs local people and sells locally manufactured products, may be gone but not forgotten. At the macro-scale, these principles do not bode well for the present-day economy that aims to increase economic growth and development through the growth of consumer spending. If economic growth increases, so too do the ecological footprints of our consumption habits (see Wackernagel and Rees, 1996). Nor do these principles bode well for the regional shopping centre or power centre complexes that grew explosively in the 1980's and 1990's. These centres rely heavily on large automobile-oriented markets, many times the size of the typical neighbourhood.

The objectives summarized in the previous paragraphs broadly outline how adding commercial enterprises to suburban neighbourhoods might lead to greater sustainability. Clearly a direct benefit is the reduction of automobile trips to distant power complexes or regional shopping centres, and greater personal health through the promotion of walking and cycling. The emphasis on small, local stores which sell and distribute locally-produced goods and services is definitely more sustainable. In turn, this supports local agricultural producers and manufacturers, decreasing the overall ecological footprint of a region through reduced transportation costs.

In the typical conventional suburban neighbourhood, commercial activity is relatively sparse, consisting perhaps of a small convenience and video store. This establishment may be within an acceptable walking distance for most residents in a neighbourhood, but this would depend on street layouts and the availability of pedestrian amenities, such as sidewalks. More often, commercial activity is located along main arterial roads or highways bordering suburban neighbourhoods in auto-centric strips (Kunstler, 1996), or concentrated into the regional power centre or mall. Buildings are set well back from the street to permit extensive parking in front of buildings with advertising signs to attract the attention of passing motorists. Access to these "strips" or malls is almost exclusively by automobile, as facilities for pedestrians or cyclists are typically lacking. These commercial strips, regional malls and power centres have attracted commercial activity out of downtowns and other older commercial districts, resulting in derelict areas. Residents in these older urban neighbourhoods, who once had goods and services within convenient walking distance, are now forced to travel further and further to the newer facilities located in the suburbs.

The proposed reconfiguration of commercial activities in urban areas is a reassignment (or decentralization) of activities from power centres and malls, back to the neighbourhood level. It is proposed that commercial and employment activities be located in identified neighbourhood hubs, as discussed earlier within section 3.2 (Figure 3.2).

The identification of goods and services to provide in a neighbourhood is dependent on the available neighbourhood population. People have a variety of needs for goods and services. Older data, on threshold populations required to support commercial enterprises, is available in Table 3.4. These numbers require modification to show the services which could be supported at the neighbourhood scale in the present day. However, they provide an initial estimate of what might be appropriate.

Table 3.4: Minimum threshold populations to support select neighbourhood services

Service	**Threshold Populations**	
	Berry and Garrison (1958)	Noble *et al.* (1976)
restaurant	-	372
beauty shop	480	423
insurance agent	409	460
physician	380	488
drugstore	458	840
women's clothing	-	748
lawyer	528	-
bank	610	1216
dry cleaner	754	1234
hardware store	431	1267
variety store	549	1352
jewellery	827	1882
movie theatre	-	2234
florist	729	2276
optometrist	1140	6078

It is unrealistic to presume that the commercial activity of a neighbourhood would adequately service all of one's needs. Residential densities are not proposed, for example, that would support a high school or hospital in each and every neighbourhood. Rather, some services would be shared between two or more adjacent neighbourhoods, depending upon demand. Table 3.5 provides a list of goods and services required by a neighbourhood's residents. These are divided into services which might be effectively provided to each neighbourhood in a region, given that a population threshold is met, and services which would best be "shared" amongst two or more neighbourhoods. Recognizing that some services will be

Table 3.5: Proposed commercial diversity in the neighbourhood, classifying services supported by an individual neighbourhood and those shared with adjacent neighbourhoods

PROFESSIONAL AND HEALTH SERVICES		PERSONAL AND HOUSEHOLD SERVICES	
(Neighbourhood)	**(Shared)**	**(Neighbourhood)**	**(Shared)**
accountant bank consulting engineer dentist financial planner insurance agent lawyer physician real estate office	medical specialists optometrist veterinarian	dry cleaner hair salon hardware pharmacy post office outlet shoe sales / repair video sales / rental	appliance repair bowling alley casino clothing stores computer sales / service florist funeral home gardening store hobby / crafts motel / inn movie theatre pet store trades (plumber, electrician)
FOOD SERVICES		**EDUCATION AND COMMUNITY SERVICES**	
(Neighbourhood)	**(Shared)**	**(Neighbourhood)**	**(Shared)**
bakery butcher / deli convenience store fast food outlet pub / tavern restaurant supermarket	specialty food store liquor store	churches day care elementary school seniors home	college / university community centre / pool high school
TRANSPORTATION RELATED SERVICES		**GOVERNMENT SERVICES**	
(Neighbourhood)	**(Shared)**	**(Neighbourhood)**	**(Shared)**
auto rental bike sales / repair public transit station service station	auto sales / repair specialized taxi for handicapped / seniors		city, provincial and federal government services fire protection police hospital

shared between neighbourhoods, reinforces the notion that effective public transit must be provided between neighbourhood hubs. Effective transit throughout a larger metropolitan region is also required to access those services provided at one location in a region (e.g., a college or university).

At the same time as the development of suburban neighbourhood hubs, current regional malls and power centres should be re-configured so they become integrated facilities with regards to residential, commercial and employment activities. There are examples of such reconfigurations or retrofits of derelict malls in the U.S. where a "Main Street" commercial district model with apartments, was created in parking lots of large shopping malls. A well known example is Mashpee Commons on Cape Cod, Massachusetts, where a conventional strip mall was transformed into a downtown core having approximately 280,000 square feet of commercial space, with residential units on the upper stories (New Urban News, 1999).

Increased commercial activity within suburban neighbourhoods has a number of links with other aspects of suburban retrofitting under consideration (Figure 3.1). As previously stated, the success of introducing commercial activity into the suburban neighbourhood is dependent upon strategies which increase residential density (see link 1). In particular, increased density will increase customer base, which in turn, will broaden the commercial diversity possible in a neighbourhood (link 7). Local commercial activities will also provide local employment for residents (see link 5). Creating vibrant commercial hubs where retail and employment activities take place, while also providing higher density residential units, requires some careful treatment of traffic, pedestrians and streetscape aesthetics. The commercial districts will, for the short term, rely on pass-by vehicle traffic (for customers) as well as nearby residents. The design of such streets should be a compromise between vehicle and pedestrian needs. What makes these kinds of districts successful to pedestrians, merchants and residents are walkability, access and aesthetics. An overly busy arterial street would not make them as attractive. Thus, there is a connection between retrofitting commercial areas, pedestrian issues and traffic calming (see link 8).

The changes suggested for retrofitting local commercial development are arguably more controversial than the naturalization of a park for neighbourhood greening, or the addition of sidewalks to improve pedestrian connectivity. They require fundamental changes to the way in which suburban neighbourhoods have been zoned for the last half century. They also suggest that suburban neighbourhoods - to make them more sustainable - will have to adopt characteristics of urban neighbourhoods, with greater diversity of land uses as well as higher residential densities. The changes suggested require the intervention of planners, politicians and governments in the suburban development process. Such involvement would be met with resistance by those who would rather let market forces drive the demand and supply (and spatial location) of commerce. Market forces could also be used in an alternate vein to argue for the commercial retrofits suggested in this dissertation. The places we often visit as tourists are those defined by integrated commercial and residential districts ("Main Street USA" or "Small Town Ontario"). Some well-known Canadian examples include Niagara-On-The-Lake, Quebec City, and Victoria.

The timing for the changes in the commercial composition of neighbourhoods is beyond most political mandates and perhaps even longer than the career length for a community planner. Thus, the process, like many aspects of suburban retrofitting, will require a visionary approach to define where the program wants to be 10, 20, 30, 40, ... years hence.

3.2.6 Local Employment

Retrofitting employment into suburban neighbourhoods, similar to commercial activities discussed in the previous section, requires a fundamental change in the way in which suburbs are viewed. A pattern of mixed land use represents a condition of greater urban sustainability than does the current pattern of single-use zoning. To achieve mixed use, a de-centralization of employment activity is required, diverting it away from the traditional concentrations in the Central Business District and Edge Cities (Garreau, 1991).

A methodology to retrofit an employment component into suburban neighbourhoods would have two parts. Firstly, it would explore the types of activities appropriate to locate within a suburban neighbourhood, since not all economic activities would be suitable to a neighbourhood scale. Secondly, it would aim to provide a range of employment options within suburban neighbourhoods, thereby reducing a significant number of employees' commuting times.

The addition of an employment component to suburban neighbourhoods is a more sustainable enterprise because of its impact on automobile dependence. If one could walk or cycle to work, time spent commuting and costs associated with car ownership and operation would be considerably reduced. As well, fewer people commuting by car improves urban air quality and reduces fossil fuel depletion. For those employment activities located outside the neighbourhood, efficient access through public transit would be a more sustainable alternative.

A key objective for adding an employment component to suburban neighbourhoods is to reduce (and ultimately eliminate) the need for commuting long distances to work. Commuting long distances has become culturally accepted in North America, even with its associated costs of car operation and maintenance, as well as total time spent away from family or workplace.

Consider three types of commuters shown in Table 3.6. A "light" commuter who spends an average 30 minutes commuting per day can expect to spend a little over one week per year driving to and from work. A "heavy" commuter, travelling upwards of 60 minutes each leg of the daily commute can expect to spend nearly 4.3 weeks each year driving to and from work. Comparable times for a commuter using transit to cover the same commuting distance might be considerably longer given the generally accepted ineffectiveness of transit systems in North America.

Table 3.6: Calculated commuting times for three hypothetical commute types

Commute Type	Time on each leg of Home-Work-Home Trip (min/day)	Total Time Spent Commuting	
		(hour/year)	(week/year)
light	15	183	1.1
medium	30	365	2.2
heavy	60	730	4.3

The reason people commute by car is the lack of an effective alternative. Transit infrastructure in North America was largely constructed to service the work trip from commuter suburb to the Central Business District. Unfortunately, this is especially true for fixed route transit types such as subway, light rail and streetcar. The result being these transit systems are unable to easily respond (provide service) to the development of Edge Cities and the growth of jobs concentrated outside of the Central Business District. In the Greater Toronto Area, for example, instead of commuters making trips from Oakville or Mississauga to the downtown core, they instead have jobs in North York or Markham, which has changed the pattern of commuting from the suburb-core model to a suburb-suburb model. Hartshorn (1992) claims that over 50 percent of all work trips, in a city of 1.5 million people, now follow a suburb-to-suburb commuting pattern.

The most easily stated solution to reducing an individual's commuting time, not requiring any retrofitting, is to move people closer to workplaces. This will not necessarily get people within walking distance of their employment, with no change in the dependence on a car, but it will shorten commuting times.

In a more sustainable suburb, we would reduce average commuting time and distance with jobs in closer proximity to residences (i.e., mixed use zoning). Ideally, it would be beneficial if everyone could all get to work by walking or a short bike ride. But, in reality, there will always be a demand for people travelling outside their neighbourhood or district to reach a workplace exceeding walking and biking distance thresholds. For these commuters, an efficient regional transit system would be a means to compete with the accessibility of the automobile. However, a commuter living in one city, expecting a good transit connection to a neighbouring city 30 km away, may be an unrealistic demand on a transit system.

To address local employment, decentralization of those activities that integrate well with residential and commercial land uses in neighbourhood hubs may be a solution. An initial listing of appropriate employment activities - office and light manufacturing - for the neighbourhood scale is indicated in Table 3.7. These activities could be located on the lower floors of multi-storey buildings retrofitted to neighbourhood hub areas (see Figure 3.5). Options for home-based businesses should also be explored, especially given the revolution of Information Technology-related employment and the ease of electronic commuting with Internet and telephone resources.

Many present-day employment activities are not well suited to a neighbourhood scale, because of health issues or land requirements. These would include heavy industrial facilities such as a coal-fired electricity-generating plant, petroleum refinery or large-scale manufacturing operations. Where these kinds of operations persist, it is proposed they could be in "industrial hubs" (or "industrial TODs") which do not contain a residential or commercial component. But like other hubs, they would connect to the regional transit system so that workers could efficiently reach the plants by transit. The company might be encouraged to partner with the transit authority, co-ordinating shift changes with peak shuttle service to nearby neighbourhood hubs (see Figure 3.6). Obviously, the regional transit service would need to absorb these service demand peaks, associated with shift changes, on a 24-hour basis.

Table 3.7: Sample of employment activities appropriate for the suburban neighbourhood

employment activity	appropriate for hubs	appropriate for home-based
banks and other financial	✓	
call centres	✓	
carpentry + home renovation	✓	✓
city services (planning, maintenance, etc)	✓	
day-care	✓	✓
health professional	✓	✓
hospital	✓	
light manufacturing (small scale)	✓	✓
lawyer and other professionals	✓	✓
retail sector	✓	
schools and education services	✓	
seniors home and home care	✓	✓

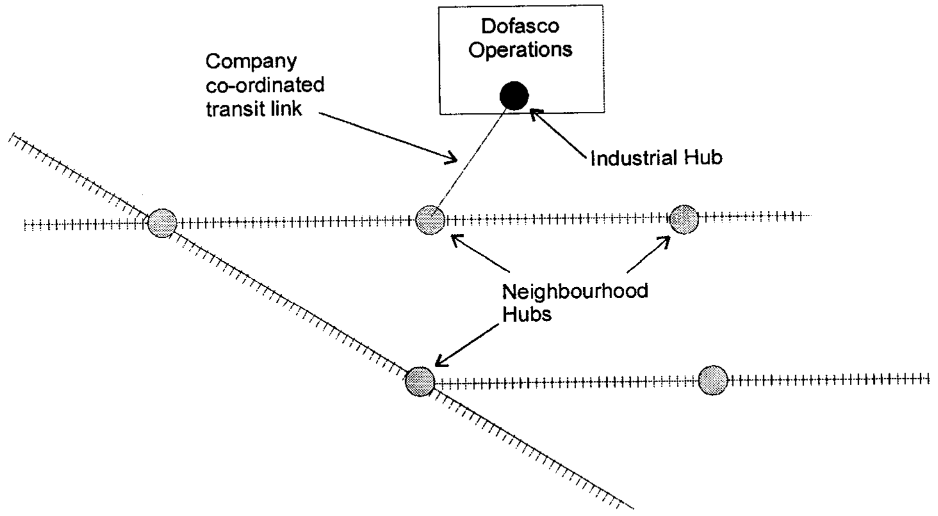


Figure 3.6: Concept of "industrial hubs", linked to the regional transit system

Increased employment activity in the suburban neighbourhood has a number of links with other aspects of suburban retrofitting under consideration (Figure 3.1). As with commercial retrofitting, the addition of multi-storey buildings in a neighbourhood hub, well serviced by transit, will act as sites for future employment activities. The commercial activities themselves will also provide some local employment (link 5). As well, the proposed densification of the suburban neighbourhood will provide the necessary customer and employment bases to support some introduction of local employment activities (link 1).

As with the density and local commercial retrofitting methodologies previously discussed, the main challenge in retrofitting local employment is the lengthy timeline for implementation. There is no quick solution to reducing the dependence on automobile commuting to work. The methods proposed here have two time periods for which solutions could be generated. Firstly, short term solutions include creating better transit links between key nodes in a particular metropolitan area, in addition to the suburb-CBD linkages. Transit should include sufficient flexibility to accommodate any to-be-established neighbourhood hubs, which in the future will become centres of commercial and employment activities. A second short-term measure is to encourage the population to work and live in closer proximity, reducing their personal costs for transportation and time.

The second time period for establishing employment activities is longer term, requiring a visionary approach with objectives and practices in place that outlive shorter-term political agendas. Longer term solutions should diversify land use in both current employment-focussed areas (CBD, Edge Cities) and current residential-focussed areas (suburban neighbourhoods). Governments may be required to implement the "carrot and stick approach" to improve conditions, making sure some of these fundamental changes occur. Recent programs to improve air quality and reduce smog, largely the result of high rates of auto use, have been implemented in the Vancouver and Toronto metropolitan areas (AirCare, 2001; Drive Clean, 2001). The public is largely critical of these programs, balking at costs for testing their vehicle emissions and potential repairs. But in the same breath, they want responsible government to provide clean air, so their health is not compromised.

3.2.7 Local Food Production

Local food production is considered an important component of more sustainable communities. With the mechanization and industralization that has occurred in farming practice in North America, the individual family farm has all but disappeared. Coincident with the loss of the family farm, is the loss of the connection between society and nature and knowledge of our dependence on it to provide food. In Canada, there is only a short time period in which we depend on our own produce. For much of the year, we are dependent on imports from California, Florida, Europe and elsewhere. The ecological footprint analysis (of Wackernagel and Rees, 1996) reveals an associated transportation cost of our food demands, stemming from an unsustainable transportation scheme. As Canadians in a global marketplace, we have become accustomed to foreign and exotic produce (bananas, mangoes, oranges), products that we are unable to grow commercially. Previous generations were less reliant on imported goods, and seemingly survived and prospered on what they were able to grow themselves.

The concept of local food production at the scale of the neighbourhood is not designed, nor would it be capable of, addressing the distribution of foodstuffs around the globe. It is based on the recognition that the importing/exporting of food is fundamentally not a sustainable practice, especially the distances that food is currently shipped. Local food production aims to encourage people to become more self- and community- reliant, rather than dependent on the agricultural productivity of a distant state or country. For the individual, this might mean actively growing some of your own produce, either on a home plot or at a neighbourhood community garden. Local farmers and community gardeners should be supported and encouraged through the promotion of local farmers markets and the marketing of locally-produced food stuffs in supermarkets.

Problems for promoting greater reliance on local food production in suburbs are climate and the lack of fertile soil. Cities in southern Canada are more fortunate, as they have better climates and some of Canada's best agricultural soils (e.g., Lower Fraser Valley; Okanagan Valley; Golden Horseshoe; Annapolis Valley). Cities in the north (Prince George, Edmonton, Saskatoon, Thunder Bay, Sudbury, Quebec City, St. John's) may not be as fortunate. There will also be a cycle of availability, with the greatest variety available during later summer and harvest times, and diminished variety in winter and early spring. It is unlikely that a consumer accustomed to current availability and breadth of produce will accept such a cycle. Another obstacle may be the cost of produce. Currently, locally produced organic produce can be more expensive than buying chemically fertilized produce, available in most grocery stores. Encouraging the consumer to buy a local organic product may be difficult, despite its advantages of being chemical-free and possibly improving one's health. Notwithstanding these obstacles, it should be possible to tailor a local food production scheme for specific climatic zones recognizing limitations on what could be successfully grown.

At the neighbourhood level, the following elements could be parts of a local food production scheme aimed to reduce dependence on exported food:

(1) Provide community gardening plots for residents of multi-unit dwellings;

(2) Encourage parks officials to plant fruit and nut trees in parks as landscaping;
(3) Encourage residents to use their backyards for vegetable and herb gardens and greenhouses;
(4) Encourage local grocery stores to promote locally-produced goods.

Local community gardens, point (1), will provide an opportunity for these residents to grow some of their food on a nearby plot during the summer growing season. Organic farming and preservation techniques are two potential seminar topics to be given to interested residents to help them grow and preserve produce. With regards to point (2), the stewardship for such trees could be passed to a neighbourhood community gardening association who could then benefit from the care of such trees. Alternatively, an entrepreneurial person could be their caretaker, as a neighbourhood fruit or nut farmer. This person would be responsible for all aspects of their care, from planting to selling products in a local farmers market.

Many suburban residents already use a portion of their backyards for local food production, although perhaps not to its full potential. The use of greenhouses would permit a number of options to the home gardener. Firstly, they lengthen the growing season as they protect crops from early frost. Secondly, they permit a greater diversity of potential crops to be grown. Commercially, greenhouses are used in Canada to produce fresh produce throughout the year, such as BC Hot House Foods Inc, a group of BC farmers who grow tomatoes, peppers, and cucumbers hydroponically (BC Hot House, 2000). Here, a potential entrepreneur could "rent" backyard space from several residents to grow food for sale in a local farmers market.

Southern Ontario is fortunate to have an extensive agricultural industry capable of growing a wide variety of crops. It is surprising, however, how often an Ontario product is not available at a grocery store, or is the same price or more expensive than something imported from abroad. Local supermarkets should be encouraged to support local producers such as those entrepreneurs described in points (2) and (3) above, as well as regional producers located on more traditional farming properties. It is certainly more sustainable for Hamilton stores to bring in produce from Niagara or Waterloo regions than to import from California or Florida.

Implementing a component for local food production has a number of links to other retrofitting aspects as shown in Figure 3.1. In particular, community gardens provide opportunity for residents to grow a portion of their own food (link 14). Increased population density will have a number of impacts, including greater demand for community gardens, and relieving development pressure on surrounding farmland (link 4). Local food production will impart a demand for irrigation which, depending upon climate, will affect how a neighbourhood's water resources are managed (link 20). Local food production also has the potential to provide local economic activity for a local farmers market and gardeners (link 5).

It is important to stress the importance of developing and maintaining a local food production strategy. As key agricultural producing states, such as California and Florida, grow in population, it is unlikely they will be able to continue providing much of North America with fresh produce during the winter. Canada may not need to find alternate sources immediately, because of a favourable trading relationship with the US. The development and promotion of local agricultural strategies, to make a population more self-reliant, will assist the shift to more sustainable communities in Canada.

3.2.8 Water Consumption and Wastewater Generation and Treatment

Water use and wastewater generation in the suburban neighbourhood have been identified as a potential aspect for suburban retrofitting. This section will provide an overview of water use and wastewater generation in Canada, and in particular, discuss why a reduction of water use and wastewater generation rates will lead to more sustainable communities. Potential conservation techniques and devices that could be implemented at the home or neighbourhood scale are considered, and links to other retrofitting aspects explored.

Water is a particularly plentiful resource in much of Canada and the US. Because of this, water prices in North America are much lower than the rest of the world, leading to higher per capita consumption rates (Table 3.8). Canadians are fortunate to have few restrictions on their water use and have become culturally adjusted to a plentiful water resource.

Table 3.8: Comparison of per capita residential water consumption (from Sharratt *et al.*, 1994) and costs (from Environment Canada, 1992).

jurisdiction	**water consumption (L/c/d)**	**water prices (1989 $Cdn/m^3)**
USA	426	0.42
Ontario	*300*	*0.36*
Sweden	200	0.78
Germany	150	1.33
France	150	0.86
Australia	n/a	1.47

Notes: L/c/d = Litres per capita per day; 1000 L = 1 m^3.

The primary uses of water in suburban landscapes are for interior domestic uses (i.e., toilet, bathroom, kitchen), and for exterior uses such as irrigation, gardens, and car washing. In fact, nearly 70% of all indoor water use is in the bathroom, with approximately 35% devoted to each of toilet flushing and showering/bathing (Gates, 1994). Figure 3.7 portrays water throughput in a typical suburban home, depicting the various inflows and outflows as arrows. From these flows, a "household water balance" could be generated, which would be done as part of the design of water and sewer mains to service a particular neighbourhood. This would require knowledge of local precipitation, evaporation and evapotranspiration rates and of local soil conditions. In addition, typical water use rates would be estimated for residential users and other user in a given neighbourhood. What is interesting to note in the present set-up, as portrayed on Figure 3.7, is the exclusive use of municipally-treated water for domestic uses. The relatively “clean” precipitation (including rain and snowmelt) falling on the roof and driveway is treated as wastewater. This unused "clean" water is directed to the combined

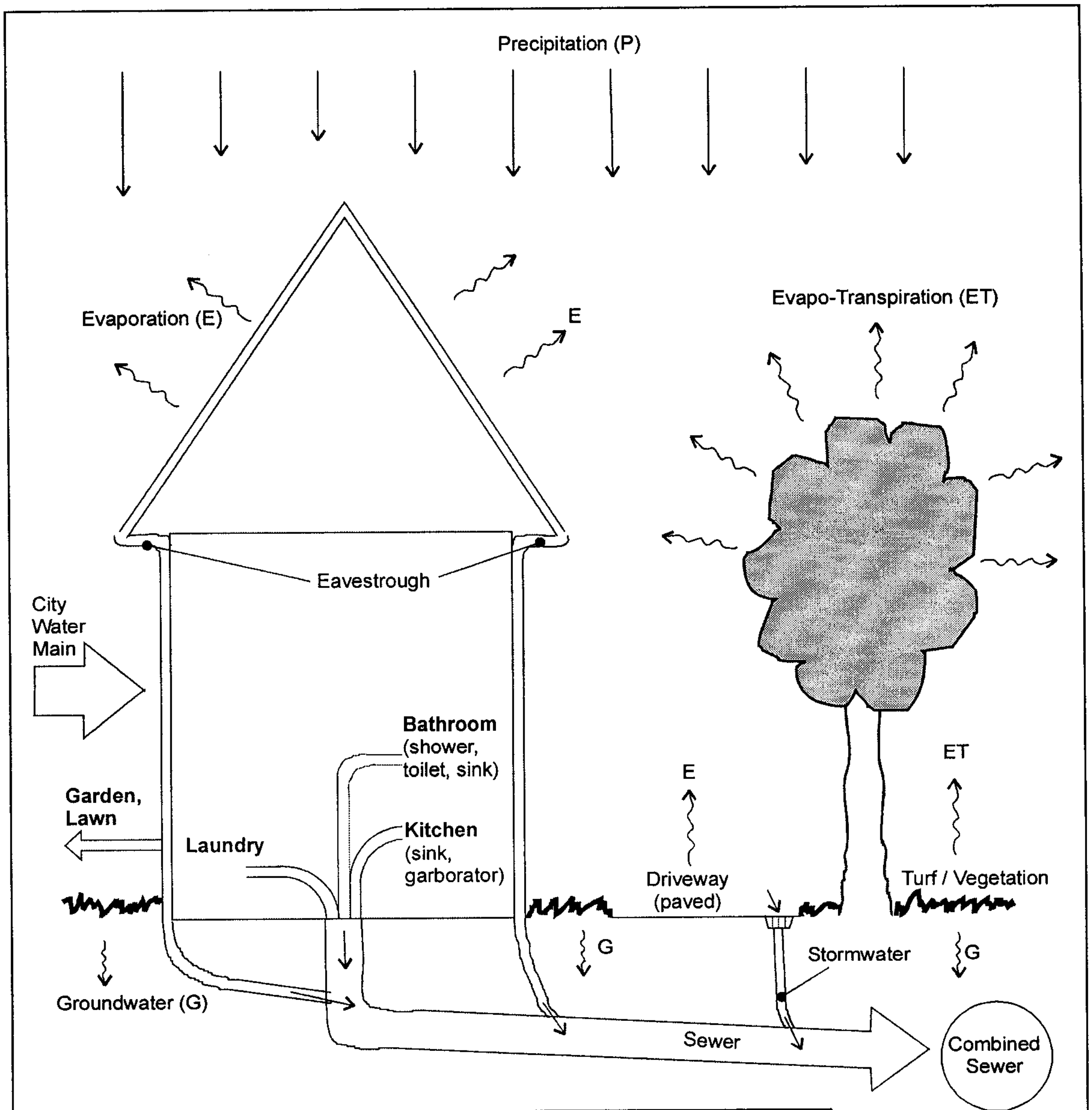


Figure 3.7: Water balance of a typical home

storm- and sanitary-sewer, then treated, at reasonably high cost, in a wastewater treatment plant. This water represents a good opportunity to significantly reduce the amount of wastewater generated by the neighbourhood (see discussion below).

There are various methods and means (devices) to lower personal water consumption and wastewater generation. Reduction of water consumption and wastewater generation, in some cases, relies on the initiative of the individual to change a fundamental lifestyle habit such as: the length of time showering, the frequency of bath, or the choice of plant for landscaping or gardening. Personal habits can only contribute so much, since there are many things we cannot do without (toilet flushing, dishwashing, clothes washing, showering). For these items, we rely on a designed device which can "painlessly" lower an individual's water consumption. These devices include low-flush or composting toilets; low-flow showerheads; and water-efficient appliances. Although these devices have some associated up-front capital costs, their payback periods can be relatively short, given the volume (and therefore cost) of water to be saved. Methods and devices for reducing water consumption and wastewater generation applicable at the neighbourhood scale are discussed in the following paragraphs, while those to be implemented within the home are discussed separately in Appendix E.

The primary means to reduce water use at the neighbourhood scale is to reduce the irrigation of landscaped areas. The fixation of North Americans with the "expected" greenscape (e.g., weed-free, chemically-treated lawn, exotic and often water-consumptive plant species) has led to our high per capita water consumption rates. Most neighbourhood scale techniques refer to reduction in the amount of wastewater generated. The contribution from roads and driveways to sewers could be reduced through the use of porous paving materials, swales or infiltration basins (Ferguson, 1998), or by reducing the amount of paved area.

Drainage swales could be designed at centralized locations such as neighbourhood parks or natural areas, where stormwater could be slowly released to nearby streams or percolate into the groundwater. Examples of stormwater collection swales installed in Woodlands, Texas and in an Ottawa housing project are discussed in Hough (1995). For driveways, one could install "landscaped driveways" to increase infiltration of water incident upon the driveway. These designs would reduce the effective width of impermeable surface by incorporating a turf component to driveways (Figure 3.8). To reduce the contribution from the dwelling structure itself, incident precipitation could be collected and stored in a cistern for landscaping and certain household uses.

Furthermore, there is some thought that wastewater treatment could be “de-centralized” from large facilities (such as a conventional WWTP) to smaller facilities located in individual neighbourhoods. It is thought that neighbourhoods (or 2 to 3 neighbourhoods linked together) might support one of John Todd's "Living Machines" for their wastewater treatment needs. A living machine in South Burlington, Vermont treats 80,000 gallons of municipal sewage per day, an amount equivalent to that generated by approximately 1,600 residential users (Living Machine Inc., 2001). The viability of this technique needs further research to determine the character and volume of wastewater it could handle. The treated sewage in the Vermont example above has been initially concentrated at a conventional wastewater treatment plant, prior to being sent to the living machine. As well, the downstream use of the water treated in a living machine would need to be considered. Would it simply be applied to natural areas or turfed parks, or could it be used for agricultural applications in close proximity (e.g., community gardens)?

Figure 3.8: Alternative driveway incorporating a turf component between paved wheel tracks

Links and interdependencies between water, wastewater, and other aspects to be retrofitted, are shown on Figure 3.1. The most obvious are those to neighbourhood greening (links 15 and 17). Landscaping techniques suggested in neighbourhood greening, such as naturalization, quasi-naturalization and xeriscaping, all have lower watering requirements than conventional suburban landscaping (link 15). As well, the use of porous paving materials for streets and roads to encourage groundwater percolation will lead to reduced demand on wastewater infrastructure (link 17), similar to the diversion of stormwater via the collection of rain water in cisterns. Diverted stormwater, and potentially the treated water from neighbourhood-scale water treatment plants, could be used to irrigate local food production initiatives, such as community gardens. And finally, any increases in residential density will mean more households exerting a greater demand on water and wastewater infrastructure (link 16).

The largest hurdle in retrofitting suburban neighbourhoods to reduce water consumption and wastewater generation is its cost. Substantial costs are borne (by the homeowner) in reconfiguring existing plumbing systems to allow for grey water recycling and the use of cistern water, as well as in constructing the cistern itself. City or region borne costs include the elimination of a combined storm and sanitary sewer system, and construction of adequate facilities for the on-site dissipation of stormwater from roads and city owned properties. A further hurdle may be faced concerning the lack of area available to dissipate collected stormwater. Many or all of the natural drainage areas that could be used to dissipate stormwater have been filled and paved over. Calculations to estimate the area requirements to deal with the volumes of diverted stormwater coming from a suburban neighbourhood, while incorporating appropriate safety factors and design storm return periods, would be needed.

In addition to these hurdles, considerable education (of the suburban population) will be necessary to adopt water consumption and recycling devices such as grey water recycling, low-flow toilets and shower heads, and the use of cistern water for cooking or cleaning. There is also a certain amount of knowledge required to adequately operate an in-house water filtration system to ensure cistern water is up to potable water standards. Potential issues with the consumption of cistern water include exposure to algae, suspended sediments from the roof, and other impurities or airborne particulates (Gates, 1994). Despite obstacles, there are significant cost savings as well as the environmental benefits of such retrofitting technologies.

3.2.9 Street Re-design for Aesthetics and Safety

This aspect considers the re-design of neighbourhood streets for aesthetics and safety reasons. Street designs would be developed to prioritize the safety of pedestrians, cyclists and children playing in the streets. Aesthetic aspects of the street and associated streetscape might include the installation and maintenance of street trees, street furniture and lighting, and landscaping. It is included as a distinct aspect, separate from street re-designs for neighbourhood traffic calming and multi-modal use (section 3.2.2), because it has the primary objective of achieving designs and configurations that provide an aesthetic benefit, but not the objectives of designs which calm traffic or encourage other transportation modes. Of course, there is overlap between the two. Many traffic calming installations, for example, provide aesthetic as well as safety benefits, the latter being the key objective of traffic calming. In addition, and of course more importantly, a municipality may wish to improve the overall aesthetic character of a neighbourhood but in no way wish to affect the existing traffic pattern through the use of traffic calming devices.

Streets in conventional suburban neighbourhoods typically have unnecessarily high design speeds. Right-of-ways are often allocated and street widths paved to provide two travel lanes plus a parking lane. Parking lanes on a typical suburban local street are largely unoccupied, because of adequate driveway storage, such that the street becomes excessively large and higher speeds are observed. On-street parking lanes work better in more traditional neighbourhoods, where driveway and garage allocations are more limited, and there is a higher demand for on-street parking from small apartment buildings. Planners and transportation engineers have recognized this characteristic and are beginning to provide standards for narrower roadway designs for new suburban neighbourhoods (Fernandez, 1994; Ewing, 1999;

WAPC, 2000). A second critique of the conventional suburban neighbourhood concerns the poor maintenance of landscaping along the streets. Suburbs are built under the premise of promised green spaces and lined with majestic street trees (once grown). But in recent years, with diminishing municipal budgets, communities are not as diligent as they once were about replacing street trees once they die. In addition, boulevard planting strips along roads (some as narrow as a metre) are converted to asphalt, a further reduction in the amount of green in our neighbourhoods.

The proposed methodology for this aspect is strongly tied to two others in the overall suburban retrofitting decision support system, namely "traffic calming and multi-modal use" and "neighbourhood greening". If one decides to undertake any of the options available in these two measures, it is likely that the user of the DSS will be addressing aesthetic issues at the same time. With regards to traffic calming, the reception of traffic calming devices by residents is based largely on aesthetic design features of the measures. In addition, roadway narrowings, suggested in the traffic calming section, address a number of key safety issues for pedestrians, cyclists and children playing adjacent to neighbourhood streets. With regards to neighbourhood greening, aesthetic issues of street design are met through the evaluation of street tree requirements so that each home along a residential street has a healthy street tree.

The linkages between street re-design for aesthetics and safety are shown in Figure 3.1. As stated already, there are direct links to the need to landscape installed traffic calming measures (link 9) as well as the need to install and properly manage a street tree population (link 10). Furthermore, success in developing viable commerce and residential development in the proposed neighbourhood hub is directly related to aesthetic streetscape features such as lighting, street furniture, and textured sidewalks and streets (links 6 and 8).

As mentioned, in times of diminishing budgets, it is unlikely that one will be able to convince a municipality to undertake street re-designs solely for the purpose of aesthetics. Rather, by its association to safety issues (links to traffic calming) and to improved local air quality (links to street trees and neighbourhood greening), streetscape aesthetics can receive some attention.

Section 3.2 has described the proposed methodologies for retrofitting the conventional suburban neighbourhood, one methodology for each of the nine aspects introduced in Table 1.1. Although these methodologies are discussed in individual sub-sections, they clearly demonstrate a number of key interdependencies (Figure 3.1; Table 3.1). The multi-faceted and interconnected nature of suburban retrofitting is what will make its ultimate implementation a rather complex process. The proposed decision support tools aim to assist the planner or engineer negotiate this complex undertaking. Tools have been developed using an ArcView GIS framework that will be discussed in the next section.

3.3 Selection of ArcView GIS as the DSS Platform

The methodologies described in the previous sections relate to modifications and additions to existing conventional suburban neighbourhoods. An effective means to disseminate these ideas to interested planners and engineers is through the use of a computerized decision support tool, as has been done by others developing such tools for a similar audience (e.g., Churchill, 1997). A geographic information system (or GIS) was selected as the most logical base for the decision support tools for three primary reasons. Firstly, suburban retrofitting decisions are to be made over a spatial area, incorporating at the very least the scale of a neighbourhood. Most community or town planning in the past has been done using neighbourhood planning and zoning maps; the use of GIS is a logical extension of this practice. Secondly, many planners and engineers (who might use these tools) are already using GIS for much of their work. Thirdly, a spatial tool based in GIS allows the integration of a number of spatial variables, and permits the user to create interesting and meaningful maps. A number of spatial analysis functions are already part of many GISs and can be incorporated into new GIS-based tools. Representation of the third dimension was not viewed as important for the development of this prototype tool for suburban retrofit. Others have created decision support tools using CADD systems because of their power in representing a 3-dimensonal model of urban settlement (Dave and Schmitt, 1994; Churchill, 1997).

ArcView GIS Version 3.1 (ESRI, 1998) was selected as the GIS software for the decision support system components for the following reasons. Firstly, ArcView is one of the more widely used GISs currently available, due likely to its relative ease in use and understanding and its lower purchase cost than other packages. A second key benefit is the ability for customization. In ArcView, these customizations are called "extensions" and allow the programmer to bring together a number of related tasks and components. The programming language for ArcView, up to and including version 3.2, is Avenue. Visually attractive user-interfaces can be created using ArcView's dialog editor feature. A third benefit of selecting ArcView, like other ESRI products, is the extensive support available for programmers. Support is provided through web sites and discussion groups, facilitated by ESRI, for programmers facing similar coding difficulties or sharing their triumphs. Sharing of code and scripts is encouraged, thus avoiding unnecessary duplication of software development. Support for coding using Avenue is also available from several books, particularly Razavi (1997). And finally, ArcView does provide links to other software so that information can be transferred from an ArcView environment to spreadsheet or database applications, such as Microsoft Excel.

The benefits of ArcView considered in the previous paragraph also contribute to a primary drawback of ArcView. When compared to other GIS products, particularly ARC/INFO, ArcView can be criticised as being too simplified and lacking sufficient analytical capabilities to carry out certain spatial analyses. For this reason, some researchers choose to work with ARC/INFO, although creating customized user applications is more difficult in ARC/INFO. Some criticism has also been made of ArcView's coding language, Avenue, saying that it is difficult to use and presents several limitations. ESRI may have recognized these limitations since they have recently announced a release of a new ArcView, version 8.1, due out in Spring 2001. This new ArcView is changing the programming language from Avenue to Visual Basic for Applications, the latter widely used in Windows applications. This is a fundamental change of the ArcView structure and will present exciting opportunities to enhance the coding abilities in ArcView. However, it remains to be seen what will happen to the existing collection of software and extensions of ArcView 3.1 written using Avenue (i.e., will these function in the new environment?).

Individual ArcView extensions have been created for the three primary retrofitting methodologies described earlier in sections 3.2.1 to 3.2.3. The code has been written almost exclusively using ArcView's own language, Avenue. The majority of the computer code has been written by the author, although some existing code has been used. For the latter, existing scripts are available as downloads from ESRI's "ArcScripts" web site. There is no guarantee, however, that these scripts will function as intended since they are not created by ESRI themselves. Only in one of the three coded extensions has another coding language been utilized. In the first-developed extension for Pedestrian Connectivity, some coding of functions in Visual Basic for Applications for manipulation of an Excel spreadsheet was done, since ArcView's manipulation of large data tables is limited. The later extensions rely less on large tabulated data structures, hence there was no need to employ Excel. The next section provides a brief overview of the data requirements for the three extensions.

3.4 Overview of DSS Data Requirements

The form of the created ArcView extensions in this dissertation has to some extent been shaped by the data available during their development. A large amount of digital information for several neighbourhoods in Hamilton was provided by the Region of Hamilton-Wentworth. These neighbourhoods were selected as potential retrofit candidates because they were constructed in the post-war period and exhibited several characteristics of the unsustainable suburban neighbourhood discussed previously in chapters 1 and 2. The digital information was in Micro Station format (.dgn files) and was converted (using ARC/INFO) to shape files that could be inputted into ArcView 3.1. The data consisted only of spatial information, lacking any "attribute" information such as population, use or address (of building themes), and widths, classifications, speeds or volumes (of road themes). During the development of the decision support tools, gaps in the attribute information have been measured where possible. Where these have been impossible to measure or obtain from other sources, assumed values have been assigned. Table 3.9 outlines the general data requirements for each of the three coded ArcView extensions. More details on theme and attribute requirements are provided in the user manuals for the three developed extensions (see Appendices B, C and D).

Table 3.9: Data theme requirements for the three coded ArcView extensions; theme type is one of the three supported by ArcView (point, polyline or polygon)

Theme Description (Type)	Extension Theme Requirements			Attributes Needed
	Pedestrian Connectivity	NTC and Multi-Modal	Neighbourhood Greening	
DWELLING UNITS				
single family home (point)	✓		✓	dwelling occupancy
single family home (polygons)			✓	area
duplex (point)	✓		✓	dwelling occupancy
duplex (polygons)			✓	area
multi-unit buildings (point)	✓		✓	dwelling occupancy; dwelling units per building
multi-unit buildings (polygon)			✓	area
OTHER BUILDINGS AND STRUCTURES				
commercial buildings (point)	✓			
commercial buildings (polygon)			✓	area
community centre (point)	✓			
community centre (polygon)			✓	area
churches (point)	✓			
churches (polygon)			✓	area
schools (point)	✓			
schools (polygon)			✓	area
all neighbourhood buildings (polygon)			✓	area
swimming pools (polygon)			✓	area
ROADS AND RELATED INFRASTRUCTURE				
road centrelines (polyline)		✓	✓	85th percentile speeds; traffic volumes; road class; length
sidewalks (polyline)			✓	length
road edges (polyline)			✓	length
driveways (polyline)			✓	length
pedestrian network (polyline)	✓		✓	length
parking lots (polygon)			✓	area
MISCELLANEOUS				
existing traffic calming installations (pt)		optional		traffic calming measure type
study area boundary (polygon)			optional	area
existing street trees (point)			✓	

3.5 Conclusion

This chapter has provided an overview of a conceptual model and its associated methodologies to retrofit a number of aspects of conventional suburban neighbourhoods. These methodologies are a first step towards creating more sustainable communities in these largely automobile-dependent neighbourhoods. They provide a means to retrofit a number of key physical characteristics of these neighbourhoods and produce land use patterns that would encourage more sustainable living and less dependence on the automobile. They have not, however, covered other key components of the sustainability matrix (e.g., economy and social issues) to the same level of detail as environmental issues.

Decision support tools, in the form of ArcView GIS-based extensions, have been created for each of the three primary aspects listed in Table 1.1. These three extensions are covered in detail in the next three chapters. Each chapter includes a more detailed description of the methodology (than was presented in this overview chapter) and a discussion of the extension's development. As well, applications to existing suburban neighbourhoods in Hamilton, Ontario are presented to demonstrate the capabilities of the decision support tools.

4. PEDESTRIAN CONNECTIVITY

4.1 Introduction

A crucial ingredient for achieving urban sustainability is reducing society's dependence on the automobile. Residents of suburban developments are often dependent on their cars for trips to destinations within the neighbourhood, due to circuitous street layouts, the lack of sidewalks and long travel distances. The term "pedestrian connectivity" is introduced as a measure of both the directness of route and the route distance for the pedestrian for each home-destination trip. Reduced energy consumption, and therefore greater sustainability, may be achieved by having suburban neighbourhoods retrofitted in such a way as to allow people to walk for some of their needs, and to be well-connected to a regional transit system.

This chapter describes a methodology and related planning tool, coded into ArcView GIS, which address retrofit improvements to a pedestrian environment in suburban neighbourhoods. Improvements include the addition of sidewalks and access pathways to isolated cul-de-sacs, to make for shorter and more direct routes. It is hoped that more residents will take advantage of an enhanced pedestrian environment and use their automobiles less frequently for local neighbourhood trips. The tool is intended for use in the planning and municipal engineering professions and for use by others involved in decisions about neighbourhood planning, whether it be planning for existing communities (i.e., retrofitting) or for new communities (i.e., greenfield development). The pedestrian connectivity tool is envisioned to be part of a larger decision support system (as discussed in chapter 3), which will retrofit multiple aspects of existing suburban neighbourhoods.

The developed methodology for evaluating pedestrian connectivity is discussed in the next section followed by a description of the development of the related ArcView tool. An application of the tool to a suburban neighbourhood in Hamilton, Ontario is then provided. Modelled results show how the retrofitted improvements could lead to measurably improved conditions for pedestrians. The material in this chapter has been summarized and published in Randall and Baetz (2001).

4.2 Measurement of Pedestrian Connectivity

Pedestrian connectivity is an indicator of how accessible, with regards to walking, a neighbourhood is to its residents. Residents may desire to walk to local destinations, such as schools, community centres, transit stops or shopping, presuming these services are available in the neighbourhood. Various factors influence an individual's decision to walk (rather than drive) for an origin-destination trip. These include: the availability of a local destination (implying some mixture of land uses); personal health and fitness; route distance; and, route directness. The methodology developed evaluates pedestrian connectivity using the latter two physical distance measures: route distance and a pedestrian route directness ratio, given that distance (between an origin-destination pairing) and lack of time are cited as the most common reasons for not walking (Hawthorne, 1989; Shriver, 1997). The developed methodology does not address land use issues or an individual's behavioural or fitness characteristics. Hence, neighbourhood plans must provide local destinations to residents, within *reasonable walking distance*, if some residents are going to walk rather than drive for local trips.

The first measure to assess pedestrian connectivity is the route distance to be walked by the pedestrian. This study has used a value for reasonable (or critical) walking distance of 400

m. Values reported from a variety of literature sources are between 300 and 400 m. Atash (1994) noted that planners and architects developing new urbanist or neo-traditional communities in the U.S. - communities designed to provide abundant opportunities for walking - work with a design distance of approximately 400 m. This value is also noted by Aultman-Hall *et al.* (1997) as the maximum distance transit users are likely to walk to a transit stop. Furthermore, groups involved in promoting urban sustainability have developed urban sustainability indicators for distance to transit stops. One of the goals of the British Columbia RTEE (1994) is to have 100 percent of the (urban) population within 300 to 450 m of a bus route.

The second measure to assess pedestrian connectivity is the pedestrian route directness (PRD) ratio, a measure of the directness of the chosen path to a particular destination (Hess, 1997). The PRD ratio is the ratio between the route distance and the geodetic (or straight-line) distance, given by equation (4.1).

$$\text{PRD} = \frac{\text{route distance}}{\text{geodetic distance}} \qquad (4.1)$$

The route distance is the <u>formal</u> route distance along existing sidewalks, paths or trails. Informal routes are those on streets without sidewalks, and on worn paths across fields or school yards. A more efficient neighbourhood, from a pedestrian's point-of-view, would be one in which the route distance was as close to the geodetic distance as possible (i.e., a PRD ratio tending towards 1.0). It is believed that people are less willing to walk to a local destination if the route is unnecessarily long or convoluted due to circuitous street layouts.

Measurements of PRD ratios are provided by Hess (1997) for two neighbourhoods in the Seattle area. His pre-war grid neighbourhood had short blocks, sidewalks on both sides of the roadway and few dead-ends to provide the best environment for pedestrians, with a PRD ratio of 1.2 (Table 4.1). The conventional suburban neighbourhood studied by Hess (1997) had a considerably higher PRD ratio of 1.7, because of poor street patterns (curvilinear, cul-de-sacs) and lack of public sidewalks. Walking distances were therefore found to be approximately 40% longer in a conventional street layout versus a traditional grid layout. Analysis of two similar neighbourhoods in Hamilton in this study have shown comparable results (Table 4.1). For a pre-war neighbourhood having a grid street plan and relatively short blocks, PRD values are in the order of 1.4 to 1.5. In contrast, PRD values ranged between 1.63 and 1.88 for a conventional neighbourhood which contained curvilinear and cul-de-sac street types. In both examples shown here, if it were possible to retrofit conventional suburban developments to have more of the characteristics of the older, traditional neighbourhoods, the pedestrian environment could be improved significantly by making walking distances more direct and shorter.

Table 4.1: Comparison of PRD values for conventional and traditional neighbourhoods

Neighbourhood Type	**PRD ratio values**	
	This Study	**Hess (1997)**
pre-1940's neighbourhoods, streetcar suburbs, grid street patterns	1.40 - 1.48	1.2
conventional suburbs, curvilinear street patterns and cul-de-sacs	1.63 - 1.88	1.7

The two measures of pedestrian connectivity are combined to determine the best locations for pedestrian network retrofits. The combined measures are represented by the four connectivity cases shown in Table 4.2. "Acceptable" pedestrian connectivity is achieved when the PRD and route distance do not exceed critical values (case 1) or when the PRD does not exceed the critical value (case 2). In case 2, the route distance remains in excess of the desired walking distance, but no further "straightening" of the route is justified. "Unacceptable" pedestrian connectivity occurs in cases 3 and 4. In case 3, the PRD ratio exceeds the critical value, although route distance criteria have been met (e.g., less than 400 m). For case 4, however, both PRD ratio and route distance exceed critical values. The four possible connectivity cases are portrayed in Figure 4.1.

Table 4.2: Four connectivity cases used to define the need to retrofit the pedestrian network

	Acceptable Connectivity	**Retrofit Connectors?**
1	PRD and route distance not in excess of critical	N
2	PRD not critical; route distance exceeds critical	N
	Unacceptable Connectivity	
3	PRD exceeds critical; route distance does not	Y
4	PRD and route distance both exceed critical	Y

4.3 Retrofits to Improve Pedestrian Connectivity

The final column in Table 4.2 indicates whether or not pedestrian connectors are to be considered for addition to the pedestrian network. For connectivity cases 3 and 4, retrofits, such as added sidewalks or pedestrian paths, create more direct pedestrian routes thereby lowering the PRD ratio. For connectivity cases 1 and 2, the PRD ratio is not critical and the route is likely as direct as possible. However, it would be possible to address an origin with connectivity case 2 by adding another destination to the neighbourhood or physically moving the existing destination. For example, one could experiment with the location of bus stops within a neighbourhood and determine which layout of stops best serves the residents of the neighbourhood.

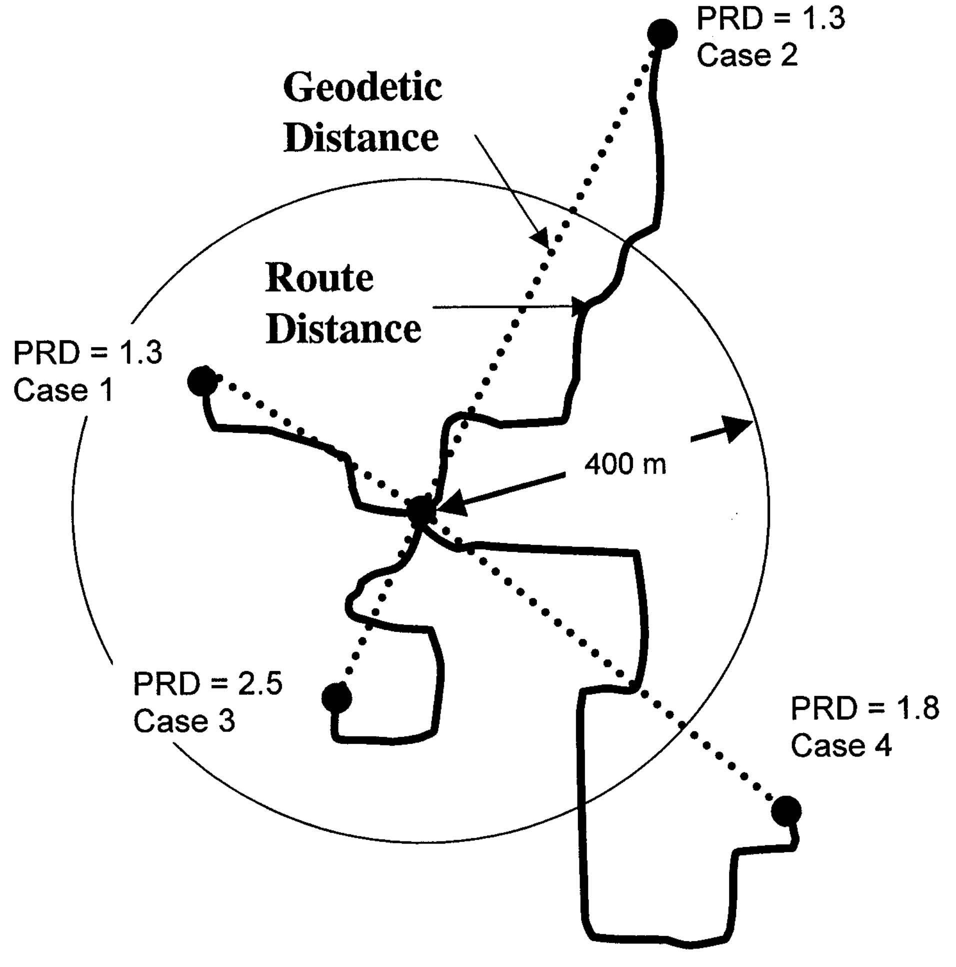


Figure 4.1: Visual representation of the four connectivity cases

The introduction of pedestrian paths to a neighbourhood poses several issues to residents, usually focused on the issues of safety, loitering and vandalism. Pedestrian paths linking cul-de-sacs and crescents to schools have been used commonly in conventional suburban plans since the 1960's. However, some have (unfortunately) been removed at the request of adjacent property owners, thereby eroding pedestrian connectivity even further. The opposition from neighbours to the introduction (or re-introduction) of pedestrian paths and sidewalks is not to be overlooked or trivialized. Although the ideal locations for new pedestrian paths or sidewalks can be determined using a computer algorithm, the planning and installation of such devices remains a very political process. Neighbourhood residents, particularly those of the adjacent impacted homes, will need to be convinced of the community benefit of such paths or sidewalks.

The design of pedestrian paths should incorporate the following elements:

- paths should link adjacent streets and should not be excessively long;
- paths should be paved and maintained for all-weather travel;
- sightlines from adjacent dwellings should be maintained (i.e., not blocked by high fences or overgrown and unkempt vegetation); paths should not become isolated pockets where travellers can pass unobserved;
- paths should be adequately lit;
- where possible, wide corridor widths are preferable to allow for multiple users (pedestrians and cyclists) and for landscaping.

In spite of the public pressure to remove pedestrian connectors, the benefits of improving the pedestrian environment persist. As stated earlier, reductions in automobile usage for neighbourhood trips (through increased pedestrian traffic) clearly benefit our overall objectives of reduced energy consumption and of enhanced individual fitness and community health. Improvements to a neighbourhood's pedestrian network, suggested here, are measured by reductions in route distances between home-destination pairings or in the increased directness of travel routes. The next section discusses the tool which has been developed to model and evaluate modifications to a particular neighbourhood's pedestrian environment.

4.4 Development of Related ArcView Extension

This section describes the development of the first (of three) ArcView GIS extensions providing decision support for suburban retrofitting. This extension - called *PRD Evaluate* - has been created to evaluate pedestrian connectivity based on the methodology described in section 4.2. The following paragraphs summarize the architecture, input requirements, assumptions and operational parameters of this extension. An overview diagram of the extension's algorithm is provided in Figure 4.2. A manual describing how to use the *PRD Evaluate* extension is provided as Appendix B.

Architecture and Coding Details

The methodology for evaluating pedestrian connectivity has been automated into an extension using two commonly used software packages: ArcView GIS 3.1 and Microsoft's spreadsheet program Excel 97. The majority of the extension is written in Avenue (ArcView's coding language), and incorporates original coding as well as some previously developed scripts (ESRI, 1999; Remington, 1999). ArcView's computational capabilities are somewhat limited, particularly for large tables, and Excel was selected to perform several computational steps. Links between ArcView and Excel were established using a Dynamic Data Exchange (DDE).

The core of the extension rests on the ability to calculate route distance and geodetic distance between origins and destinations in a neighbourhood. Route distance is calculated using a modified version of *Shortest Network Paths v1.1* (Remington, 1999), and geodetic distance is calculated by a modified version of *View.CalculateDistance* (ESRI, 1999). Code has been written to integrate these two scripts together and create the DDE link with Excel. In particular, two scripts (*DDECreateSpreadsheet* and *Table.MakeFromExcel*) have been used to create this link, both scripts being downloaded from one of ESRI's support web sites. To run the *PRD Evaluate* extension, two other extensions must also be activated: *Network Analyst* and *Digitizer* (both available from ESRI). Network Analyst supports the *Shortest Network Path* extension, and the *Digitizer* extension permits the addition of line segments to the pedestrian network using the digitizing tools on ArcView's menu bars. In addition to the Avenue coding, some Visual Basic for Applications coding work was done, and compiled as an Excel executable file.

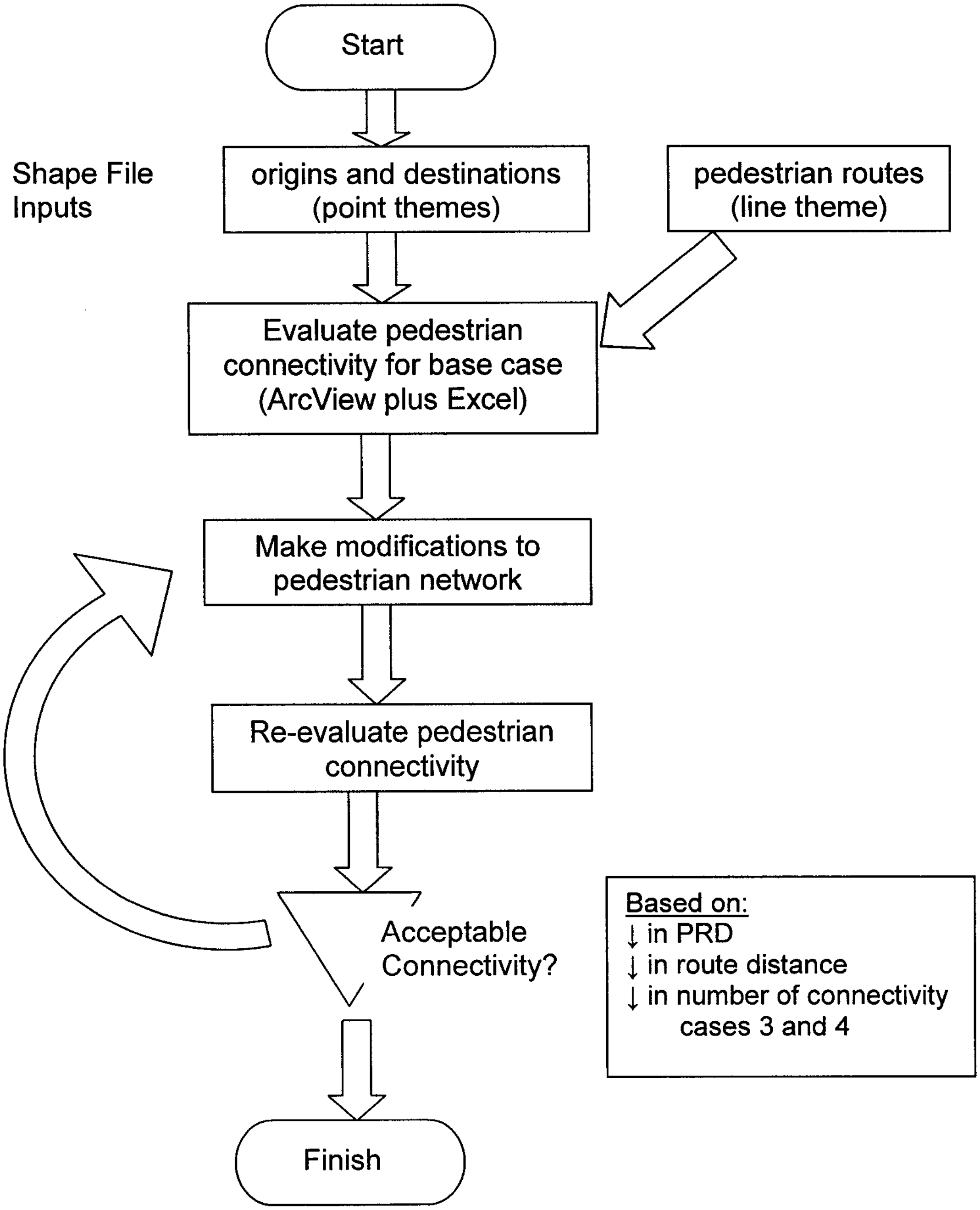


Figure 4.2: Flowchart showing steps in the *PRD Evaluate* extension

Input Requirements and Assumptions

The data inputs consist of at least three shape files. Two of these are point themes, required for at least one origin and one destination in the neighbourhood. Origins represent the nodes (or centroids) of residential dwellings and can include single family homes, duplexes and multi-unit buildings (e.g., townhomes, apartments). Potential neighbourhood destinations include schools, transit stops, shopping, employment locations, churches or community centres. The attribute table for each building type (both origin and destination nodes) has a data field for a unique "building identity number". The extension can currently analyze pedestrian connectivity for all dwellings in the neighbourhood to one destination. Additional destinations are analysed in separate runs.

The third shape file is a line theme representing the pedestrian network. The pedestrian network consists of any sidewalks and paved pedestrian paths already present in the study neighbourhood. The attribute table contains fields for "segment identity label" as well as the "segment length". The creation of this network is subject to the discretion of the user, although it is recommended to use only the formal pedestrian network of paved sidewalks and trails, which are regularly maintained throughout the year. There may also be an "informal" network of unpaved trails crossing school yards and parks, but unless paved and maintained for all-year access, it is assumed that pedestrians will use only the formal pedestrian network. An additional simplification for the developed tool was to restrict the input data to two dimensions. Thus, in neighbourhoods having significant topographic variability, the tool would not generate accurate distances. In much of conventional suburban North America, significant topographic variations were (and still are) removed at the time of construction and grades remain small enough that the simplification to a two dimensional model is considered acceptable.

Extension Operation

Upon loading ArcView and the necessary extensions, the user uploads the input themes for analysis into a new View screen and proceeds to analyse the "base alternative", prior to any modifications to the pedestrian environment or network (Figure 4.2). The query and display capabilities of ArcView highlight areas of poor pedestrian connectivity (to the user), which then become areas the user may wish to consider for retrofits. As mentioned earlier, areas of unacceptable pedestrian connectivity are either those with convoluted routes (high PRD ratio) but of reasonable length (case 3; Table 4.2), or those with high PRD ratio and excessive length (case 4; Table 4.2). In these cases, the user is instructed to modify the pedestrian network by adding sidewalks and/or pedestrian paths, following which the pedestrian connectivity is re-evaluated. These alterations help to "straighten" the route, and the measured improvement to pedestrian connectivity can be expressed by:

- a reduction in the PRD ratio;
- a reduction in the route distance and/or;
- a lowering of the connectivity case from cases 3 or 4 to cases 1 or 2.

It is noted that excessively long but fairly direct routes (case 2; Table 4.2) cannot be helped by the above modifications to the pedestrian network. These cases require more substantial land use changes, such as re-locating the destination or adding another destination to the neighbourhood, and are to be dealt with in future work.

Currently, *PRD Evaluate* operates independently on an ArcView platform and can provide analysis of pedestrian connectivity within a desired study neighbourhood. Future versions are to be incorporated within a larger decision support system capable of evaluating and retrofitting multiple aspects of suburban neighbourhoods. The application of *PRD Evaluate* is now considered.

4.5 Application of Developed Extension

PRD Evaluate was applied to a suburban neighbourhood in Hamilton, Ontario. This application was provided to demonstrate the use of the tool for evaluating and retrofitting access to a neighbourhood elementary school.

Neighbourhood Description

The selected neighbourhood - Berrisfield - is characteristic of those constructed in the area since the 1960's. Berrisfield is defined by three arterial roads on its north, east and west sides, and by the recently-completed Lincoln Alexander Expressway (LINC) to the south (Figure 4.3). The area encompassed by this section of Hamilton, similar to much of southern Ontario, was previously occupied by farmland, which explains the coarse-grid pattern of neighbourhoods and their relative uniformity in dimensions. The Berrisfield neighbourhood was built like many of its contemporaries, primarily as "bedrooms" for workers employed elsewhere in the region. Land use is zoned primarily for residential development, although small parcels are available for limited commercial activity and school buildings.

The physical plan for Berrisfield (Figure 4.3) shows the use of cul-de-sacs and curvilinear streets to provide quiet residential streets. Each neighbourhood was planned to include a local public (elementary) school in its centre, so that children would have a safe walk to school rather than cross busy arterial roads. Berrisfield also has a high school. Apartments and higher-density dwellings and commercial buildings are concentrated along arterial roads. The majority of the neighbourhood's interior is devoted to single family dwellings.

The estimated population for the Berrisfield neighbourhood is 3,310 (Table 4.3), covering a gross area of approximately 87.5 hectares (218.8 acres). Population estimates have used residential dwelling occupancy values from Baetz (1994). Gross residential density is approximately 37.8 persons/ha (15.1 persons/acre) or 15.5 dwelling units (d.u.)/ha (6.2 d.u./acre).

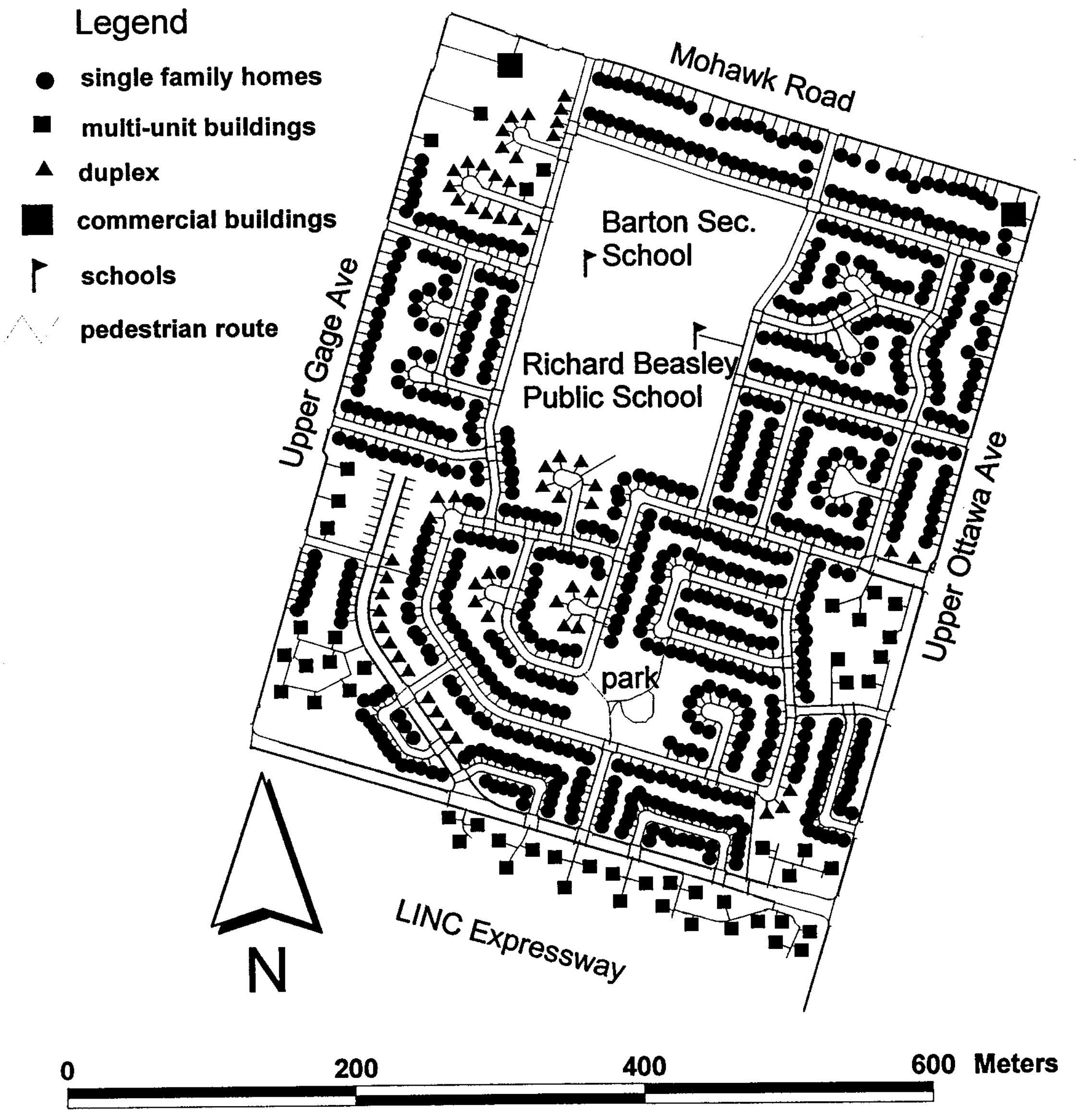


Figure 4.3: Berrisfield study neighbourhood

Table 4.3: Berrisfield neighbourhood's residential building characteristics and estimated population

dwelling unit type	residents per dwelling unit	number of buildings	number of dwelling units	population
single family	3	743	743	2,229
duplex	2	57	114	228
apartment	1.25	2	204	255
townhouse	2	50	299	598
totals	**n/a**	**852**	**1360**	**3,310**

The pedestrian network in suburban neighbourhoods can vary widely. Berrisfield is more fortunate than others in that most of its streets have sidewalks on both sides and there are already a number of short pedestrian paths between cul-de-sacs. A recent upgrade to the pedestrian environment was the paving of paths through the park in the southern half of the neighbourhood in the late 1990's (Figure 4.3). At present, there is approximately 21.2 km of paved sidewalk in Berrisfield.

Analysis

The use of *PRD Evaluate* is shown in the following analysis of pedestrian connectivity between all residential dwellings and the public school located in Berrisfield's northeast quadrant. The initial analysis, utilizing an unaltered pedestrian network, is referred to as the "base case" alternative (Figure 4.4). Note that only the formal pedestrian network is used, including paved sidewalks and existing pedestrian paths. Subsequent analyses are referred to as "Alternative_n", where n is the number of the particular alternative. In this example, it is assumed that the critical values for route distance and PRD ratio are 400 m and 1.5, respectively. However, it is possible, when using *PRD Evaluate*, to modify these critical values.

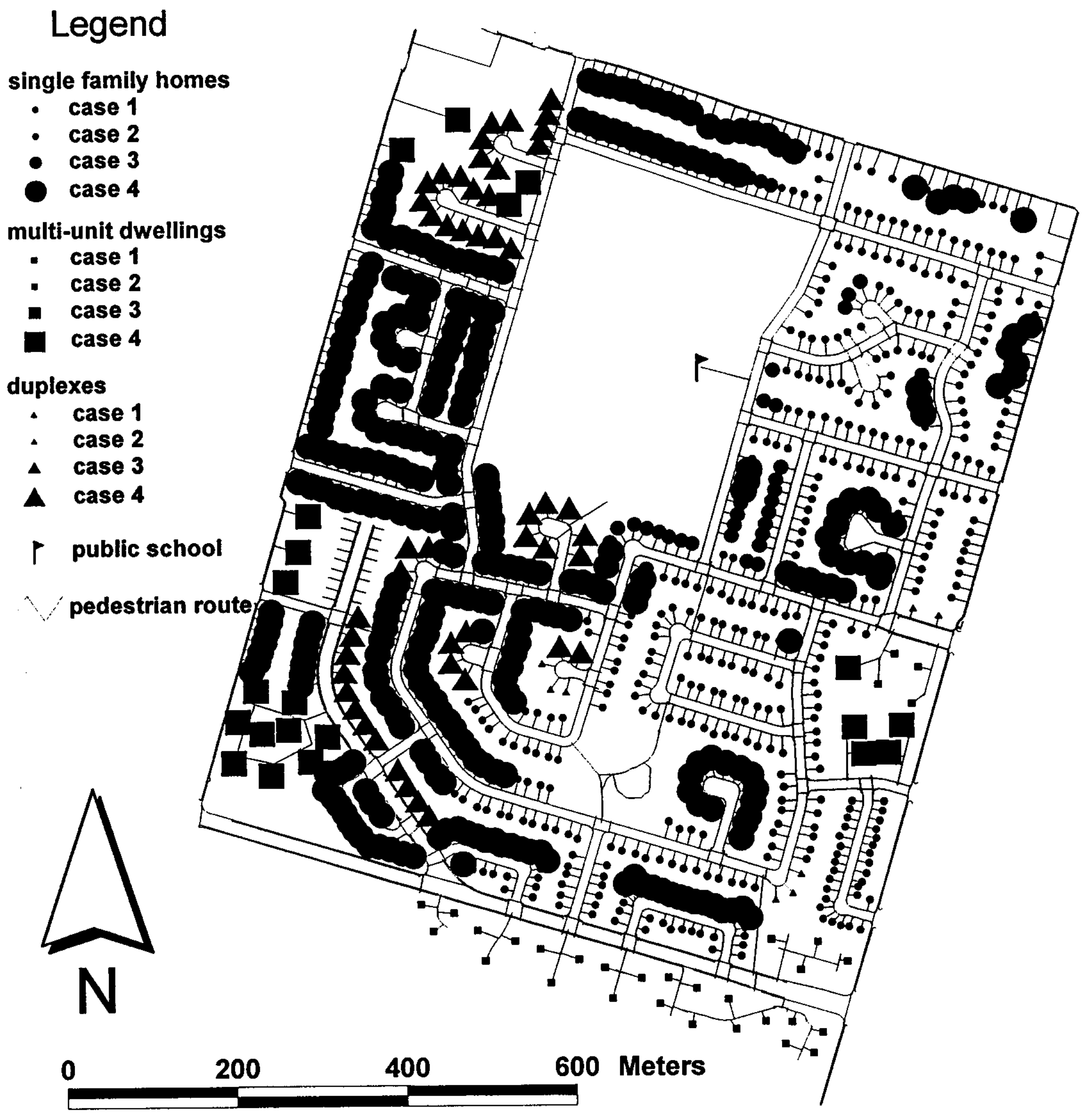


Figure 4.4: Locations of connectivity cases for "base case alternative" for Berrisfield neighbourhood

Tabulated results from the base case alternative indicate that the average route distance from residences to the public school is 744.0 m and that the PRD ratio is 1.70 (Table 4.4), both in excess of the assumed critical values. With regards to the defined connectivity cases (as shown in Table 4.2), a total of 1543 residents have acceptable pedestrian connectivity, while the remaining 1767 residents have unacceptable pedestrian connectivity. Of the former 1543 residents, it is noted that 1216 of these residents have route distances in excess of the desired 400 m (connectivity case 2 from Table 4.4). With regards to route distance, the base case alternative indicates that only 142 residential buildings (all types) of a possible 852 have a route distance less than the desired 400 metres.

Table 4.4: Results of connectivity analysis to Berrisfield's public school

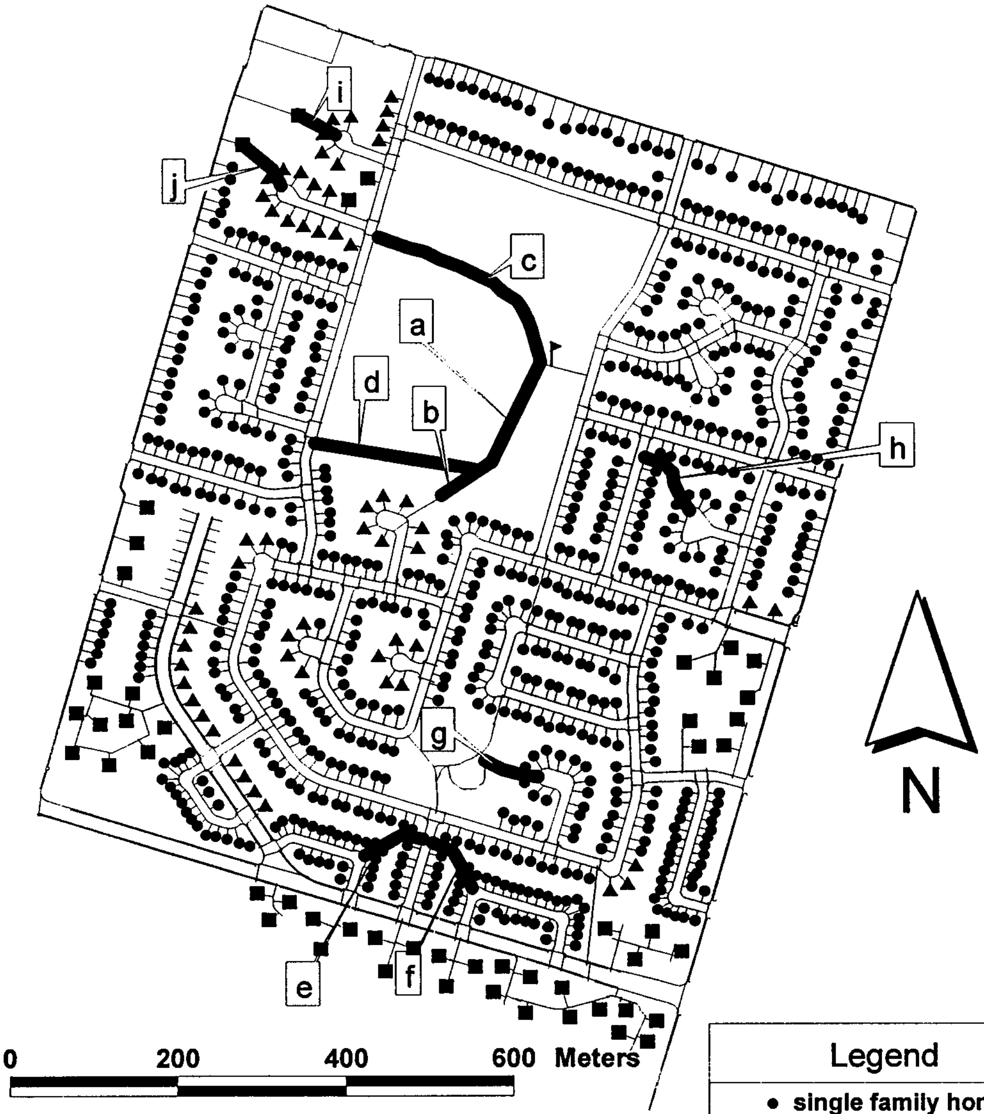
Alternative	Number of Residents Having Acceptable Connectivity		Number of Residents Having Unacceptable Connectivity		Average Route Distance (m)	Average PRD Ratio
	case 1	case 2	case 3	case 4		
base case	327	1216	99	1668	744.0	1.70
Alternative 1	382	1718	99	1111	699.3	1.60
Alternative 2	379	1368	102	1461	679.8	1.52
Alternative 3	339	1797	99	1075	682.6	1.55
Alternative 4	327	1276	99	1608	741.5	1.70
Alternative 5	437	2057	102	714	638.7	1.44
Alternative 6	467	2424	102	317	609.1	1.37

An ArcView layout is generated to help the user assess the geographic locations having unacceptable pedestrian connectivity, and to identify which locations need to be retrofitted with pedestrian network enhancements (as shown in Figure 4.4). In this example, the western portion of Berrisfield is poorly connected to its public school because of the large number of connectivity cases 3 and 4. For the eastern portion, pedestrian connectivity is much better with a few isolated exceptions. Subtle changes in measured geodetic distance, even across a street, can alter the PRD ratio sufficiently to result in one side (of the street) having acceptable pedestrian connectivity while the other side has unacceptable pedestrian connectivity. An example of this is observed in the southeast corner of the study neighbourhood (Figure 4.4).

To better the pedestrian connectivity, improvements to the pedestrian network are needed. For Berrisfield, this involves the addition of pedestrian paths to create more direct routes to the public school, thereby lowering the PRD ratio. Note that no additional sidewalks are required, since nearly all of the streets have sidewalks on both sides. For this example application, four pedestrian paths were added one at a time to the neighbourhood's pedestrian network and the improvements to connectivity were evaluated *independently* (Alternatives 1 to 4). These four paths were selected particularly to improve the connectivity of the western portion of Berrisfield (as shown in Figure 4.5). Two additional alternatives demonstrate the cumulative benefits of retrofitting several pedestrian paths into the neighbourhood. Path segments used in each of the six alternatives are shown in Figure 4.5.

New values for average route distance, PRD ratio and connectivity case frequencies are reported for each alternative in Table 4.4. Of the four independent alternatives, Alternative 2 provides the single best outcome since it produces the largest reduction in both average route distance and average PRD ratio. Average route distance was reduced to 679.8 m (a reduction of 8.6%) and average PRD ratio was reduced to 1.52 (a reduction of 10.4%). Alternative 3 also provides a good outcome with a reduction in the same two values of 8.3% and 9.0% respectively.

The reason to evaluate alternative paths independently is to allow the choice of the "best" alternative, one which provides the greatest benefit, if a municipality is unable to implement all of the available connectors. If only one path were chosen for the neighbourhood,



alternative	path segment(s) installed
Alternative 1	a, b
Alternative 2	c
Alternative 3	a, d
Alternative 4	e
Alternative 5	a, b, c, d, e
Alternative 6	a, b, c, d, e, f, g, h, i, j

Figure 4.5: Map of six alternatives considered for retrofits to pedestrian network for Berrisfield

Alternative 2 may be preferred, since it results in the most effective reduction (8.6%) in the average walking distance to the school.

The cumulative effects of retrofitting several pedestrian paths into the neighbourhood are demonstrated by Alternative 5 and Alternative 6 (as shown in Table 4.4). For example, Alternative 6 provides significant changes in both average PRD ratio and route distance to the public school, by 19.4% and 15.4%, respectively. The new paths implemented in Alternative 6 have addressed most of the "unacceptable" connectivity initially identified on the western portion of Berrisfield neighbourhood in the base case alternative (Figure 4.4). With Alternative 6, nearly all of the connectivity cases 3 and 4 have been eliminated (as shown in Figure 4.6). Only 419 residents (12.6% of total population) have unacceptable connectivity (Table 4.4), improving connectivity for approximately 40% of the neighbourhood's 3310 residents. This improvement has been achieved by the addition of 1.1 km to the pedestrian network, an increase of approximately 5% over the existing 21.2 km of paved sidewalk and paths. In total, just over 87% of the neighbourhood's population (2891 of 3310 residents) have acceptable connectivity, up from 47% prior to any modelled retrofits.

The analysis example presented in this sample application has been limited to evaluating the pedestrian connectivity between residences and the public school. When implementing retrofits, it is important they are also well-suited to other destinations. Other destinations include the high school, the two commercial properties in the northeast and northwest corners of the neighbourhood and bus stops on the surrounding arterial roads. An analysis for bus stops would provide the opportunity to review their best locations, ensuring that residents are adequately served and that reasonable walking distances to bus stops are maintained.

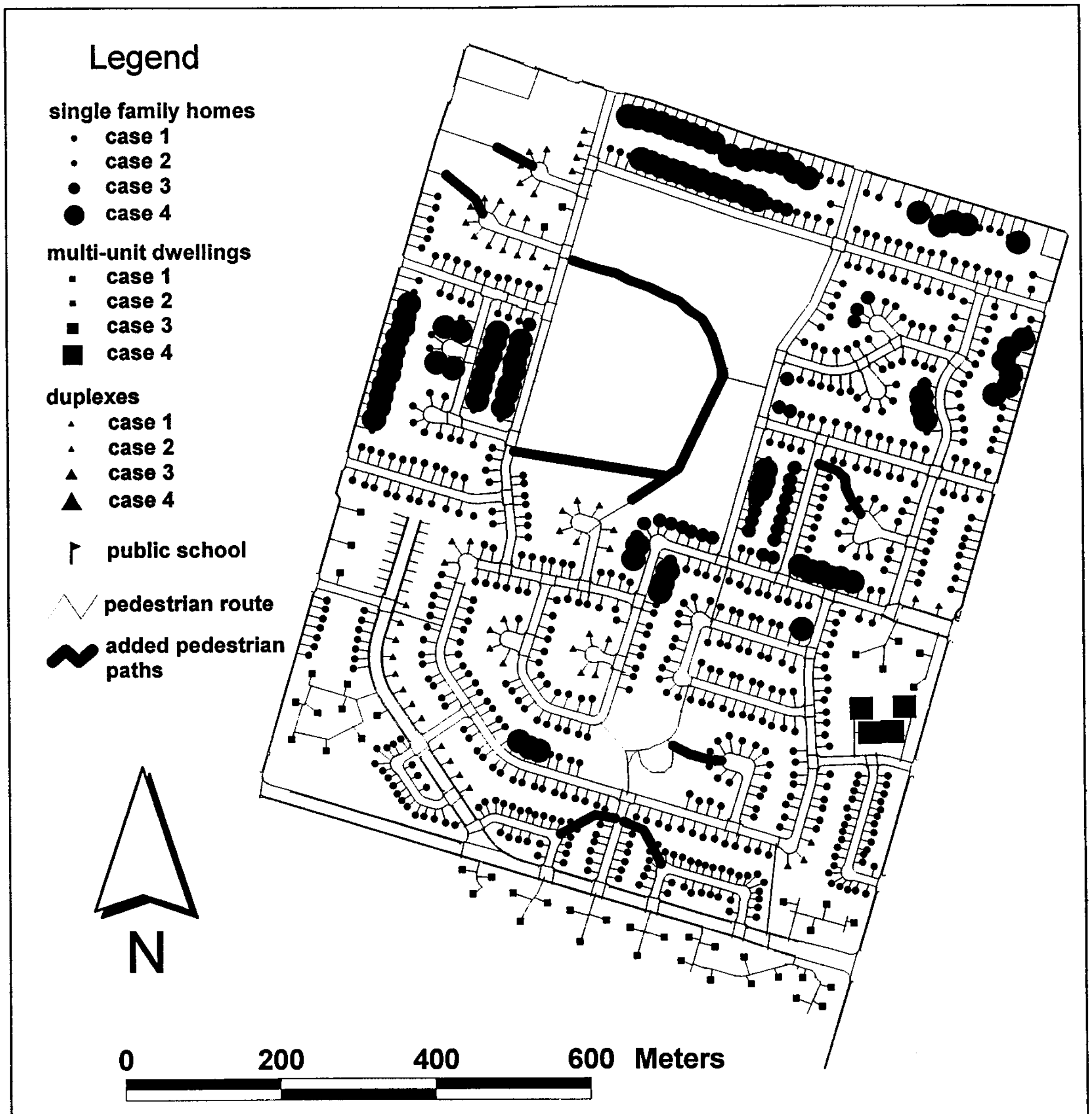


Figure 4.6: Locations of connectivity cases for Alternative 6 for Berrisfield

4.6 Conclusion

The developed ArcView extension described in this chapter is a prototype tool for planners and municipal engineers to generate and evaluate potential retrofitting alternatives for the pedestrian environment. Improvements to the pedestrian environment, through the provision of more direct and shorter routes than previously available to neighbourhood residents, may provide an incentive to reduce neighbourhood car trips and to stimulate walking trips. Increased pedestrian travel and better connections to a regional transportation network will ultimately lead to more sustainable and responsible transportation alternatives. The tool would also be useful for those planning new communities. *PRD Evaluate* would provide the opportunity to investigate a variety of road and pedestrian network layouts during the design stages, prior to any site preparation or construction. In addition, one of the benefits of mixed use zoning - the provision of destinations within acceptable walking distances of residences - could be clearly demonstrated using this tool.

The improvements to the pedestrian environment suggested by this chapter are not to be applied strictly in isolation from other neighbourhood improvements. However, on their own, pedestrian connectivity retrofits do exhibit significant merit as shown by the application to the Berrisfield neighbourhood in Hamilton, Ontario. The addition of just 1.1 km of pedestrian paths to the network resulted in acceptable pedestrian connectivity conditions for nearly 87% of total residents, up from 47% of residents prior to any retrofits.

Retrofits to the pedestrian network should be accompanied by other neighbourhood improvements. Aspects such as providing a greater variety of intra-neighbourhood destinations (e.g., commercial and employment activities) and improving the aesthetics of the street environment will also stimulate more pedestrian travel in the neighbourhood. These additional aspects are to be addressed in a more comprehensive decision support tool designed for retrofitting numerous aspects of conventional suburban development, as was discussed in chapter 3.

5. NEIGHBOURHOOD TRAFFIC CALMING

5.1 Introduction

Suburban streetscapes are commonly dominated by the automobile, often displacing other modes of transportation. Coincident with the post-war growth in automobile usage (Newman and Kenworthy, 1989), traffic congestion and volume, traffic noise and air pollution have become key issues for municipal officials and politicians. To address these issues, transportation engineers and urban planners have developed a series of initiatives aimed at reducing car use and making the streets safer and more friendly for pedestrians and cyclists (Bicknell, 1993). These are collectively known as traffic calming measures.

The definition of traffic calming, adopted by the Institute of Transportation Engineers, is "the combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behaviour and improve conditions for non-motorized street users" (Lockwood, 1997). Traffic calming is used for a variety of objectives, such as the control of traffic volumes and speeds (Cottrell, 1997; Lockwood, 1997; Sarkar, *et al.* 1997), accident and casualty reductions (Lockwood, 1997; Zein *et al.*, 1997), or when traffic conditions are out of character with their adjacent residential, institutional and recreational uses (Atkins and Coleman, 1997). A summary of the benefits and costs associated with traffic calming programs is provided in Table 5.1. The typical (negative) impacts of traffic calming are related to vehicle delay, impacts on emergency, maintenance and transit vehicles, and diversion of traffic to adjacent streets. Acceptance of these added impacts (or costs) is usually gained by including any affected parties during planning, design and implementation (Atkins and Coleman, 1997).

Table 5.1: Benefits and costs associated with traffic calming (from Litman, 1997)

Benefits	Costs
• increased road safety • increased pedestrian and bicyclist comfort • increased non-motorized travel, and reduced auto travel • local environmental benefits • increased street activity and neighbourhood interaction • increased property values • reduced suburban sprawl • more attractive streets	• project expenses • vehicle delay • problems for emergency and service vehicles, and for snow removal • traffic spillover onto other streets • problems for bicycles and visually impaired pedestrians • increased drivers' effort and frustration

Neighbourhood traffic calming has been almost exclusively applied to local and collector residential streets (Leonard and Davis, 1997; City of Portland, 1999), as this is where the majority of people live. It is not surprising then, that the quality of arterial streets (in North America) has suffered during the post-war period. Arterial streets, which may have once been lined with large trees, parked cars and full of pedestrian activity (such as the present-day arterials of Paris, London or Berlin), have been altered over the decades to increase roadway capacity (West, 2000). These streets, now lined with fast food outlets, expansive parking lots and other symbols of an automobile-based culture, have become places not worth caring about (Kunstler, 1996).

There have been recent attempts to address issues of traffic speed, safety, and streetscape aesthetics on arterial streets, despite a certain amount of pessimism (Robinson, 1999). Measures successfully installed include on-street bike and parking lanes (Macbeth, 1998a), turn and parking lanes and pedestrian refuge islands (Skene, 1999), and community gateway treatments, medians and textured crosswalk materials (West, 2000).

Traffic calming is usually installed in response to a public complaint about neighbourhood traffic. Thus, current applications tend to be retrofits into existing neighbourhoods (Leonard and Davis, 1997), rather than installations at the time of initial development. However, there are initiatives to design and build streets promoting slower speeds and incorporating facilities for bikes, transit and pedestrians. Three examples of such standards are shown in Table 5.2, with design speeds, street widths and allotted right-of-ways considerably less than those prescribed by AASHTO (1994) or TAC (1999). North American residential streets also provide considerable on-street parking, despite adequate garage and driveway capacity. There is no need to provide on-street parking - itself a traffic calming measure - unless deemed necessary for adjacent land uses. The new "narrow" standards, shown for local streets in Table 5.2, suggest there is opportunity to review street designs for suburban neighbourhoods. New standards have also been proposed for collector roads, although they are not shown here.

This chapter describes a computerized decision support tool for neighbourhood traffic calming, "NTC extension", coded for use in ArcView GIS (ESRI, 1998). The developed tool provides decision support for the implementation of traffic calming on local, collector and arterial streets. This tool is potentially useful because of the increase in academic and professional literature on the use of traffic calming measures and the growing public desire to increase the safety of neighbourhood streets. It is important to remember that traffic calming is not implemented in isolation from other transportation objectives. Through the provision of safe and efficient pedestrian and cycling networks and access to an effective regional public transit system, the traffic calming goals of reduced effects of motorized vehicles and the promotion of more sustainable modes of transportation can be realized.

Table 5.2: Existing and new "narrow" residential local street standards

Standard	Street Type	Volume (VPD)	Design Speed (km/h)	ROW (m)	Pavement Width (m)	Parking
existing	TAC local street (TAC, 1999)	< 1000	50	20	6.0 8.5 11.0	none one side both sides
	AASHTO local street (Ewing, 1999)	400 to 1500	30 to 50	15.2	8.0	none
new "narrow"	residential street (Fernandez, 1994)	500 to 1000	40	14.6	6.1 7.9 9.8	none one side both sides
	access street (WAPC, 2000)	1000	40	14 to 16	5.5 to 6	one side
	DelDOT local street (Ewing, 1999)	400 to 1500 < 500	30	12.5	5.5	none one side

The traffic calming measures utilized by the NTC tool are described in the next section, followed by a discussion of the tool's development and the benefits of using GIS for neighbourhood traffic calming. An application of the tool to a suburban neighbourhood in Hamilton, Ontario is then provided, outlining a potential neighbourhood traffic calming program.

5.2 Traffic Calming Measures Used in Urban Areas

This section contains a brief overview of the traffic calming measures available to the transportation engineer. A subset of these measures has been incorporated into the developed decision support tool. This overview is followed by a discussion on the effectiveness of traffic calming measures in achieving the objectives of traffic calming. The final paragraphs illustrate some examples of neighbourhood traffic calming plans that have been built in Canada.

5.2.1 Selected Neighbourhood Traffic Calming Measures

The most commonly described traffic calming measures are appropriate only for local and collector streets, such as those discussed by TAC and CITE (1998) and Ewing (1999). In contrast, there is neither significant discussion in the literature nor widespread implementation of traffic calming measures on arterial streets in North America. There is considerable opportunity for certain suburban arterials to be calmed of automobile traffic while promoting other modes of travel (bicycle, transit, HOV).

Embedded within the developed NTC methodology is a desire to re-think our streets as currently planned or built. Elements that are often suggested in standards such as boulevard widths, provisions for street trees, sidewalks, and pedestrian refuges are often not built. To this end, a "base case" is provided for each of the three road classes considered (local, collector and arterial). The base case is a sketch of how that particular roadway could be constructed according to current standards, with all of these other elements present. The other traffic calming measures for each road type are then assumed to be modifications to the base case configuration.

Traffic Calming Measures for Local and Collector Streets

Ewing (1999) and TAC and CITE (1998) discuss a range of traffic calming measures in use across North America, broadly classified as volume and speed control measures. Volume control measures include obstruction devices such as street closures, diverters, and intersection channelizations. Commonly applied speed control measures include speed humps, raised intersections, traffic circles, chicanes, and re-aligned intersections. Obstruction measures - for volume control - are generally not that applicable for suburban neighbourhoods since the street network (if curvilinear) may already be relatively convoluted (as compared to a grid network). Street closures in a suburban environment would generally be considered as too extreme. Signing can be an effective measure, if the number of signs is kept at effective levels, without bombarding the driver with unnecessary stops or turn restrictions. All-Way Stop Control is included in the developed tool, as it is one of the least expensive traffic calming options, although its effectiveness at reducing speed or volume has been questioned (Cottrell 1997; Ewing 1999). TAC and CITE (1998) have sub-divided traffic calming measures into four general categories: 1) vertical deflection; 2) horizontal deflection; 3) obstruction; and 4) signing. A subset of these measures is used in the current study to generate neighbourhood traffic calming plans (Table 5.3).

Table 5.3: Traffic calming measures used in this study as a subset of those described in TAC and CITE (1998)

Measures in TAC and CITE (1998)	**Measures in the NTC Extension (this study)**		**Measures in TAC and CITE (1998)**	**Measures in the NTC Extension (this study)**	
Vertical Deflection	***for locals***	***for collectors***	***Obstruction***	***for locals***	***for collectors***
raised crosswalk	✓	✓	directional closure	✓	✓
raised intersection	✓	✓	diverter		
rumble strip			full closure		
sidewalk extension			intersection channelization		
speed hump	✓	✓	raised median through intersection		
textured crosswalk		✓	right in / right out island		
Horizontal Deflection			***Signing***		
chicane	✓	✓	maximum speed	✓	✓
curb extension	✓	✓	right (left) turn prohibited		
curb radius reduction			one-way		
on-street parking			stop		
raised median island		✓	through-traffic prohibited		
traffic circle	✓	✓	traffic calmed neighbourhood		

A total of 21 measures are included in the NTC extension for local and collector streets (Table 5.4). These provide varying benefits in terms of speed and volume reduction or enhancement of the cycling and pedestrian environment. The relative magnitude of this benefit is rated (by TAC and CITE 1998) as either "significant" or "minor", although the benefit may not necessarily be quantified. Where sufficient data are available from this and other sources such as Ewing (1999), tables of quantified benefits are available to the user of the NTC extension. Traffic calming installation costs vary widely. Some per unit costs are provided in Table 5.5. Examples of extensive neighbourhood traffic calming programs, shown later in section 5.2.3, can cost municipalities in excess of $100,000 per block.

Table 5.5: Costs for select traffic calming measures in Canadian dollars (From TAC and CITE, 1998)

measure	per unit cost ($)
chicane	10,000 to 100,000
curb extension	3,000 to 10,000
landscaped median island	5,000 to 10,000
raised crosswalk	2,000 to 10,000
raised intersection	20,000 to 75,000
speed hump (parabolic)	1,000 to 5,000
speed hump (flat-topped)	2,000 to 5,000
traffic circle	5,000 to 30,000

Traffic Calming Measures for Arterial Streets

The installation of traffic calming measures along arterial streets is a relatively new and controversial idea in transportation engineering (Macbeth, 1998a; Robinson, 1999). Many of the measures applicable to local and collector streets cannot be used on arterial streets because of their higher design speeds and volumes, larger design vehicles (e.g., buses), and the use of arterial streets by emergency and transit services (Leonard and Davis, 1997). Calming measures on arterial streets are substantially different than measures on local or collector streets because humps, chicanes and diverters are not feasible (Robinson, 1999). Experience of calming higher order streets comes largely from Europe, employing devices such as "lateral roadway shifts" and re-allocation of the right-of-way in favour of alternative transportation

Table 5.4: Traffic calming measures used in the NTC extension

Local Streets		**Collector Streets**		**Arterial Streets**	
Code	Description	Code	Description	Code	Description
L1	Base Case Configuration	C1	Base Case Configuration	A1	Base Case Configuration
L2	Raised Crosswalk	C2	Raised Crosswalk	A2	Add Continuous 2-Way Turn Lane and Bike Lanes
L3	Raised Intersection	C3	Raised Intersection	A3	Add One Parking Lane, Bike Lanes and Landscaped Median Islands
L4	Speed Hump (parabolic)	C4	Speed Hump (flat-topped)	A4	Add Two Parking Lanes and Shared Curb Lane
L5	Chicane (1-lane)	C5	Textured Crosswalk	A5	Add Two Parking Lanes and Bike Lanes
L6	Curb Extension	C6	Chicane (2-lane)	A6	Designate HOV/Transit/Bike Lane and Add Landscaped Median
L7	Traffic Circle	C7	Curb Extension	A7	Designate HOV/Transit Lane and Add Bike Lanes and Landscaped Median
L8	Intersection Channelization	C8	Landscaped Median Island	A8	Pedestrian Crosswalks with Flashing Light
L9	All-Way Stop Control	C9	Traffic Circle		
		C10	Intersection Channelization		
		C11	All-Way Stop Control		
		C12	Stripe Bike Lanes		

Note: Base case configurations are designed using existing street standards.

modes (Ewing, 1999). Design speeds on traffic calmed urban arterials in Europe are 50 kph as compared to 60 kph or greater in North America (AASHTO, 1994; TAC, 1999). Calmed designs have also been implemented in Europe for 2-lane arterials with high daily volumes of through traffic (> 13,000 vehicles per day) (Ewing, 1999).

Taking North American and European experience into consideration, the traffic calming measures considered in this paper for arterial streets have the following goals:

- narrow the travelled portion of an arterial street, through lane and lane width reductions, so that speeds are reduced;
- provide horizontal deflections, such as raised median islands and on-street parking, to reduce speeds;
- encourage more sustainable modes of transportation by prioritizing access for cyclists, public transit, and carpool vehicles;
- improve the aesthetics along arterial streets through landscaping medians and boulevards, and;
- provide safe roadway crossings for pedestrians.

Eight traffic calming measures have been developed for arterial streets to meet the above goals (Table 5.4). Six of the measures are reconfigurations of a current 4-lane arterial street, having travel lane widths of 3.5 m and provision for boulevards and sidewalks. These meet the AASHTO (1994) and TAC (1999) standards for an undivided urban arterial (design speed of 60 km/h), and provide sufficient room for street trees and other landscaping.

Two examples of reconfigured arterial streets are shown in Figure 5.1. Traffic calming measure "A3" removes a travel lane in each direction, providing enough space for bike lanes, a parking lane and raised median islands (Figure 5.1A). This is an appropriate option where there is sufficient demand for on-street parking. Low maintenance landscaping would be added in the median islands and in locations to protect parked cars. Note that the initial 4-lane configuration is maintained at signalized intersections, allowing the intersections to function at volumes similar to the pre-calmed arterial (Macbeth, 1998a). Traffic calming measure "A7" is

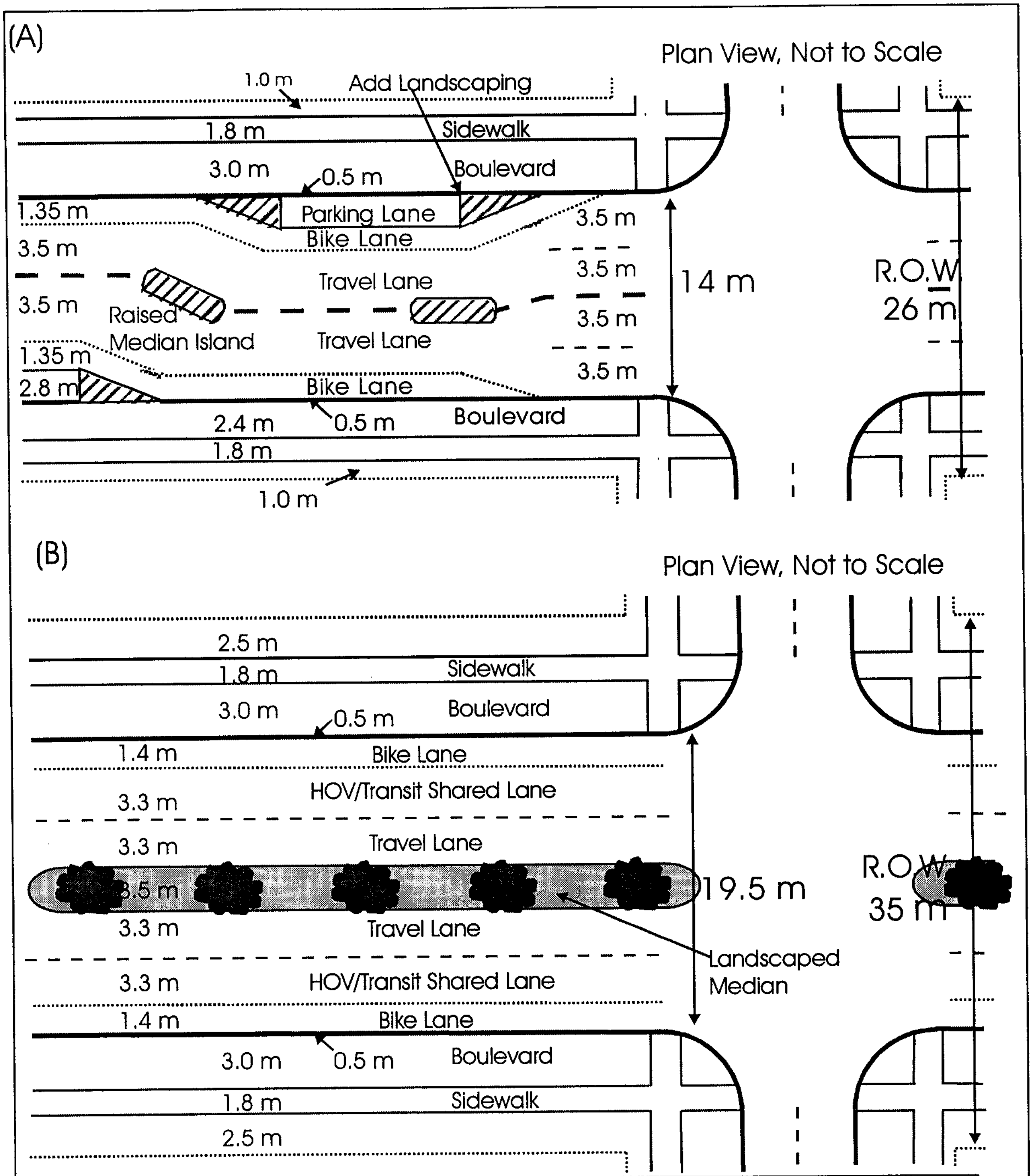


Figure 5.1: Plan view for arterial traffic calming measures A3 (top) and A7 (bottom)

applicable for an arterial street having a ROW of at least 35 m (Figure 5.1B). In this case, the width is sufficient to install a landscaped median down the centre of the arterial, and add bike lanes in each direction. Multi-modal use along this arterial would be facilitated through the designation of a shared HOV/transit lane and bike lanes.

The calming of arterial streets needs to be accompanied by other retrofits in a suburban neighbourhood if it is to be successful and receive public support. Calming arterial streets will only function if other modes of transportation are improved along these corridors, in particular provision and management of transit. Otherwise, street narrowing and lane reductions will only lead to greater congestion, noise and air pollution (Gattis and Watts, 1999). Furthermore, land use in suburban developments must provide local destinations to the resident that can be reached on foot or by bicycle. In conclusion, the list of traffic calming measures used in the NTC extension is not exhaustive. Those considered for local and collector streets are more commonly installed and have documented evidence of their effectiveness (TAC and CITE, 1998; Ewing, 1999). For arterial streets, many more potential configurations (such as those shown in Figure 5.1) could have been generated. Limiting the number to eight was deemed appropriate for a prototype version of the decision support tool.

5.2.2 Effectiveness of Traffic Calming Measures

Traffic calming measures are only effective when implemented as “area wide traffic calming” rather than calming individual streets. If the latter is done, traffic simply shifts to another route through the neighbourhood, assuming one is available. It is important that the area of planning and implementation not be too large, since it is difficult to achieve a consensus amongst impacted residents with too large an area (Ewing and Kooshian, 1997). The City of Portland has extensive experience in traffic calming and has established the neighbourhood as the optimal scale for planning and implementation (Ewing and Kooshian, 1997).

As stated earlier, the main objectives of traffic calming include reduced traffic volume and speed in the study area, and an increased level of safety for pedestrians, cyclists and motorists. A successful traffic calming program will commonly result in a shift from one mode (auto) to another (transit, walking, cycling), or the diversion of traffic from one route (local street) to another more appropriate route (collector street) (Leonard and Davis, 1997). Traffic calming programs can also lower accident rates and associated insurance costs significantly, while providing greater survival rates in pedestrian-auto and cyclist-auto collisions (Zein *et al.*, 1997; Macbeth, 1998b). The following paragraphs discuss the effectiveness of the described traffic calming measures in meeting these objectives.

Zein *et al.* (1997) report quantifiable and significant safety benefits as a result of traffic calming programs implemented for four neighbourhoods in Greater Vancouver. Traffic calming reduced average collision frequency and collision claim costs by 40% and 38% respectively (Table 5.6). However, since the study was funded by the provincial insurer (Insurance Corporation of BC), emphasis was placed on the aforementioned results (Table 5.6) and not on the collision rate nor the reduced speed achieved by the traffic calming programs (Zein *et al.*, 1997). It is not known, for example, whether the collision costs are reduced simply due to the reduced volume or if the reduction in cost is due to a decrease in the collision rate. If it is the latter case, traffic calming was able to produce safer road conditions. Zein *et al.* (1997) also reported on the safety benefits of traffic calming achieved internationally. Most traffic calming programs, they report, could pay for themselves in less than 2 years, due the savings in reduced collision costs. They also estimate that 200 to 300 lives and 15,000 injuries could be prevented annually if all of the local authorities in the UK were to "vigorously implement" traffic calming programs.

Table 5.6: Safety benefits of traffic calming measures implemented in four neighbourhoods in greater Vancouver (Compiled by Zein *et al.*, 1997)

Neighbourhood	**Change in Collision Frequency**	**Change in Annual Collision Claim Cost**
Vancouver - West End	-18 %	-10 %
Vancouver - Mt. Pleasant	-46 %	-37 %
Burnaby - Willingdon Parker	-60 %	-48 %
New Westminster - Kelvin North	-34 %	-57 %
AVERAGE	**-40 %**	**-38 %**

In addition to accident and casualty reduction statistics, there are quantified speed and volume benefits for select traffic calming measures. Extensive summaries on these benefits are provided in TAC and CITE (1998) and Ewing (1999). The amount of data for each type of measure varies since some have widespread use while others have only been recently introduced and have not been tested. Examples of those in widespread use include parabolic speed humps and traffic circles. Thus, there are numerous reports on their effectiveness in the literature. Tables 5.7 and 5.8 represent a sample of data available for speed and volume reductions achieved through the use of parabolic speed humps on local streets. Other measures have not been applied widely or have yet to be tested, such as the proposed arterial calming measures (Table 5.4), and little or no quantified benefit records exist. Data are not statistically representative for all of the traffic calming measures, as many types of measures have yet to be fully field-tested. Since speed humps have been most widely installed, it stands to reason that much of the available speed and volume reduction data are for this measure. Such data are made available to the user of the NTC extension, described later in section 5.3.

Table 5.7: Measured change in 85th percentile speeds achieved on local streets using parabolic speed humps. Speeds are those measured between the humps.

Location	No. of Humps	Spacing (m)	Traffic Speed (km/h) Before	After	Change (km/h)
Ottawa (1)	one pair	50	45	34	-11
Ottawa (1)	one pair	50	44	34	-10
Toronto (1)	9	60-78	47	38	-9
Toronto (1)	9	68-95	44	38	-6
Toronto (1)	7	65-77	46	38	-8
Toronto (2)	-	-	47	32	-15
Toronto (2)	-	-	48	32	-16
Scarborough, ON (1)	2 pairs +1	137-160	-	41	n/a
Sherbrooke, QC (1)	4	120-170	75	60	-15
Thousand Oaks, CA (1)	6	76-122	61	27	-34
Thousand Oaks, CA (1)	6	134-174	69	48	-21
Maryland (3)	-	-	61	43 to 46	-15 to -18
Maryland (3)	-	-	64	45	-19
Bellevue, WA (1)	2	104	62	43	-19
Bellevue, WA (1)	3	67	57	40	-17
Bellevue, WA (1)	4	176-183	59	41	-18

Sources: (1) TAC and CITE (1998); (2) City of Toronto (1997); (3) Walter (1995).

Table 5.8: Measured change in traffic volume on local streets achieved using parabolic speed humps. Volume is measured in "vpd" (vehicles per day).

Location	No. of Humps	Spacing (m)	Traffic Volume (vpd) Before	After	Change (vpd)
Scarborough, ON (1)	2 prs +1	137-160	5615	3840	-1775*1
Sherbrooke, QC (1)	4	120-170	2500	2125	-375
Toronto (1)	9	60-78	1200	1000	-200
Toronto (1)	9	68-95	1800	1600	-200
Toronto (1)	7	65-77	2200	1600	-600
Bellevue, WA (1)	2	104	800	540	-260
Bellevue, WA (1)	2	122	3685	2930	-755

Source: (1) TAC and CITE (1998).
Notes: (*1) traffic volume on adjacent streets increased by the same amount as this reduction.

All-Way Stop Control (AWSC) has often been used as a traffic management tool in urban and suburban neighbourhoods. A study by Cottrell (1997) demonstrated that AWSC provides significant benefits in reducing cut-through traffic through the study area but not significant speed reduction benefits. This confirms the generally-accepted view that AWSC is an ineffective traffic calming measure for reducing speed in neighbourhoods (Ewing, 1999).

5.2.3 Examples of Traffic Calming Programs

This section discusses some traffic calming programs which have been implemented in Canada. They are similar to the types of plans that can be generated using the NTC extension discussed later in section 5.3. A successful traffic calming program usually includes a combination of the following design features (City of Toronto, 1994):

- changes to the horizontal and/or vertical alignment of the roadway;
- road or lane narrowings;
- changes of roadway surface texture or colour; and
- increases in vegetation (including tree cover and ground cover).

With the growth in traffic volumes over the last several decades and the concerns for safety on neighbourhood streets, many jurisdictions in Canada, the US, the UK and Australia are now actively installing traffic calming devices into existing neighbourhoods (Ewing and Kooshian, 1997; Evans, 1994; Bicknell, 1993). In many ways, transportation engineers in these jurisdictions are just catching up to the work done in the Netherlands and Germany on prioritizing pedestrians and cyclists over motorists on neighbourhood streets (e.g., as embodied in the Woonerf or "living street"; Hough, 1995).

Traffic calming programs commonly use a number of measures together, instead of installing exclusively one measure. The Balliol Street project in Toronto (Figure 5.2) is a good example. Here, a 3-block length of the street was narrowed, at both intersection and mid-block

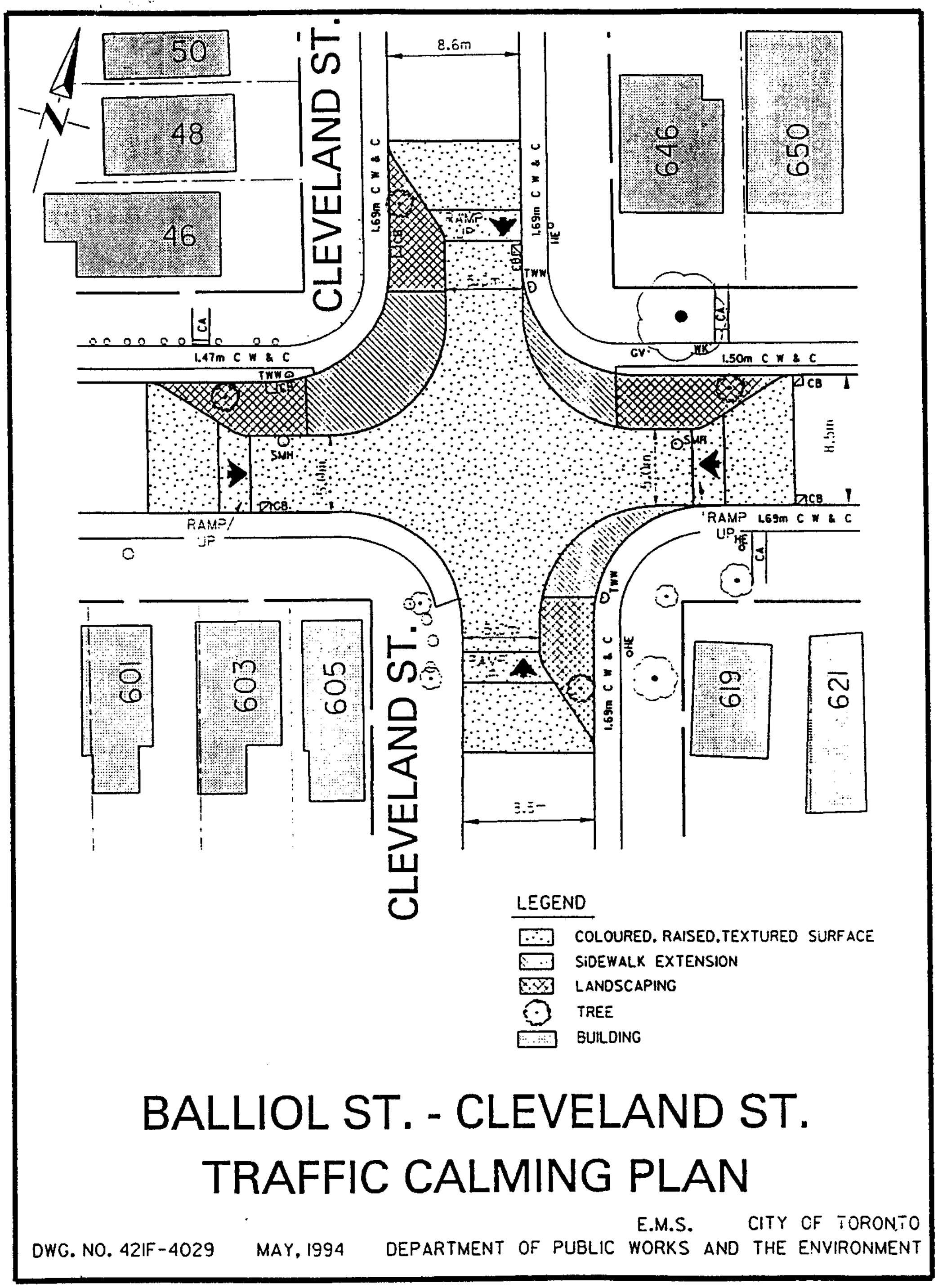


Figure 5.2: Plan view of calmed intersection along Toronto's Balliol Street (From Macbeth, 1998b)

locations, using curb extensions and landscaping. Shorter crossing distances and the use of textured paving materials on the raised-ramp intersection enhanced the pedestrian access on the street. No speed humps, other than raised table intersections, were installed on Balliol Street. Fire hydrants were moved to the curb extensions so that a maximum amount of on-street parking could be preserved, a key concern of local residents. Speed reductions of 85th percentile speeds achieved on Balliol Street were on the order of 23%, to speeds of 32 km/h at mid-block locations. Of particular interest was that emergency service providers approved the Balliol design (Macbeth, 1998b).

Another example of extensive neighbourhood modifications is the traffic calming project in Vancouver's West End, done in the early 1980's (Figure 5.3). Here, the program included the closure or diversion of a number of streets in the neighbourhood, and numerous traffic circles and travel restrictions (one-way streets and turn islands). Pedestrian and cycling access were maintained since the constructed barriers diverted vehicular traffic only. These obstructions and closures have been effective at reducing cut-through traffic in the neighbourhood (Zein *et al.*, 1997).

More locally, an example of a traffic calming project on an arterial road was recently completed in the Region of Hamilton-Wentworth. Rousseaux St. is an two-lane arterial road connecting Ancaster's principal main street (Wilson St.) to Mohawk Road and the Lincoln Alexander Expressway. Construction of the expressway together with big-box store development in the Meadowlands complex produced increased pressure on Ancaster's arterial roads to and from West Hamilton and Dundas. The calming devices implemented on Rousseaux St. include the installation of intermittent landscaped median islands and the striping of unmarked cycling lanes. Neighbourhood aesthetics were addressed not only by the islands, but by reconstructing the curbs on both sides of the road and adding new sidewalks and lamp posts (Figure 5.4).

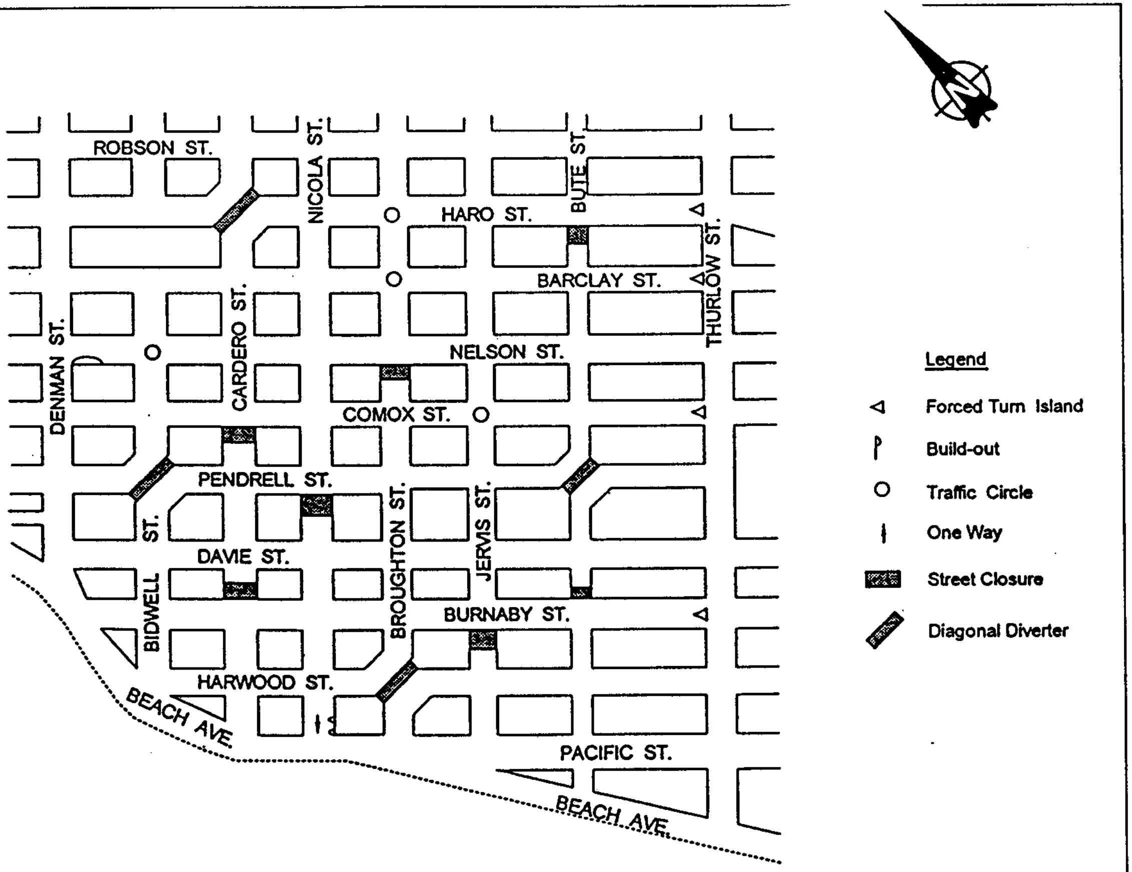


Figure 5.3: Traffic calming plan for Vancouver's West End, showing the use of various measures (From Zein *et al.*, 1997)

Both the Balliol St. and West End projects discussed above required substantial financial resources, particularly Balliol ($750,000 for 3 blocks of traffic calming, or $250,000 per block). The West End area involved approximately 54 blocks at a cost of approximately $139,000 per block. More modest traffic calming projects include the use of speed humps, stop sign installations, turning restrictions and traffic circles, at substantially lower costs (e.g., see Table 5.5). For example, four blocks of Toronto's Glengrove Avenue was calmed in the vicinity of a public school using 10 sinusoidal speed humps (Figure 5.5). The cost of this installation would have been on the order of $15,000, assuming a per unit cost of $1500 including signing and marking (City of Toronto, 1994). Although the more expensive options may be more aesthetically attractive and thus more desirable to residents, their costs mean that traffic calming cannot be implemented over a large area at the present time. Thus, the cheaper (but still effective) options may suffice for short term calming. More extensive calming, as was done on Balliol Street in Toronto, could be done together with future street reconstruction projects.

Figure 5.4: Traffic calming installed along Rousseaux Street, Ancaster, ON

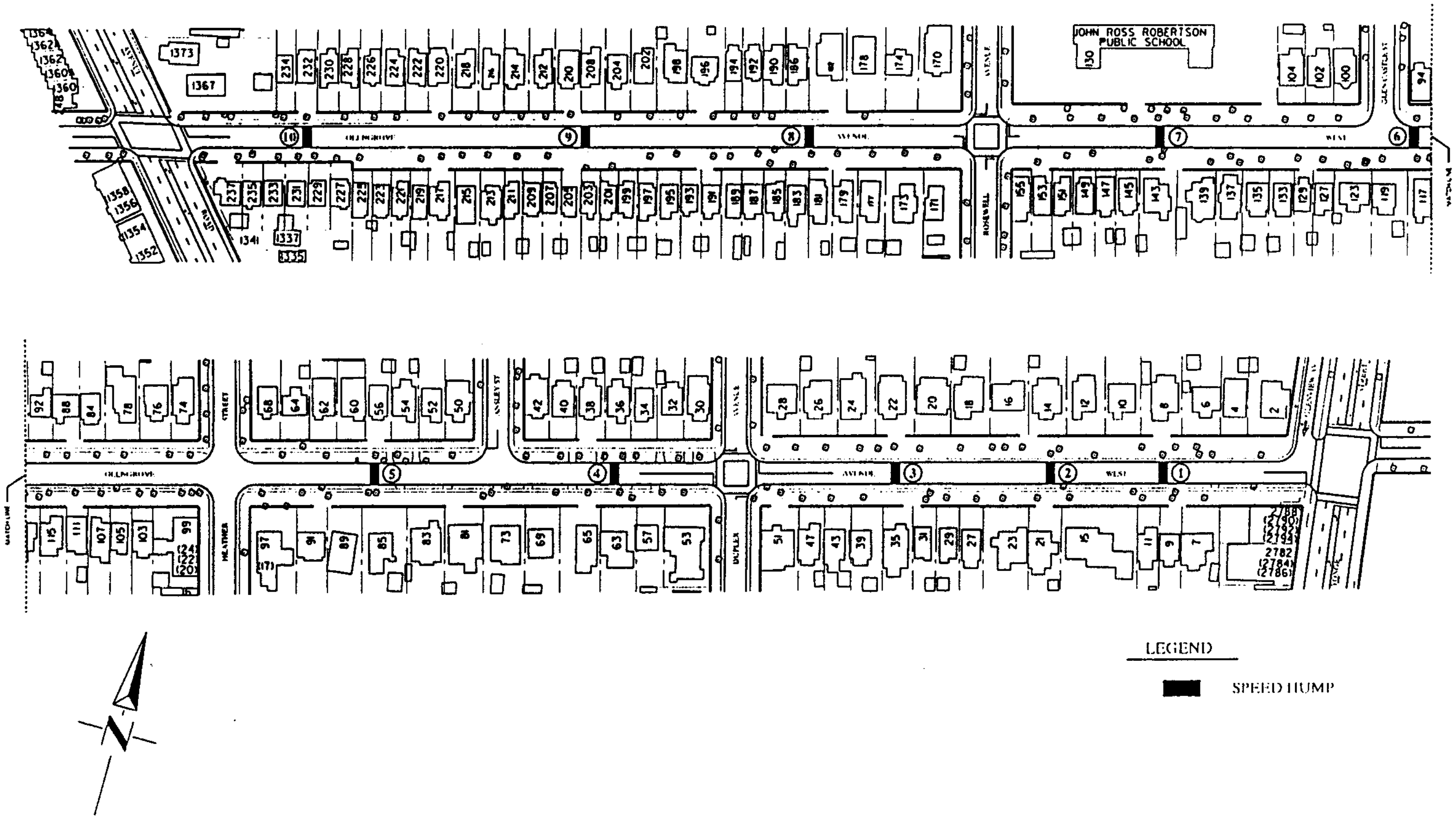


Figure 5.5: Proposed speed hump installation along Toronto's Glengrove Avenue (From Macbeth, 1998b)

5.3 Development of Related ArcView Extension

This section describes the development of the second (of three) ArcView GIS extensions that provide decision support for suburban retrofitting. This extension, called *Neighbourhood Traffic Calming* (NTC), has been created to provide decision support for selecting and locating traffic calming measures. Through the use of this tool, a user is able to generate alternative scenarios that could be implemented as neighbourhood traffic calming programs. The NTC tool provides suggestions to reduce speed and volume and to prioritize safety and facilities for pedestrians, cyclists and transit. The following paragraphs summarize the structure, input requirements and operation of this extension. An overview of the extension's algorithm is provided in Figure 5.6. A manual describing how to use the NTC extension is provided as Appendix C.

Structure

The NTC extension is constructed around a list of menu options that carry out the key tasks in evaluating the need for, and the implementation of, neighbourhood traffic calming. The NTC extension has been coded exclusively in ArcView, using its own programming language, Avenue (ESRI, 1998). Dialog boxes are used throughout to provide explanations to the user of the steps to follow, and to disseminate information about traffic calming measures in both text and visual forms. The design of the extension is such that information, whether it be text, sketch, photo or tabulated information, is easily added or altered. Hence, updated versions are readily created.

Input Requirements

The data inputs to utilize the NTC extension consist of two key parts. The first is an ArcView shape file representing the street network's road centreline position. This input theme

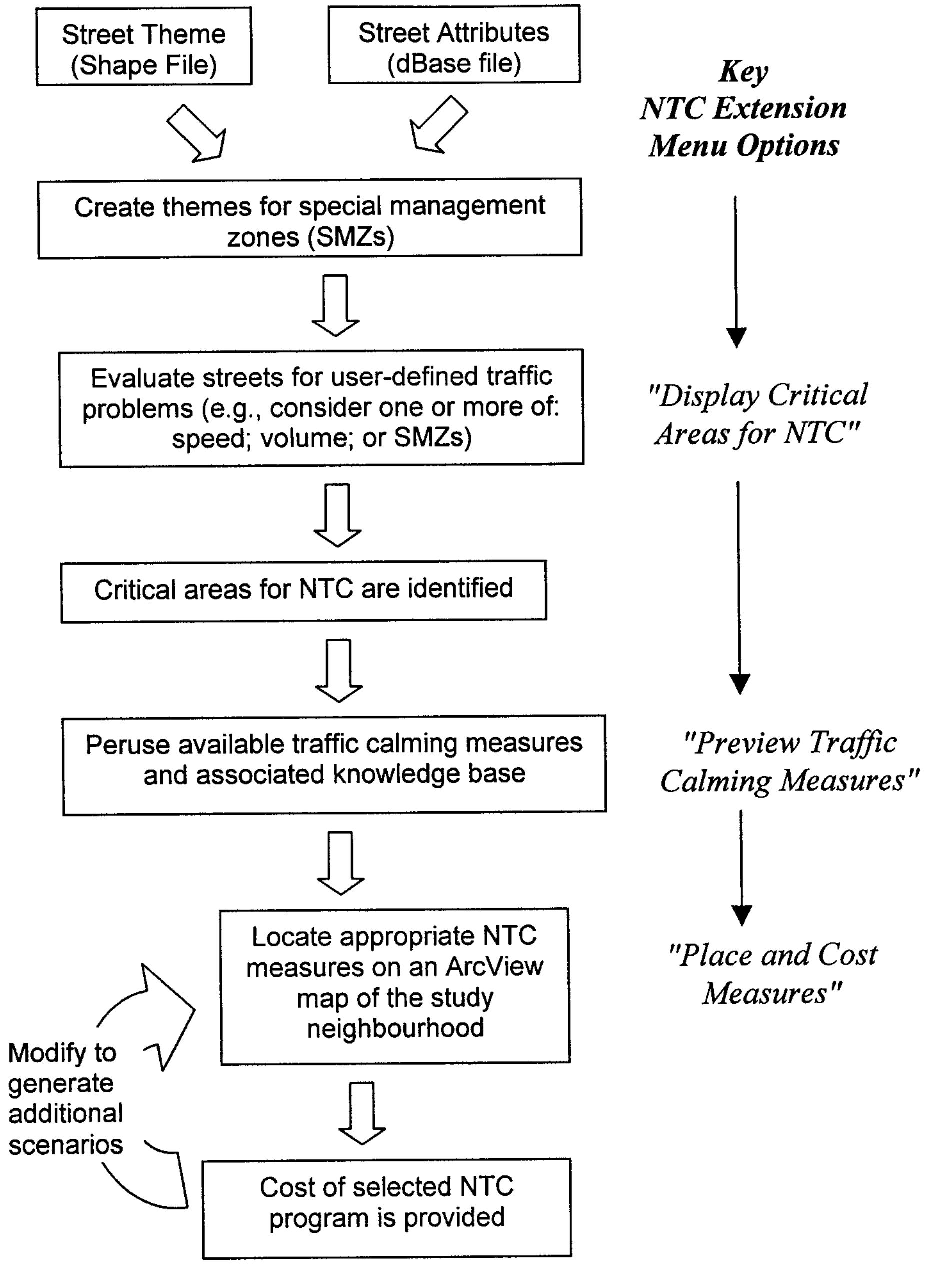


Figure 5.6: Conceptual model for the Neighbourhood Traffic Calming extension

should have an associated attribute table with fields for segment identification number and segment length. The second input is a database file containing a number of attributes of the street's individual segments as well as their measured traffic data. Each record in this file should include the following fields: identity label; street type; street ROW width; the number of travel and parking lanes, 85th percentile speed, and daily traffic volume. In addition, a field entitled "pub_req" should exist so that a request for calming received from the public can be indicated. The database file and theme attribute table are ultimately linked (Figure 5.6).

In addition to the above information, the user should have knowledge of any special management zones (SMZs) in the study area. The NTC extension is designed to include a SMZ theme for each of: school zones; playground zones; high pedestrian zones; transit routes; and emergency vehicle routes. The user will be prompted to create themes for any or all of these SMZs if so desired, as these impact the choice of traffic calming measures.

Operation of the Extension

The operation of the NTC extension is described using the three key menu options shown in Figure 5.6. Firstly, given that the user has all the required themes and associated data, the first step in the process is to "Display Critical Areas for NTC". Identified critical street segments are of three types:

- measured 85th percentile speeds exceeding the desired speed limit;
- daily traffic volumes exceeding a desired design traffic volume;
- road segments which have received requests for traffic calming.

A new map is created in this evaluation step showing problem segments (i.e., one or more of speed, volume or public complaint). The locations of the special management zones are also highlighted, since these may prohibit the use of certain traffic calming measures. In addition, the user is told the number and length of street segments requiring some form of traffic calming based on the evaluation criteria.

Once the problem areas have been located, the user then selects the "Preview Traffic Calming Measures" menu option. Here, the user can preview a series of dialog boxes providing a wide variety of descriptive and visual information. Descriptive information, based largely on Ewing (1999) and TAC and CITE (1998), includes a brief outline of the measure, its intended benefits and other measures that might be considered for simultaneous installation to increase effectiveness. Negative impacts, locations to avoid, and approximate installation costs are also presented. In total, the system provides information about 29 available traffic calming options (Table 5.4). Visual information provided includes sketches of measures (plan views and cross sections), as well as photographs of sample installations. Tabulated benefits, in terms of volume and speed reduction, and design details of specific measures are also provided for measures where such information is available.

In the third key menu option, "Place and Cost Measures", the user is prompted to select traffic calming measures and add them to the map created during the evaluation process. Once the measures have been digitized, the user is then able to view a summary of the anticipated cost of the proposed neighbourhood traffic calming plan. A range of costs is generally provided because of the variability in cost for each particular measure. Some example costs were shown in Table 5.5.

During the decision process in locating measures, the user is encouraged to make the following considerations when weighing the various options:

- calm school, playground and high volume pedestrian zones;
- make allowances for bikes on major collector and arterial streets; and
- prioritize access for transit on arterial streets.

The first point highlights the safety aspect of implementing traffic calming. Young children in the vicinity of schools and playgrounds are not fully cognizant of the potential dangers of approaching motor vehicles. The latter two points are part of an overall objective to reduce automobile dependence of suburban neighbourhoods. To achieve some reduction in automobile dependence, facilities must be provided for cycling and transit.

5.4 Application of Developed Extension

The NTC extension was applied to a suburban neighbourhood in Hamilton, Ontario. An application is provided to demonstrate the use of the extension in evaluating the need for traffic calming and generating a neighbourhood traffic calming plan.

Neighbourhood Description

The selected neighbourhood - Huntington - is characteristic of those constructed in the area since the 1960's. Huntington is defined by three 4-lane urban arterial roads on its north, west and south sides, and by a 2-lane urban arterial to the east (Figure 5.7); all have a posted speed limit of 50 km/h. The neighbourhood was built like many of its contemporaries, primarily as "bedrooms" for workers employed elsewhere in the region. Land use is zoned primarily for residential development, although small parcels are available for limited commercial activity, school buildings, churches and a community centre. Apartments and townhouses are placed around the neighbourhood perimeter, while the interior is reserved almost exclusively for single family dwellings.

The physical plan of Huntington shows the use of cul-de-sacs and curvilinear segments to provide quiet residential streets (Figure 5.7). There is a small resemblance to a more traditional grid network, although few of the local streets meet the surrounding arterial roads - a key criterion of the grid pattern. In addition to the bordering arterial streets, the neighbourhood has two primary collector streets: Broker Drive and Upper Kenilworth Avenue. Currently a total of ten intersections in the neighbourhood are signed for All-Way Stop Control (AWSC), a common response of municipal traffic engineers to speeding and cut-through traffic in neighbourhoods, despite their generally accepted ineffectiveness for speed or volume reduction (Cottrell, 1997; Ewing, 1999). It is likely that AWSC was installed in an attempt to reduce traffic speed and increase driver awareness of young school-aged pedestrians in the vicinity of the neighbourhood's two schools.

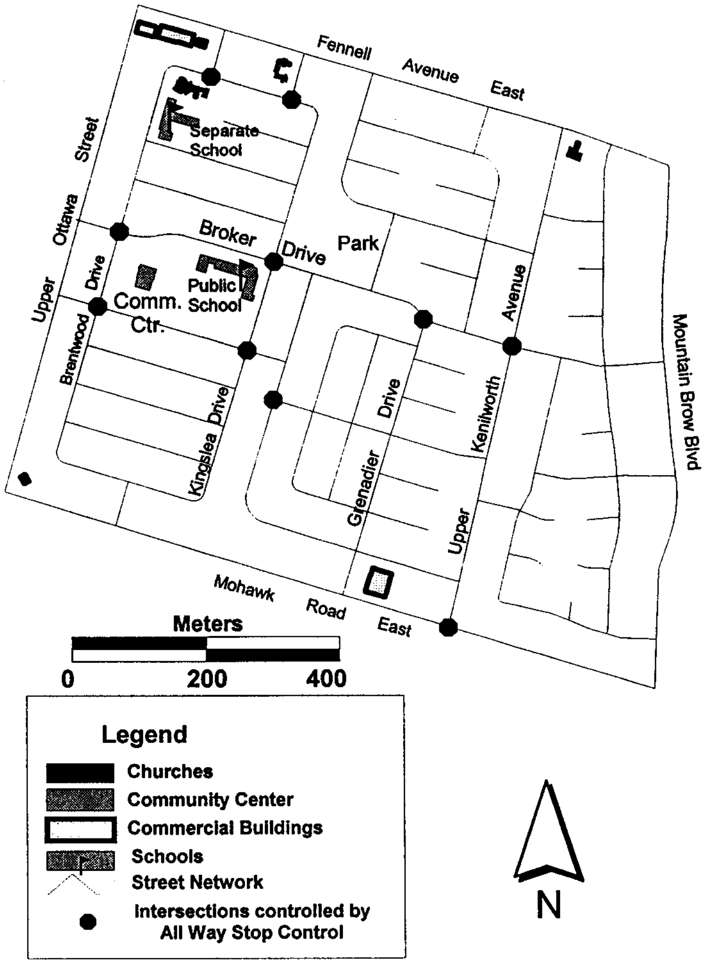


Figure 5.7: Map of the Huntington study neighbourhood

Available Data

To demonstrate the use of the NTC extension, the necessary data for the Huntington neighbourhood have been compiled. Road attribute variables, such as segment type, paved width and ROW width, have been measured whenever possible. Traffic flow variables, such as 85th percentile speed and daily traffic volumes, have been assumed rather than measured. The use of assumed data does not affect the illustration of the capabilities of the tool, but the reader is cautioned that the results of this example will not represent the actual traffic conditions in the Huntington neighbourhood.

Special management zones are a key input for the NTC extension. For use in this example, all five possible zones are included. Assumptions about the locations of designated emergency vehicle routes and high pedestrian zones have been made to augment knowledge about school and playground zones, and existing transit routes.

Analysis

Based on data for the Huntington neighbourhood, a number of traffic calming problems are identified for all three levels of the road hierarchy. Design values used to identify these speed and volume problems are shown in Table 5.9. The map of traffic calming problems (Figure 5.8) highlights those road segments having a particular problem or having received a request for traffic calming from a resident. Details about the number and length of roadway segments requiring some form of traffic calming treatment are provided to the user, as is information about any potential conflicts with special management zones (see Figure 5.8). In particular, traffic calming is desired along Broker Drive in the vicinity of the public school and the park, to address speed and volume problems. In this same stretch of Broker Drive, the map

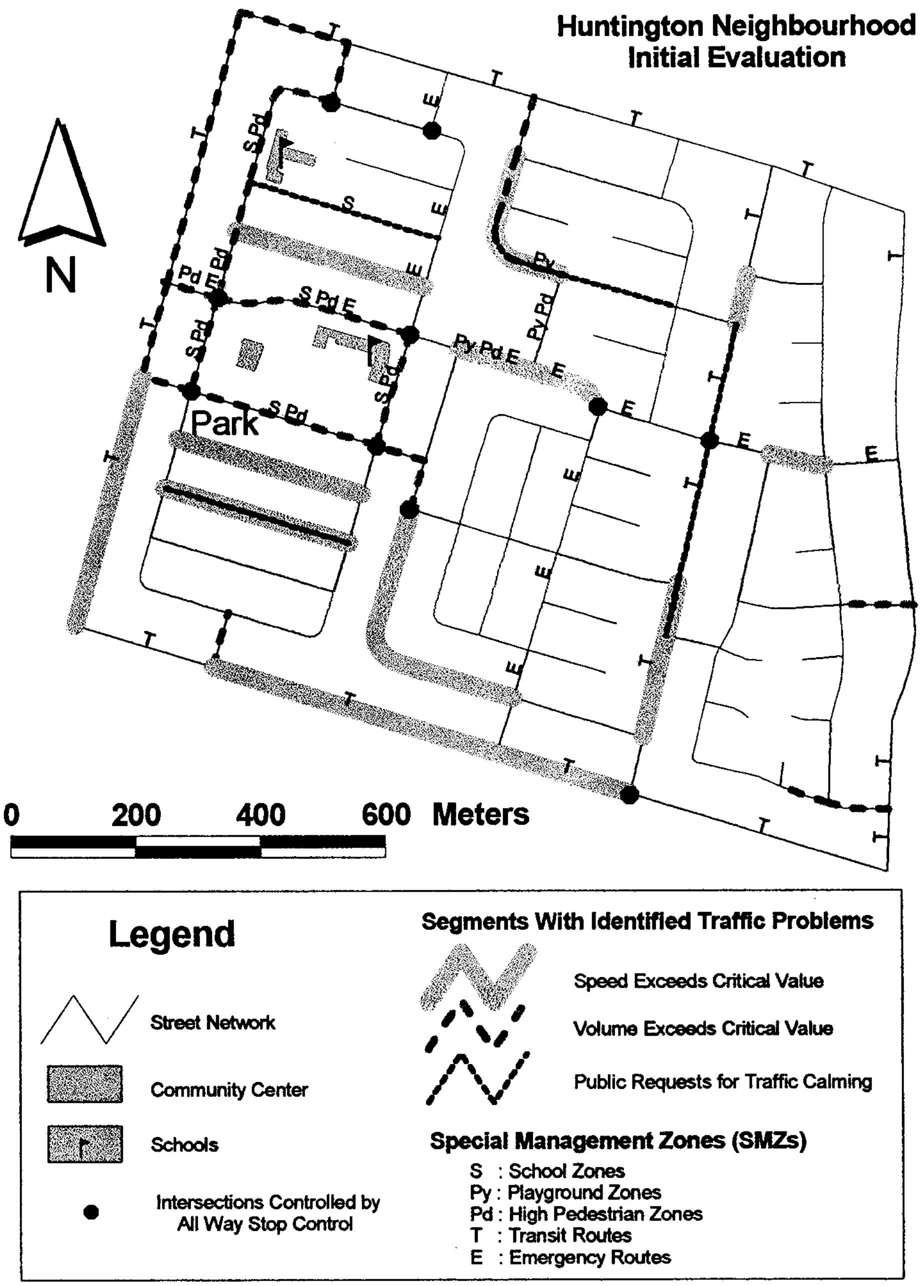


Figure 5.8: Map of the initial evaluation of the Huntington neighbourhood, highlighting the traffic calming issues and potential conflicts with SMZs

illustrates to the user that the road is also a designated emergency route (E), a school zone (S), a playground zone (Py) and a zone with high pedestrian activity (Pd).

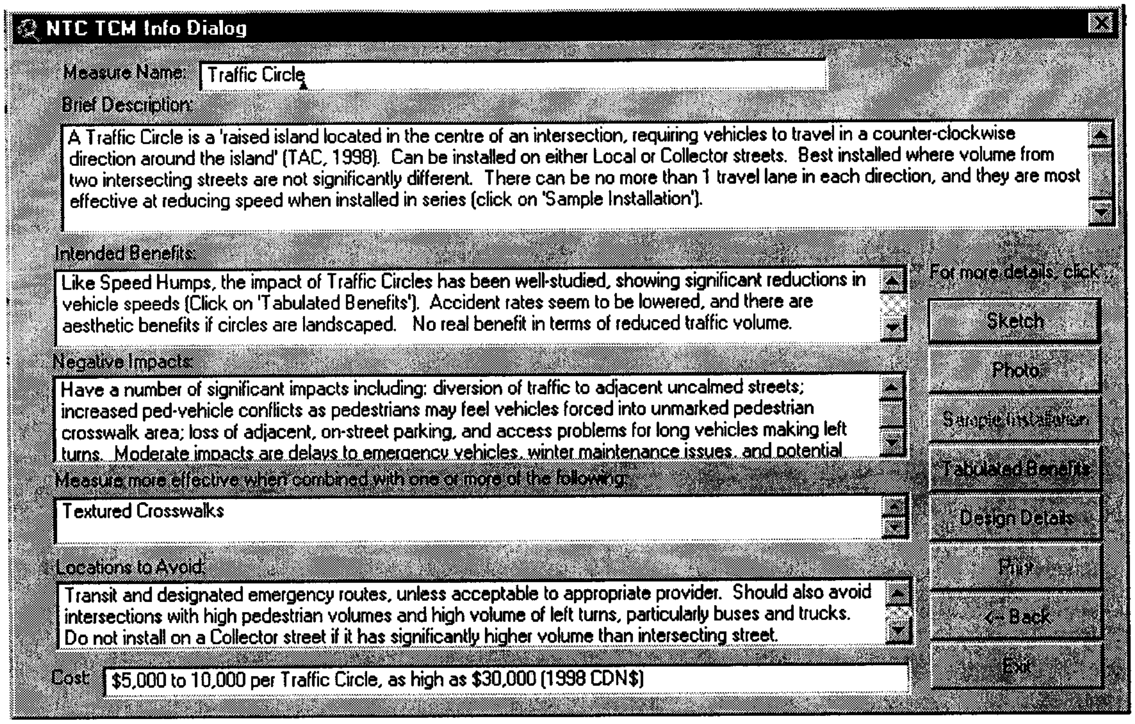
Table 5.9: Design volumes and speeds used to identify critical roadway segments

	Design Volume (vpd)	Design Speed (km/h)
Local Streets	1,000	50
Collector Streets	3,500	50
Arterial Streets	10,000	60

From here, the NTC extension will provide information about the various traffic calming measures. Depending upon the objective of the program, one or a combination of "reduce traffic speed", "reduce traffic volume", or "enhance the pedestrian and cycling environment", the user will be directed to a list of appropriate measures. For the neighbourhood evaluation shown in Figure 5.8, the suggested measures for each of the three calming objectives are shown in Table 5.10. Detailed information is available to the user by clicking on a series of dialog boxes on locating the suggested measure (i.e., appropriate street type, potential negative impacts, locations to avoid) from which the user can make an informed decision (Figure 5.9). The final step in the process is to actually select and then place traffic calming measures onto an output map. Each of these output maps is an alternative outlining a potential solution to the identified traffic calming problems. As an example, Alternative 1 shows the proposed locations for traffic calming measures having the objective of "reducing traffic speed", in the vicinity of the two schools and neighbourhood park (Figure 5.10). Alternative 1 includes the installation of 13 parabolic speed humps on local streets (measure L4) and 6 flat-topped speed humps on collector streets (measure C4). The estimated costs for these installations ranges from $25,000 to $95,000 (in Canadian dollars), based on 1998 estimates provided in TAC and CITE (1998) (Table 5.5). For comparison, the cost of the AWSC currently installed (at 10 intersections) is $100 to 200 per sign for a total cost of approximately $3,600 to $7,200 (measures L9 and C11 on Figure 5.10).

Table 5.10: Traffic calming measures recommended for the initial evaluation shown in Figure 5.8

Objective	Benefit Level	Traffic Calming Measure Recommended for:		
		Local Streets	Collector Streets	Arterial Streets
Reduce Traffic Speed	significant	• raised crosswalk (L2) • parabolic speed hump (L4) • traffic circle (L7)	• raised crosswalk (C2) • flat-topped speed hump (C4) • traffic circle (C9)	• A2 • A3 • A5 • A6 • A7
Reduce Traffic Volume	significant	• 1-lane chicane (L5)	• none	• none
	minor	• parabolic speed hump (L4) • intersection channelization (L8) • AWSC (L9)	• flat-topped speed hump (C4) • intersection channelization (C10) • AWSC (C11)	• A6 • A7
Enhance the Pedestrian and Cycling Environment	significant	• raised crosswalk (L2) • raised intersection (L3) • curb extension (L6)	• raised crosswalk (C2) • raised intersection (C3) • curb extension (C7) • stripe bike lanes (C12)	• A2 • A3 • A5 • A7 • A8



Measure Name: Traffic Circle

Brief Description:
A Traffic Circle is a 'raised island located in the centre of an intersection, requiring vehicles to travel in a counter-clockwise direction around the island' (TAC, 1998). Can be installed on either Local or Collector streets. Best installed where volume from two intersecting streets are not significantly different. There can be no more than 1 travel lane in each direction, and they are most effective at reducing speed when installed in series (click on 'Sample Installation').

Intended Benefits:
Like Speed Humps, the impact of Traffic Circles has been well-studied, showing significant reductions in vehicle speeds (Click on 'Tabulated Benefits'). Accident rates seem to be lowered, and there are aesthetic benefits if circles are landscaped. No real benefit in terms of reduced traffic volume.

Negative Impacts:
Have a number of significant impacts including: diversion of traffic to adjacent uncalmed streets; increased ped-vehicle conflicts as pedestrians may feel vehicles forced into unmarked pedestrian crosswalk area; loss of adjacent, on-street parking, and access problems for long vehicles making left turns. Moderate impacts are delays to emergency vehicles, winter maintenance issues, and potential

Measure more effective when combined with one or more of the following:
Textured Crosswalks

Locations to Avoid:
Transit and designated emergency routes, unless acceptable to appropriate provider. Should also avoid intersections with high pedestrian volumes and high volume of left turns, particularly buses and trucks. Do not install on a Collector street if it has significantly higher volume than intersecting street.

Cost: $5,000 to 10,000 per Traffic Circle, as high as $30,000 (1998 CDN$)

Figure 5.9: Example of "TCM Info" dialog box showing information available for each traffic calming measure

A user could experiment with a number of different arrangements and combinations of traffic calming measures. Only one potential traffic calming program was shown for illustrative purposes, although many more could have been generated for possible consideration by decision makers and the residents of the affected neighbourhoods.

5.5 Conclusion

This chapter has described a prototype ArcView GIS-based tool for neighbourhood traffic calming. The developed prototype is intended to show how decision support could be provided to transportation engineers and planners involved with traffic management in suburban neighbourhoods. The information used to develop the tool is drawn from Canadian and U.S.

experience with traffic calming. Thus the prototype's content would be applicable to a wide range of North American jurisdictions.

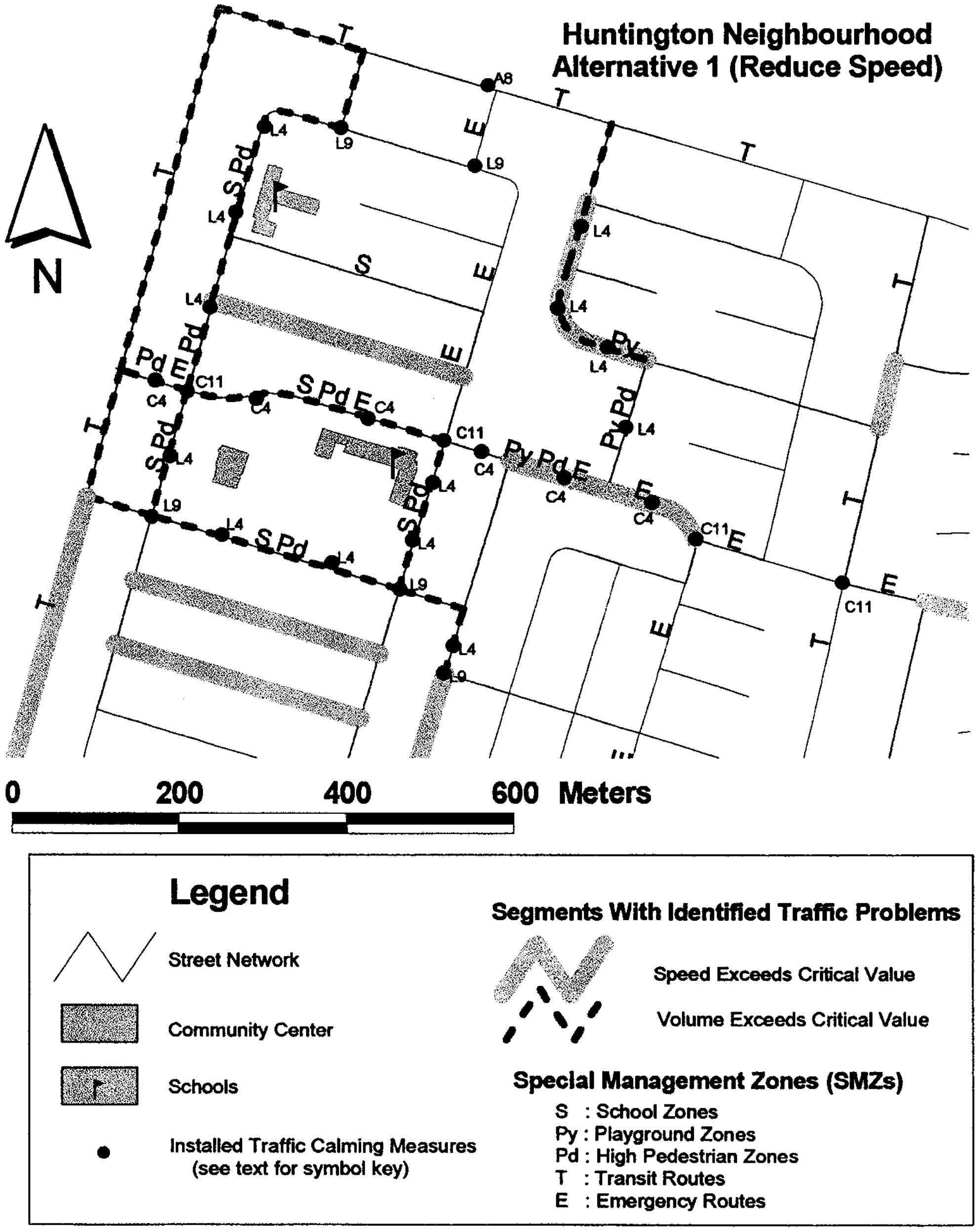


Figure 5.10: Map of traffic calming program "Alternative 1" for the northwest portion of the Huntington neighbourhood

A GIS-based decision support tool is a useful addition to a municipal engineer's tool kit for several reasons. For one, GIS tools are particularly helpful for handling large amounts of spatial information and portraying results in meaningful and helpful ways. Secondly, the tool assists the user in negotiating a large amount of information currently available on traffic calming. And finally, ArcView GIS extensions are readily updated when more information becomes available. This is particularly true for the benefits of the individual traffic calming measures, only available once a measure has been installed and tested.

A second key contribution of this work on traffic calming is the synthesis of measures for the calming of arterial streets. Various traffic calming measures have been described which promote more sustainable modes of transportation on arterials (e.g., transit, bicycles, pedestrians). Some researchers and practitioners have argued that, with correct designs, these objectives can be met with minimal impact on traffic congestion. The arterial calming measures discussed here, and potentially others, need to be tested to determine their potential benefits for volume and speed reductions. Successful volume reductions are only achieved by shifting the mode of travel away from automobiles, not simply diverting the traffic to other roads. A key goal of traffic calming, reducing the effects of motorized vehicles and the promotion of sustainable modes of travel (Lockwood, 1997), will be realized through the provision of safe and efficient pedestrian and cycling networks and access to an effective regional public transit system. It is hoped that the prototype decision support tool will be useful for municipal applications where neighbourhood traffic calming measures are being considered within the overall context of transportation planning and management.

6. NEIGHBOURHOOD GREENING

6. 1 Introduction

This chapter addresses the third of the "primary aspects" for suburban retrofitting. Neighbourhood greening incorporates strategies for the creation of new greened areas in neighbourhoods, as well as potential change in the management of existing ones. These green spaces serve a number of purposes, whether it be for active recreation (soccer, baseball) or more passive pursuits (walking, bird watching). Existing green spaces in suburban neighbourhoods include elements in the public realm such as parks, playgrounds, school fields and street trees that occupy city-owned right-of-ways. They also include privately-owned lands such as utility-leased lands and the yards and gardens of homeowners. In most conventional suburban neighbourhoods, green spaces are characteristically highly-manicured through regular mowing, pruning, watering and the application of pesticides and herbicides. Suburban homeowners feel compelled to regularly upkeep their property. There often exists a certain pride in ownership by having the greenest lawn or the most beautiful collection of exotic flowers. Water demands to irrigate lawns and non-indigenous plants unfortunately occur in the summer when water is typically in shorter supply and municipal reservoirs are most taxed. More rare, in suburban neighbourhoods, are areas of native vegetation (large pockets or larger tracts) left relatively unmanaged and unpolluted.

The overall objective in greening a neighbourhood, under the premise of sustainability principles, is to foster green space management that utilizes "naturalization" techniques, such as those discussed in Hough (1995). These kinds of activities consume less material resources (fertilizer, pesticide, gas, water), while relieving a homeowner or Parks Department of the time and associated costs of maintaining the manicured suburban landscape. Generally, naturalization is associated with a return to the use of indigenous plantings native to the soil and climatic conditions of a particular area. The decision support methodology proposed here has the overall aim of assisting a municipal engineer or planner with the re-thinking of our neighbourhood green spaces. While there will always be a need for the well-groomed soccer pitch or the little league ball diamond in neighbourhoods, there are means to incorporate naturalization techniques for both the public and private realms mentioned above.

This chapter outlines a methodology for neighbourhood greening, discussing greening elements and management techniques as yet unutilized in most suburban neighbourhoods. The objectives and benefits of such a methodology are discussed, especially in the context of how they promote a more sustainable urban environment. The development of an ArcView GIS-based decision support tool for the neighbourhood greening methodology is then described, followed by an application to a suburban neighbourhood in Hamilton to illustrate the tool's capabilities.

6. 2 Benefits and Objectives of Neighbourhood Greening

Why does anything need to be done concerning greening in conventional suburban neighbourhoods? These neighbourhoods are considerably "greener" than their urban counterparts, with larger individual building lots and greater areas (per capita) devoted to parks. In the previous section, the consumption of resources to maintain the current state of manicured landscapes in suburban neighbourhoods was introduced. Reducing this consumption and the associated pollution of air, water and soil are the key benefits in changing the ways in which suburban neighbourhood landscapes are managed.

Neighbourhood greening, involving the greater use of naturalized landscaping techniques, provides a number of benefits for the overall cause of sustainability (Table 6.1). Of these, some are more tangible than others, such that a quantified impact of a particular landscaping technique can be estimated. More tangible benefits are numbers 1 to 4, while those providing less tangible benefits are numbers 5 to 8 (Table 6.1). These are listed in this order only for convenience; the listing does not reflect the importance of achieving one benefit over another.

Table 6.1: Benefits of neighbourhood greening

(1) Improvements to air quality;
(2) Reduced energy consumption;
(3) Reduced water consumption;
(4) Reduced costs of green space management;
(5) Improvements to neighbourhood aesthetic character;
(6) Shared landscape between humans and local fauna;
(7) Connection to nature is re-established in urban and suburban areas;
(8) Recreational nature opportunities, on a daily frequency, become more accessible.

Increasing the area of green space in neighbourhoods, particularly trees, provides significant air quality and energy benefits. Trees are net producers of oxygen and net consumers of carbon dioxide, a benefit towards global warming attributed to the increasing concentrations of CO_2 and other greenhouse gases in the atmosphere. As well, trees act as atmospheric filters, reducing amounts of harmful airborne pollutants such as ground level ozone, carbon monoxide, and sulphur dioxide (Dwyer *et al.*, 1992). Reducing ground level ozone has been demonstrated as a significant potential health benefit in Toronto that would result in 83 fewer deaths each year (City of Toronto, 1998; Hudson, 2000). In addition, increasing the vegetative cover alters the surface albedo and may counter the urban heat island effect commonly observed in cities (Oke, 1987; City of Chicago, 1998). Street trees may cool suburban streets as well as improve aesthetics. Energy benefits are gained through appropriately siting trees around structures, to provide shade in summer and a shield from harsh winter winds (Kirnbauer and McCaig, 2000). Building air conditioning and heating costs, in the respective seasons, can be reduced significantly as shown by Heisler (1986). Savings of 10 to 15 percent on winter heating costs and 20 to 50 percent on summer cooling costs, due to strategic tree placement, were reported. Another tangible benefit of naturalization techniques is the reduced use of materials (energy, water, fertilizer, pesticide) and savings in terms of time and cost. A report by CMHC (2000a) quantitatively demonstrates some of these expected reductions and savings. Water consumption is typically highest in the summer period, and often doubles the winter consumption rate, when watering of lawns, gardens, and other landscaping peaks (CHMC, 2000a). Water reductions are achieved through the use of xeriscaping and indigenous species of trees and plants for landscaping. Examples are shown later, in section 6.5, where reductions in maintenance costs and time requirements are achieved through a shift away from conventional suburban landscapes. A final point concerns the overall economic benefits of green space to a community. Studies have shown that property with mature landscaping including street trees, have higher retail values (Arendt, 1994), also providing a benefit to a municipality via increased taxes based on assessed values (Brabec, 1994; City of Vancouver, 2000a). A report by the Vancouver Parks Board showed that the estimated value of all the city-owned street trees was $500 million, and represented one of a small set of assets the City could expect to increase in value over time (City of Vancouver, 2000a).

In terms of less tangible benefits, some might argue that natural landscaping in parks and around structures is an aesthetic improvement over current practices. This is debatable, however, since practices of lawn care and gardening are well entrenched in current culture. Aesthetics aside, the inclusion of nature in neighbourhoods will facilitate more frequent passive recreational opportunities and may reinforce the important connection between humans and their environment. The latter could be used to help children learn about important dependencies between humans and nature (e.g., how soil and forests are used to produce food and to clean the atmosphere).

The neighbourhood greening methodology has been formulated to reflect a number of these key benefits. A program of neighbourhood greening includes a variety of landscaping techniques, reflecting the diverse needs of the neighbourhood's residents. Naturalization is encouraged wherever possible, with conventional facilities (e.g., playing fields) maintained where sufficient demand exists. The objectives of the neighbourhood greening methodology are listed in Table 6.2 and described briefly below.

Table 6.2: Objectives of neighbourhood greening

- Increase natural areas within suburban neighbourhoods
- Encourage more natural landscaping techniques for private yards and gardens
- Provide conventional green space for recreation and aesthetics
- Add a productive component to green space areas

Increasing natural areas allows the greater use of vegetation native to a particular area, adapted to the local soil conditions and water availability. This includes the naturalization of current landscapes such as parks and areas around individual structures. Enhancement of the natural environment along natural corridors (e.g., creeks, streams, lakeshore, riverfront) would provide means to enhance wildlife and biodiversity. It is suggested to implement gardening and landscaping techniques which require considerably less additions of pesticide, fertilizer, and water, and save a person time and money, while also benefiting the environment (CHMC, 2000a).

In the conventional suburban neighbourhood, greening additions are typically parks, playing fields for school and community athletics and trees along a neighbourhood's streets. In a greened neighbourhood, portions of existing fields and parks, no longer in use or thought redundant, could be converted to a more naturalized state. Addition of a productive component in neighbourhood green spaces could be achieved through the installation of neighbourhood community gardens, the planting of fruit and nut trees (climate permitting), and the management of grassland and forestland within a neighbourhood. Annual (or semi-annual) cutting of fields (rather than weekly) could provide a marketable source of animal feed. Periodic select cutting in a managed neighbourhood forest could provide a small wood source, further demonstration of our reliability on the earth's resources. Such urban forests have been developed in Europe (an example of a managed urban forest in Zurich is discussed in Hough, 1995).

This section has demonstrated some of the benefits that could be achieved through a program of neighbourhood greening. A neighbourhood greening methodology has been developed to realize some of these benefits, through the installation of a number of greening features. These features are now discussed.

6. 3 Neighbourhood Greening Features

The methodology for neighbourhood greening involves both changes in the management of an existing green space feature, as well as the creation of new green space features. A total of six features are considered in the developed methodology (Table 6.3); the potential land use conversions (or transformations), to create or augment green space features are shown on Figure 6.1. The methodology, although recognizing the importance of conventional parks and playgrounds in suburban neighbourhoods, does not specifically address how to retrofit these features. More than likely, sufficient park and playground facilities already exist. Moreover,

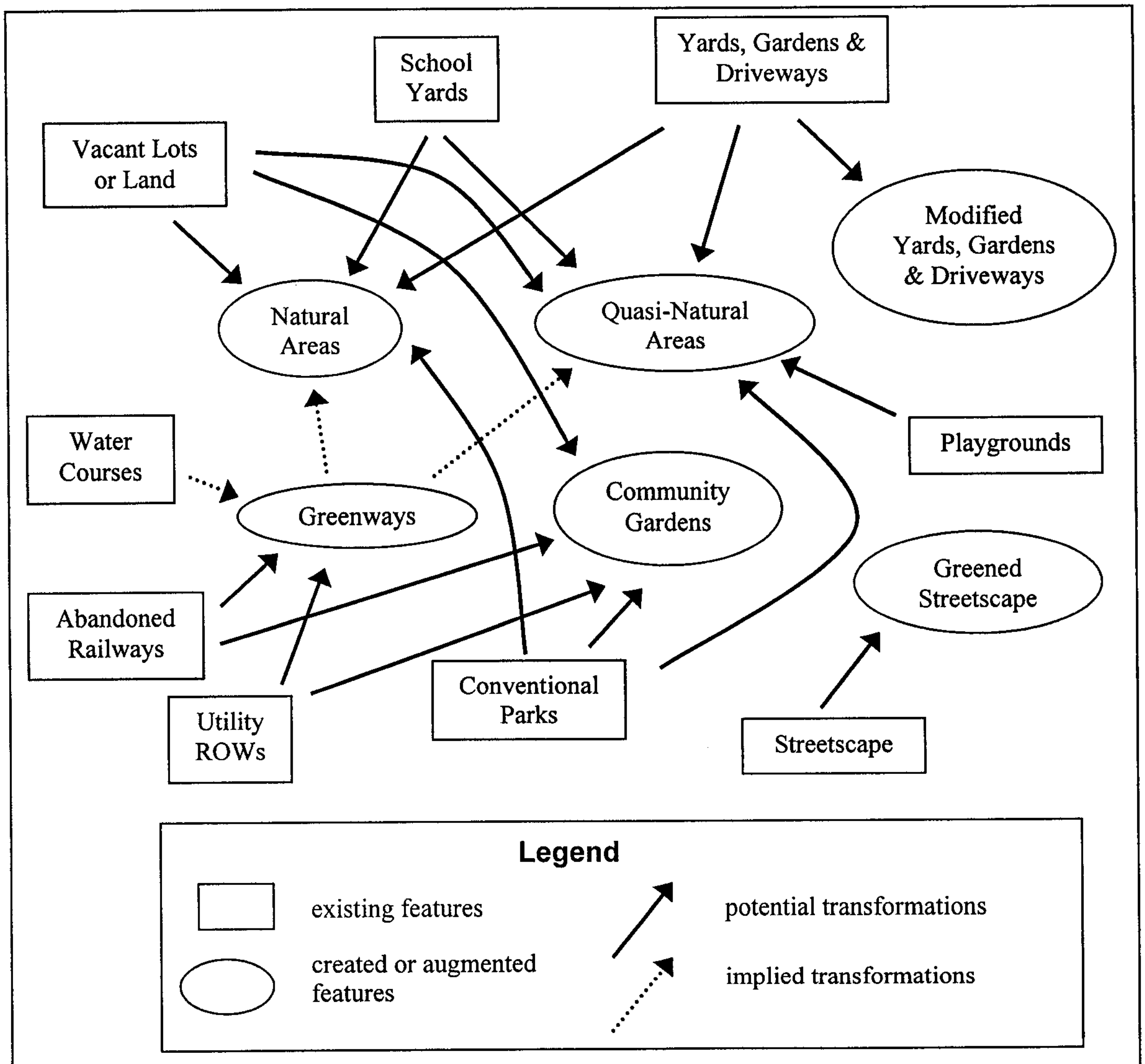


Figure 6.1: Neighbourhood greening transformations

conventional parks are a key source of neighbourhood land which could be converted to community gardens and more naturalized uses (see Figure 6.1). The last feature listed in Table 6.3 - "Yard, Garden, and Driveway Options" - differs from the other five features in that it includes options applied at the scale of the individual home or yard. Arguably, this feature has little place within a decision support tool discussing retrofitting solutions at the neighbourhood scale. But it is viewed as an important feature in the neighbourhood greening methodology, because, if implemented, it may represent the largest single impact on creating a greened neighbourhood. The area represented by the gardens and yards in the conventional post-war suburb is considerably larger than the area of any other neighbourhood greening feature considered. Thus, it represents too great an opportunity, for lowering the environmental impact of a whole neighbourhood, to ignore. The features in Table 6.3 are now briefly described.

Table 6.3: Neighbourhood greening features considered

- Natural Areas
- Quasi-Natural Areas
- Greenways
- Greened Streetscape
- Community Gardens
- Yard, Garden, and Driveway Options

Natural Areas

Natural areas employ indigenous shrubs, trees and ground cover to emulate natural forest cover. The overall objective is to re-establish the climax forest community native to a particular geographic region. The use of indigenous vegetation includes those species that are native to a particular geographic location. This differs from xeriscaping in which both native and imported species, suitable to a particular climatic regime, are incorporated. Natural areas would have limited trail access provided, and have little in the way of human intervention other than for safety issues.

Returning nature to the city and suburban environments will reinforce the concept that our cities, and their well-being, are dependent upon a larger natural system. Nature close at hand will provide opportunity for daily recreational nature opportunities for adults and children, and promote learning and respect for nature's flora and fauna. Natural areas perform very important functions such as oxygen production, pollutant filtering and cooling of the urban environment - all direct benefits to society. As well, the use of more natural landscaping techniques will reduce unnecessary costs to maintain and water manicured suburban landscapes.

Natural areas can be established on a variety of places in the neighbourhood. Note that commitment to creating a truly natural area exceeds several decades and is not to be undertaken as a temporary land use for a particular site. It may be appropriate to convert portions of schoolyards and conventional parks to natural areas. It is recommended to leave a portion of schoolyards and adjacent fields available for school and community sporting activities. Naturalization techniques are very applicable to linear elements along which greenways would be developed (particularly streams), and to vacant land not destined for some other use (Figure 6.2). Naturalization can also be encouraged in yards and gardens of individual homes.

To create naturalized areas when starting from a bare, unvegetated site, Hough (1995) recommends a process of "enhanced succession" in which the natural process of vegetation succession is managed so as to increase the speed at which the climax forest community is reached. When unmanaged, natural succession may take many decades or longer to be realized. Management techniques to achieve succession include the simultaneous planting of colonizer and climax species together; the colonizers are periodically cut back in the early years of the program to allow the climax species to develop a strong foothold and to be able to out-compete the colonizer species (Hough, 1995). Other interventions would include maintenance at parcel edges to keep branches from affecting pedestrian and vehicular traffic, and routine trimming at the edges to create a transition between the adjacent manicured streetscape and an essentially natural unkempt parcel within a neighbourhood.

Figure 6.2: Example of a "natural area" from Dundas, ON

Quasi-Natural Areas

Quasi-natural areas consist of techniques used to emulate a natural vegetative cover, but the ultimate progression to the local climax forest community is prevented through annual maintenance. It is hoped to create open areas of grassland and meadow that provide aesthetically attractive landscapes, while reducing the need for regular cutting and the use of chemical additives (Figure 6.3). These techniques are not restricted to larger fields in neighbourhoods, but are applicable for small parcels of landscaping in and around homes and buildings. Quasi-natural areas have trails provided through them that are routinely cut to provide access to nature viewing and for pedestrians. Their benefits are similar to those of natural areas, described above. In addition, through less frequent cutting, quasi-natural landscaping techniques will reduce unnecessary costs to maintain and water manicured suburban landscapes. However, quasi-natural areas do require some annual or semi-annual maintenance to keep the growth of climax species at bay.

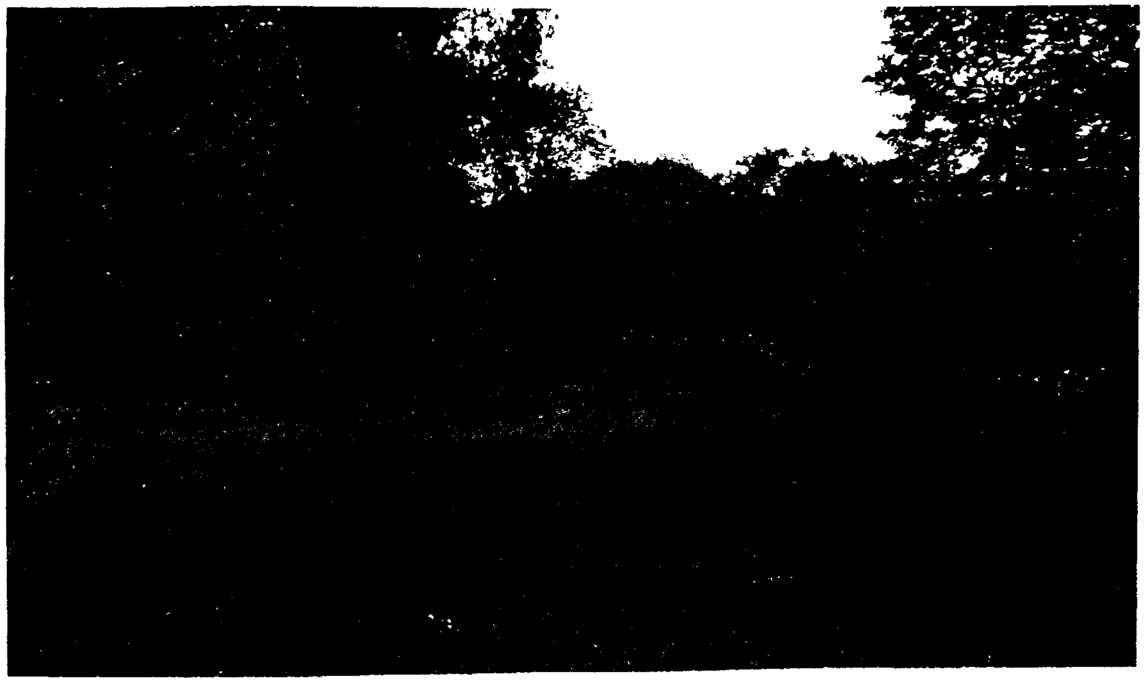


Figure 6.3: Example of a "quasi-natural area" requiring periodic maintenance to prevent succession to climax forest community

Quasi-natural areas can be established on a variety of places in the neighbourhood, and unlike natural areas, could be used as a temporary landscaping technique. Portions of schoolyards and conventional parks can be converted to quasi-natural areas. It is recommended to leave a portion of schoolyards and adjacent fields available for school and community sporting activities. Quasi-naturalization techniques could be applied to greenways developed for higher volumes of pedestrian and bike travel, in which periodic maintenance of the trail and cutting back vegetative growth for safety reasons would be required. This type of naturalization would be appropriate to utility corridors, especially those with overhead utilities. Quasi-naturalization can also be encouraged in yards and gardens of individual homes and on vacant land within the neighbourhood.

These landscapes require less time and material inputs for maintenance than conventional landscaping. Mowing is done on an infrequent basis (once or twice annually), only to prevent the process of natural succession to a forest community. This would be especially important in utility ROWs so that a dense forest cover does not impact overhead wires or underground pipes. Fields can be planted as grassland or as wildflowers, with the latter requiring some additional knowledge about appropriate seed types for specific locales.

Greenways

Greenways are linear corridors in neighbourhoods, typically developed along existing linear elements such as utility and railway ROWs or streams (Little, 1990). They provide both opportunities for nature observation as well as for improved access throughout a neighbourhood. Greenways developed on utility corridors or former railroad beds can be used to link neighbourhoods together and thereby enhance both pedestrian and cycling circulation for a larger region. When wide enough, greenways can become important wildlife corridors, linking larger natural areas together, and therefore can encourage biodiversity (Arendt, 1994). The development of greenways and links to other neighbourhood trail networks have been shown to add considerable value to real estate values in a neighbourhood (Arendt, 1994).

The management and maintenance requirements of a greenway is related to its overall function. For a linear greenway developed on a former railroad bed running through an urban area, it may be appropriate to pave a 'multi-use path' - constituting a portion of the allocated greenway - to provide a hard surface for cyclists, pedestrians and roller-bladers. This provides a path that can be maintained for all-season access. However, paving a path through a greenway takes away from it being an opportunity for nature to reclaim former territory, so one should carefully weigh the desired function of the greenway prior to paving. Greenways should be constructed to augment, not to replace, the development of on-street utilitarian cycling facilities. For less-linear elements, such as greenways developed along streams, dirt or gravel paths are sufficient with minimal signing.

Greened Streetscape

The target greened streetscape for a suburban neighbourhood is a street lined with majestic street trees whose branches reach across the street and create a canopy over both the road and sidewalks. Trees should be planted in linear patterns and with a uniform distance setback from the road to form the walls of this "outdoor room". Trees should be planted at regular intervals along the street, within the city-owned ROW, and be replaced upon death and disease, so that the canopies remain relatively intact and in perpetuity.

The use of street trees provides a number of key benefits to neighbourhoods. In addition to the obvious aesthetic benefits, they provide important roles in filtering pollutants and reducing the urban heat island effect (Dwyer *et al.*, 1992; City of Chicago, 1998). Lower surface temperatures have been shown to reduce summer energy costs for air conditioning (Heisler, 1986). Street trees add considerable financial value to a city (City of Vancouver, 2000a), in that homes with mature vegetation often have higher assessed values (Arendt, 1994). And finally, street trees are also necessary elements for a streetscape to visually narrow overly wide streets and to define a distinct pedestrian realm. Trees will protect pedestrians psychologically and physically from vehicles in the roadway (Kunstler, 2000).

Selection of appropriate tree types is important. Trees should be tolerant of urban conditions, such as air pollutants and salt spray, and should meet the objectives of using species native to a particular geographic area. Trees having a productive component such as fruit or nut production might also be considered, although their smaller crown sizes may not provide sufficient shade. The rewards of having tree-lined streets are achieved through regular maintenance and replacement. Most cities have pruning programs that prune each tree in the city once within a 6 or 7 year cycle. Pruning is done to remove sappers and direct growth away from any overhead utilities. The disease and death of trees needs to be met with removal and replanting, so to minimize the impact on the streetscape. For this reason, it is important that tree populations are "multi-aged" and are comprised of a variety of types.

Community Gardens

A community garden is a collection of plots on publicly-owned lands temporarily allocated to a group of neighbourhood residents. The residents likely to be interested in community gardens are those living in multi-unit buildings (apartments or townhouses), who do not have an opportunity to grow their own herbs, flowers or vegetables. Community garden plots are to be sited within a neighbourhood so that the distance to the garden facility from these users remains walkable. However, this may not be possible if little vacant or unused land is available within a neighbourhood. A variety of locations can be considered. Community gardens could be created on a portion of a conventional park and preferably adjacent to the portion of the park that may be undergoing some quasi-naturalization. They also can be developed along utility ROWs or within vacant lots. Gardens would be appropriate overtop of underground utilities, but not underneath hydro lines because of suspected health concerns of long term exposure to magnetic fields (Bates, 1994; California EMF Program, 2000). It is not recommended to locate community gardens on school properties due to potential vandalism concerns, unless the students were to participate in the gardening initiative.

A neighbourhood community gardening association will generally form in each neighbourhood to oversee membership and technical issues related to the garden's operation. All gardeners are expected to use organic farming principles which will help promote ideas surrounding more sustainable living. City or regional officials will be available to disseminate information about organic gardening, as well as to check compliance. In addition to their fostering more sustainable practices, community gardens are also credited with building community spirit and environmental stewardship.

Yard, Garden and Driveway Options

This section discusses greening options which can be applied to the yards, gardens, driveways and roofs of an individual home. As suggested earlier, the cumulative area of the yards and gardens of a neighbourhood's homes represent the single largest potential area for greening, and could result in significant reductions in the use of water and other materials. In addition to these reductions, other benefits, gained through vegetation placement around a home and alternative strategies for driveways and roofs, are briefly explored.

Home yards and gardens, typical of suburban neighbourhoods, commonly use landscaping techniques with high maintenance, water and fertilizer requirements. A study by CMHC (2000a) identified seven yard and gardening options available to the homeowner (Table 6.4) and reported on the associated use of water, gas, fertilizer, and pesticides, as well as cost of maintenance in terms of time and money. Not surprisingly, landscaping options employing trees, shrub and turf types suited to local climatic conditions (xeriscape; woodland shade; wildflower meadows; and low maintenance lawn), use less water and other materials for maintenance. Low maintenance lawns, composed of hardy, drought-tolerant, slow-growing grass requiring less mowing, provide considerable savings (over conventional lawns) in terms of mowing time and fuel costs. Ornamental gardens, featuring primarily exotic species, have higher time, fertilizer, pesticide and water demands, because they utilize species not as well suited to local environments. In addition to CHMC's listing, vegetable gardens and greenhouses are two additional gardening options that should be considered. These provide means to grow organic produce in the neighbourhood. Greenhouses lengthen the growing season and permit a greater variety of crops to be grown, which would be especially useful in marginal climates.

Table 6.4: Home garden types discussed in CMHC (2000a)

- xeriscaping
- woodland shade gardens
- wildflower meadows
- conventional lawns
- low maintenance lawns
- ornamental trees and shrubs
- ornamental flowerbeds
- vegetable gardens[1]
- greenhouses[1]

Note: 1) Not discussed in CMHC (2000a)

The placement of vegetation around the home can have important ramifications for energy conservation. Generally, there are four main climatic factors, in order of importance, to consider when landscaping around a structure: 1) sun; 2) wind; 3) temperature; and 4) humidity. Deciduous trees can be planted on the SE and SW sides of dwellings to provide shade in summer, reducing building air conditioning costs. In winter, the sun is able to reach the structure, aiding in heating and reducing costs for conventional heating fuels. Hedges and shrubs can be used to shade sidewalk, patio and driveway areas, thereby reducing radiant heating from these surfaces and cooling the surrounding air several degrees. Windbreaks shield a structure from winds and have considerable aesthetic value. Coniferous trees and shrubs, planted to the N and NW of a structure, can be an effective windbreak for identifiable prevailing winter winds, and can provide significant heating fuel savings. This is a brief synopsis of the use of landscaping to achieve energy conservation around the home. Additional details are available in several sources, including Kirnbauer and McCaig (2000).

The objectives of changing the driveway surface, from conventional concrete or asphalt, are: 1) to increase its permeability; and 2) to reduce radiant heating due to large driveway areas. With regards to the former, by changing the driveway material to brick or other porous paving material, incident water on the driveway can percolate through and recharge groundwater (see example of a combined turf-concrete driveway in Figure 3.8). Increasing the area of permeable surfaces in a neighbourhood will also reduce storm water sent to wastewater treatment plants. The driveway surface (like road surfaces) is a greater source of radiant heat than vegetated surfaces. Reductions in driveway areas and the introduction of vegetation to shade or to actually replace portions of driveway will result in lower air temperatures locally.

The rooftops of homes and ancillary buildings can be used for a number of tasks in "green" or more sustainable building practices. Firstly, like driveways, they (especially dark asphalt shingle roofs) are sources of radiant heat in neighbourhoods. The use of light coloured-materials on roofs, as done in hot climates in the Middle East and Mediterranean, could significantly reduce radiant heat generated and lower air conditioning costs. Secondly, roofs could be used to mount photovoltaic cells for the generation of electricity (from solar energy). The "Healthy House" in Toronto, sponsored by CMHC, is able to generate all of its own power needs through these cells (CMHC, 2000b). And thirdly, roofs can be used to collect rain and snowmelt in cisterns for a number of home and yard uses. This option was described more fully in the methodology on water conservation in suburban neighbourhoods (refer to section 3.2.8).

These home, yard and driveway options receive only an overview treatment in the prototype version of the neighbourhood greening tool. The tool is more focussed on the five greening features applicable at the scale of the neighbourhood (see Table 6.3). The development of this decision support tool for the greening of neighbourhoods is now discussed.

6. 4 Development of Related ArcView Extension

This section describes the development of a third ArcView GIS extension providing decision support for suburban retrofitting. This extension - *Neighbourhood Greening (NG)* - incorporates the knowledge of the neighbourhood greening features discussed in the previous section, and contains individual methodologies to carry out the following tasks:

- Quantify the benefits of alternative landscaping techniques;
- Generate a street tree planting schedule;
- Determine the best location(s) for NG features, and;
- Investigate NG features and create a map depicting a potential NG program.

The following paragraphs discuss the greening methodology, and the structure, input requirements, and assumptions of the NG extension. A manual describing how to use the NG extension is provided as Appendix D.

Methodology Overviews

In the first greening task, the user can investigate the potential benefits of alternative landscaping techniques. In order to calculate any benefits, the landscapeable area is first determined. The user is able to delimit a study area of interest, ranging from the scale of an entire neighbourhood to a fraction thereof, such as an individual park, street or open space parcel. Potential benefits of greening the delimited area are achieved when conventionally-manicured landscaped areas are altered to one of the types shown in Table 6.4. These benefits include changes in the use of materials such as water, gasoline, fertilizer and pesticides, and in the allotments needed in terms of time and cost for maintenance. Estimated consumption rates of these variables for garden types, except for vegetable gardens and greenhouses, are provided in CMHC (2000a) and included in this dissertation as Appendix F. Vegetable gardens and greenhouses have been added as garden types because of their benefit in providing residents with the ability to grow food, although data on the consumption of material resources, time or cost for these options are presently unavailable. Results are tabulated for the user, and can be recorded on an appropriate data form.

In the second greening task, the user can investigate the required number and placement of street trees in a particular neighbourhood (or selected portion). In doing so, one can generate maps showing potential street tree planting schedules. Deciding on where to plant trees, along a street, is subject to a number of constraints including: 1) desired spacing between street trees; 2) installation cost per tree; and 3) the annual budget available for a planting program. For example, a tree might be placed in front of every home along a street and at similar spacings for larger buildings (Figure 3.3). Hence a gap, equal to the average frontage length for homes in the study neighbourhood, could be selected. Installation costs would vary by tree type, age and geographic area. The NG extension identifies gaps between existing trees, and a list of planting locations is generated for those gaps exceeding the desired spacing. The size of the gap would determine the number of trees to be installed. If the gap were 35 m with a desired spacing of 15 m, a total of 2 trees would be suggested to reduce the gaps between trees along this road segment to less than or equal to 15 m. The annual planting budget is used to calculate the number of years required to plant all of the suggested trees. The final output map consists of a colour-coded planting schedule for the first 5 plant years.

Although street trees are typically located on a city-owned right-of-way, some aspects of their care, following installation, generally become the responsibility of the property owner. Hence, the owner should be well-informed on the importance of the tree program, and should contact the city if a problem with the tree develops (disease, accident, scar, vandalism). Selected tree types should be tolerant of urban conditions (e.g., air pollution, salt splash). Since one objective for planting street trees is to benefit pedestrians (in terms of shade and separation from vehicular traffic), they should be planted sufficiently close to sidewalks or within boulevards (Figure 3.3). Street trees should be uniformly spaced with similar setbacks from the street. Aesthetic considerations aside, placement is also dependent on the location of under- and above-ground utilities which could be affected by tree roots and branches, respectively.

In the third greening task, an algorithm has been developed to help the user determine the best location(s) for neighbourhood greening features. In the prototype version of the NG extension, preferred facility locations for community gardens and playgrounds in a neighbourhood are determined. The algorithm used is the simplified version of the p-median location-allocation model discussed in Ghosh and Ruston (1987), where the best configuration of potential facilities is determined from all available facilities. In the case of community gardens, the weighted route distance from the selected facilities to the demand points is to be minimized. The demand points for a neighbourhood community garden are the residents of multi-unit dwellings. The general form of the p-median location-allocation model is shown in equation (6.1).

$$\text{(6.1)} \qquad \text{Min } C = \sum_{i=1}^{n} \sum_{j=1}^{p} o_i \cdot \lambda_{ij} \cdot c_{ij}$$

where:

C = total weighted distance

n = demand locations (e.g., multi - unit dwelling nodes)

p = set of uncapacitated facility supply centres

$$\lambda_{ij} = \begin{cases} 1 \text{ if demand point is allocated to facility} \\ 0 \text{ otherwise} \end{cases}$$

o_i = quantity demanded at location i (i.e., number of dwelling units at each building node)

c_{ij} = route distance between the demand location and the allocated facility

A key assumption in this approach is that the "consumers" are allocated to the nearest supply centre or facility. This assumption holds for locating playgrounds or community gardens, where all facilities have similar characteristics. However, it does not hold when considering commercial enterprises since retail stores have different characteristics, and people may travel further than the nearest centre or facility to obtain specialized goods or services (Ghosh and Ruston, 1987).

No existing scripts or extensions for utilizing location-allocation models in ArcView were available. Coding the p-median model (equation 6.1) into ArcView initially presented some computational difficulties, which were resolved by limiting the number of potential facilities considered to four. This simplification does not impact the selection of a community garden facility, where the number of potential sites in any given neighbourhood is probably less than four, and the number to be constructed is likely to be just one or two. It would, however, affect the selection of other facilities (e.g., bus stops) if the desired number of facilities to service the neighbourhood would exceed four. In the operation of the algorithm, the user is required to digitize the locations and areas of the proposed community garden facilities, and to input a number of constraints. In particular, the user is prompted to enter the desired number of facilities, the number of plots to provide and the average plot size. These constraints are then used by the algorithm, in addition to the calculated weighted route distance, to determine the preferred facility locations.

In the fourth and final greening task, the user is able to investigate a number of neighbourhood greening features, and then to create a map of a neighbourhood greening program. A transformation matrix (Table 6.5) was used in the creation of the NG extension, to indicate what land use transformations are considered possible to further a neighbourhood greening program. These transformations are embedded in the NG extension code to assist the

Table 6.5: Matrix showing possible transformations of land use elements to create a neighbourhood greening program

		Alterable to				
		natural area	quasi-natural area	greenway	greened streetscape	community gardens
Convert from	vacant land or lot	✓	✓	✓		✓
	school yards	✓	✓			
	conventional parks	✓	✓			✓
	playgrounds		✓			
	utility ROWs	✓	✓	✓		✓
	yards and gardens	✓	✓			
	streetscapes				✓	

user in making informed decisions about the selection of NG features. Descriptive information (of features) concerning their respective benefits, recommended locations, and maintenance issues is presented in a series of dialog boxes and illustrations. Maps, comprised of features selected from Table 6.3, can then be generated. Information about home yard, garden and driveway options for greening are available in the developed tool, although not included when creating a map of neighbourhood greening. The structure, input requirements, and assumptions made in developing the NG extension are now discussed.

Structure

The NG extension is constructed around a list of menu options that carry out the greening methodologies presented in the previous section (Table 6.6). The extension is written in Avenue (ArcView's coding language) and incorporates mostly original coding, although some previously developed scripts and extensions are utilized to prevent unnecessary duplication of effort. In particular, three existing ArcView extensions are required to operate the NG extension. These include the *Geoprocessing* and *Network Analyst* extensions (ESRI, 1998), and the *Shortest Network Path (SNP)* extension (Remington, 1999). *Network Analyst* and *SNP* were used in the *PRD Evaluate* extension discussed in chapter 4. In addition, several short scripts, provided within ArcView version 3.1, were incorporated into the NG extension.

Table 6.6: Menu options in the NG extension

(1)	• Delimit Study Area for Landscapeable Fraction
(2)	• Evaluate Landscapeable Area and NG Potential [GREEN GARDENING] or [STREET TREES]
(3)	• Select Locations for NG Features
(4)	• View and Place NG Features

Input Requirements and Assumptions

A variety of input files (ArcView shape files and database files) are needed to utilize the NG extension. Many of these relate to the area of land use elements, such as roads, buildings or sidewalks, used to determine the landscapeable area of the neighbourhood. Additional information for multi-unit dwellings (number of dwelling units per building) and roads (road classification) is required to complete area calculations. A shape file for the location of existing street trees is needed to generate a planting schedule. A complete list of input file requirements for the extension is provided in Appendix D.

Several assumptions are made in the determination of landscapeable area. Road and sidewalk widths, used to calculate the area of these features, are standard design values suggested in TAC (1999). The driveway input data, available in this study, was a polyline theme, meaning that an average driveway width was used to determine driveway areas. Driveway segments in the neighbourhood used in the application of NG (see section 6.5) were measured and averaged. The average width obtained - 3 m - was then applied to driveways across the neighbourhood.

As a final point, it is important that the user fully understands the nature of the required data, particularly their ArcView shape classes. The NG extension is constructed assuming the shape files for each neighbourhood element are either polygon, polyline, or point (as indicated on Table 3.9). The user may be required to manipulate the data prior to running NG extension and will likely need to consult Appendix D. The prototype version of the tool does prompt a user, with an error message, when insufficient or incorrect data have been entered. The application of the decision support tool for neighbourhood greening is now considered.

6. 5 Application of Developed Extension

The NG extension was applied to a suburban neighbourhood in Hamilton. Applications are provided to demonstrate the function of the four key menu options discussed in the previous section.

Neighbourhood Description

The selected neighbourhood - Huntington - is characteristic of those constructed in the area since the 1960's. Huntington is defined by three 4-lane urban arterial roads on its north, west and south sides, and by a 2-lane urban arterial to the east. The neighbourhood was built like many of its contemporaries, primarily as "bedrooms" for workers employed elsewhere in the region. Land use is zoned primarily for residential development, although small parcels are available for limited commercial activity, school buildings, churches and a community centre. Apartments and townhouses are placed around the neighbourhood perimeter, while the interior is reserved almost exclusively for single family dwellings. A map of the study neighbourhood is shown in Figure 6.4.

Available Data

To demonstrate the use of the NG extension, the necessary data for the Huntington neighbourhood has been compiled. The majority of the ArcView shape files used have been obtained from the Region of Hamilton-Wentworth. These were initially in MicroStation format (.dgn files), but were converted to shape files using ARCINFO. A field reconnaissance was conducted to obtain other attribute information for roads and multi-unit dwellings, including roadway classification, and the number of dwelling units per building. In addition, the locations of existing street trees in a portion of Huntington neighbourhood were determined. A tree in the front yard of a home was considered a street tree if it provides (or has the potential to provide) shade for the sidewalk and street. Thus, trees needed to be relatively close to the street (within the city-owned ROW) and have crowns likely to provide shade. Conifers and some deciduous species (e.g. catalpa) were not included in street tree counts because of their typical crown shapes. Landscaping trees located in front of a home, but too far from the street and sidewalk, were not counted either.

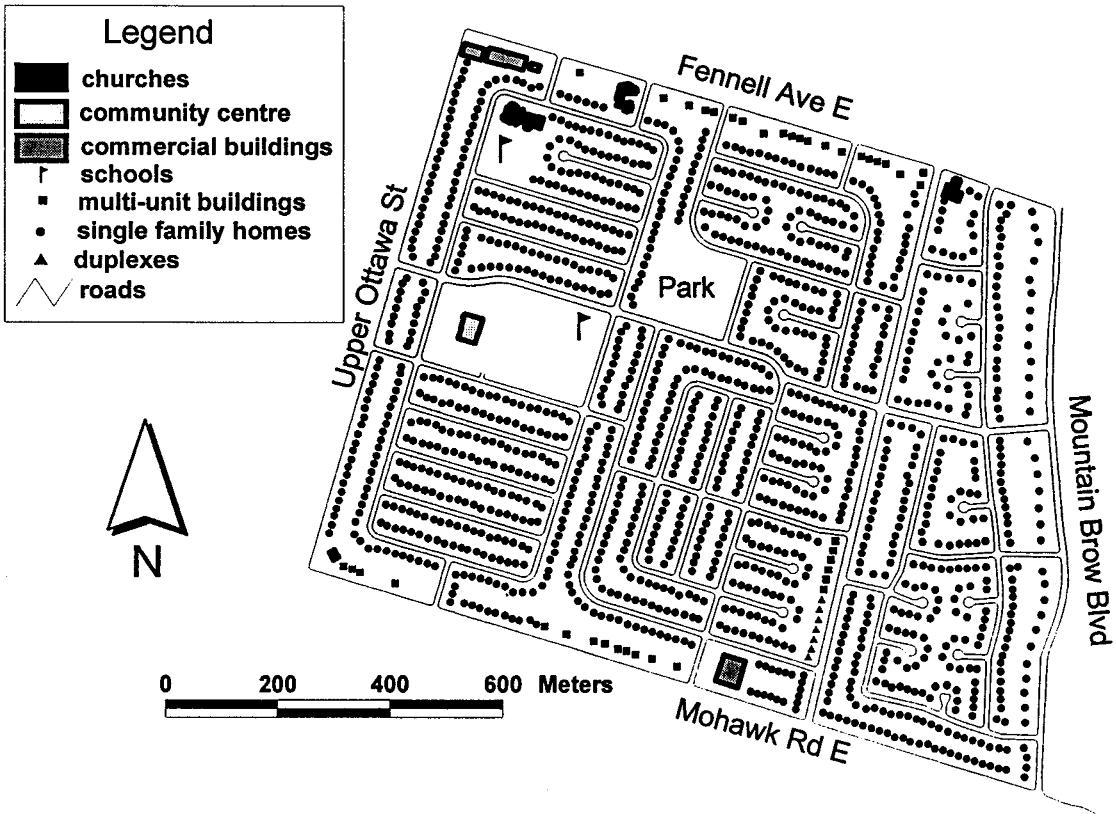


Figure 6.4: Map of the Huntington study neighbourhood

Analysis

A total of five applications are discussed to show the functionality of the developed NG extension. The first and second applications consider the use of the menu options for evaluation of landscapeable area and the potential for neighbourhood greening [Green Gardening] (options 1 and 2 on Table 6.6). Improved neighbourhood greening in these two applications is achieved by reducing the amount of water and other materials used for gardens and landscaping. The third application considers the selection of the best locations to install a community garden in the neighbourhood, targeted to the neighbourhood's residents of multi-unit dwellings (option 3 on Table 6.6). In the fourth application, a street tree planting schedule is generated using the algorithm [Street Tree], to suggest planting locations to green the overall streetscape (option 2 on Table 6.6). In the final application, the use of the extension to generate maps displaying a comprehensive neighbourhood greening program is demonstrated (option 4 on Table 6.6).

- *NG Application 1*

The first application considers the landscapeable area of the entire neighbourhood (Figure 6.5), which is the net area not devoted to roads, driveways, sidewalks, buildings or swimming pools. In the Huntington neighbourhood, the total study area is approximately 127 ha, of which 78.7 ha is landscapeable. Land areas devoted to other uses is shown in Table 6.7. This landscapeable area includes land that residents and the City would use for front, side and rear yards, lawns, trees, hedges, patios, street trees, and boulevards. It is estimated that approximately 70% of this area would be "conventional lawn" in the typical conventional suburban neighbourhood. The remaining 30% is devoted in equal parts to "woodland shade" (trees), "ornamental shrub/tree" and "ornamental flower" garden types.

Four alternative landscaping configurations, in terms of percentage allocations to the garden types, were considered. In each configuration, a portion of land is devoted to one or more other garden types to show possible reductions in the various materials, time and cost.

Configurations (Alt1 to Alt4) are shown in Table 6.8. The objectives and net benefit of each are described briefly below.

Table 6.7: Land allocation areas in Huntington neighbourhood

	Area (ha)		Area (ha)
buildings	23.2	sidewalks	5.3
roads	13.9	swimming pools	0
driveways	5.9	new landscapeable area	78.7
parking lots	0	total study area	127.0

Table 6.8: Percentage allocations to garden type for the entire Huntington neighbourhood

garden type	Percent Allocated to each Garden Type				
	current	Alt 1	Alt2	Alt3	Alt4
xeriscape	0	5	0	0	0
woodland shade	10	15	10	10	15
wildflower	0	5	0	23.3	5
conventional lawn	70	50	35	23.3	35
low maintenance lawn	0	5	35	23.3	35
ornamental tree / shrub	10	10	10	10	5
ornamental flower	10	10	10	10	5
vegetable garden	not available				
greenhouse	not available				

The objective of Alt1 is to explore a small reduction in conventional lawn area by converting 20% of it, in equal amounts, to low water demand options (e.g., xeriscape, woodland shade, wildflower, and low maintenance lawn). Here, significant reductions (≥ 9%) have been achieved for most variables, over the current configuration, with the exception of cost (Table 6.9). Less significant reductions in cost (≈5%) in this alternative are attributed to the costs of tree and shrub specimens for xeriscape and woodland shade garden types. The second configuration (Alt2) explores the effects of converting half of the conventional lawn to low maintenance lawn. For Alt2, considerable reductions are achieved for all measured variables (Table 6.9), most in excess of 20%. In the third configuration (Alt3), two-thirds of the existing conventional lawn area has been converted, in equal parts, to other options that would be relatively easy to implement (e.g., wildflowers and low maintenance lawn). Again, significant reductions in measured variables (all >26%, except cost) have been achieved. The ornamental garden types have considerably higher rates of water, pesticide and fertilizer consumption, compared to the other garden types (CMHC, 2000a). The fourth configuration (Alt4) shows how a slight reduction in these ornamental garden types - 5% for each - can lead to further reductions. Substantial savings (in all variables except gasoline consumption) have been achieved by these 5% shifts (compare Alt4 to Alt2 in Table 6.9). These four

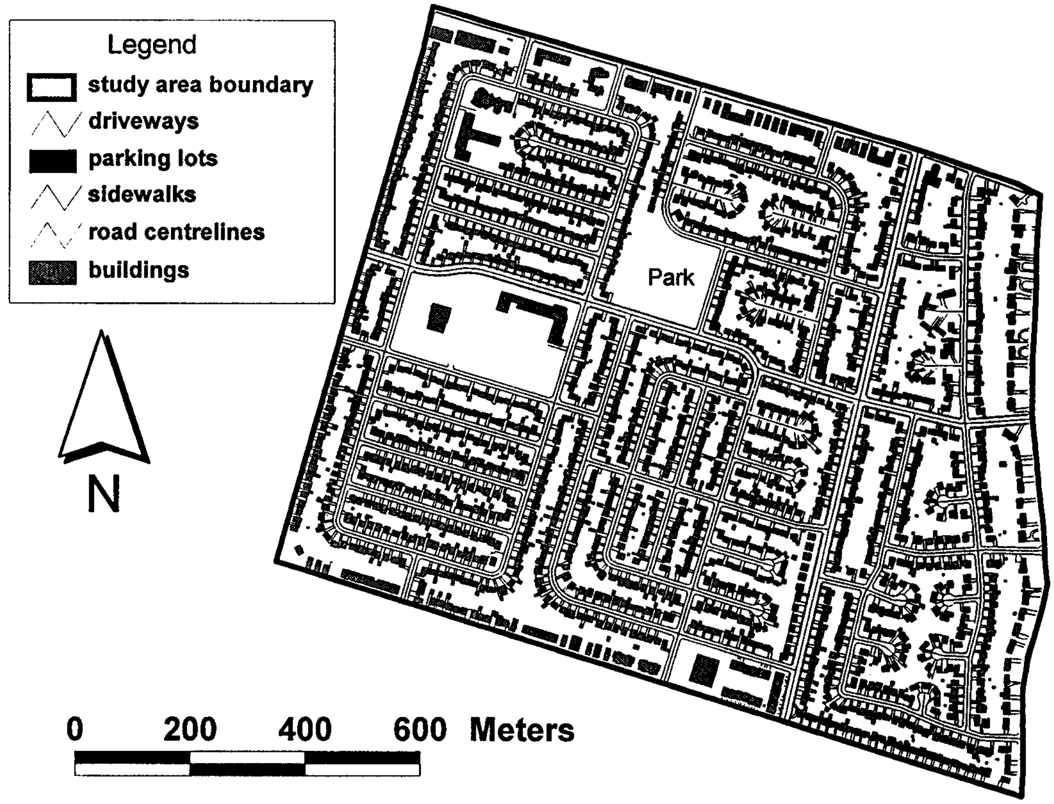


Figure 6.5: Map of Huntington neighbourhood used in NG application 1

configurations have investigated savings to be achieved with the implementation of neighbourhood greening at the scale of the neighbourhood. Similar savings (in percentage terms) can be achieved by application to a smaller area such as an individual home or park, as shown in the next application.

Table 6.9: Net neighbourhood benefits (potential changes in landscaping variables) if alternatives applied for the entire Huntington neighbourhood

	Actual Rates		**Percent Change from the Current Case**			
variable	**current**	**Alt 1**	**Alt 1**	**Alt2**	**Alt3**	**Alt4**
water consumption (m^3/yr)	43700	39600	-9	-24	-27	-44
gasoline consumption (m^3/yr)	18100	13600	-25	-24	-48	-23
pesticide use (kg/yr)	3740	2920	-22	-40	-52	-50
fertilizer use (kg/yr)	65200	52100	-20	-32	-47	-44
time inputs (days/yr)	4536	4935	9	-8	-3	-31
cost (\$/yr)	558,800	531,200	-5	-20	-26	-40

- *NG Application 2*

In the second application of the NG extension, the park within the Huntington neighbourhood is considered. The park has an area of approximately 2.3 ha and is predominantly mown turf (Figure 6.6). There are several individual deciduous trees within the park itself as well as a perimeter of street trees. Most of the trees appear to be less than 15 to 20 years old. It is estimated that approximately 90% of the park area is conventional lawn and the remainder is treed (woodland shade). This is the assumed current landscaping. Four alternative landscaping configurations are considered for the park to reduce consumption of water and other materials (Table 6.10). In each configuration, a portion of land is devoted to one or more other garden types to show what magnitudes of reduction could be possible.

For the first configuration (Alt1), the park has been designated to passive recreational uses, hence there is no need for conventional lawn. The existing lawn has been converted to woodland shade and wildflower in equal proportions. In the second configuration (Alt2), the use of a low maintenance lawn is considered; all the conventional lawn is converted to the lower maintenance option. A variety of park uses are considered in the third configuration (Alt3), including: naturalization, open mown fields (for children to play) and a community

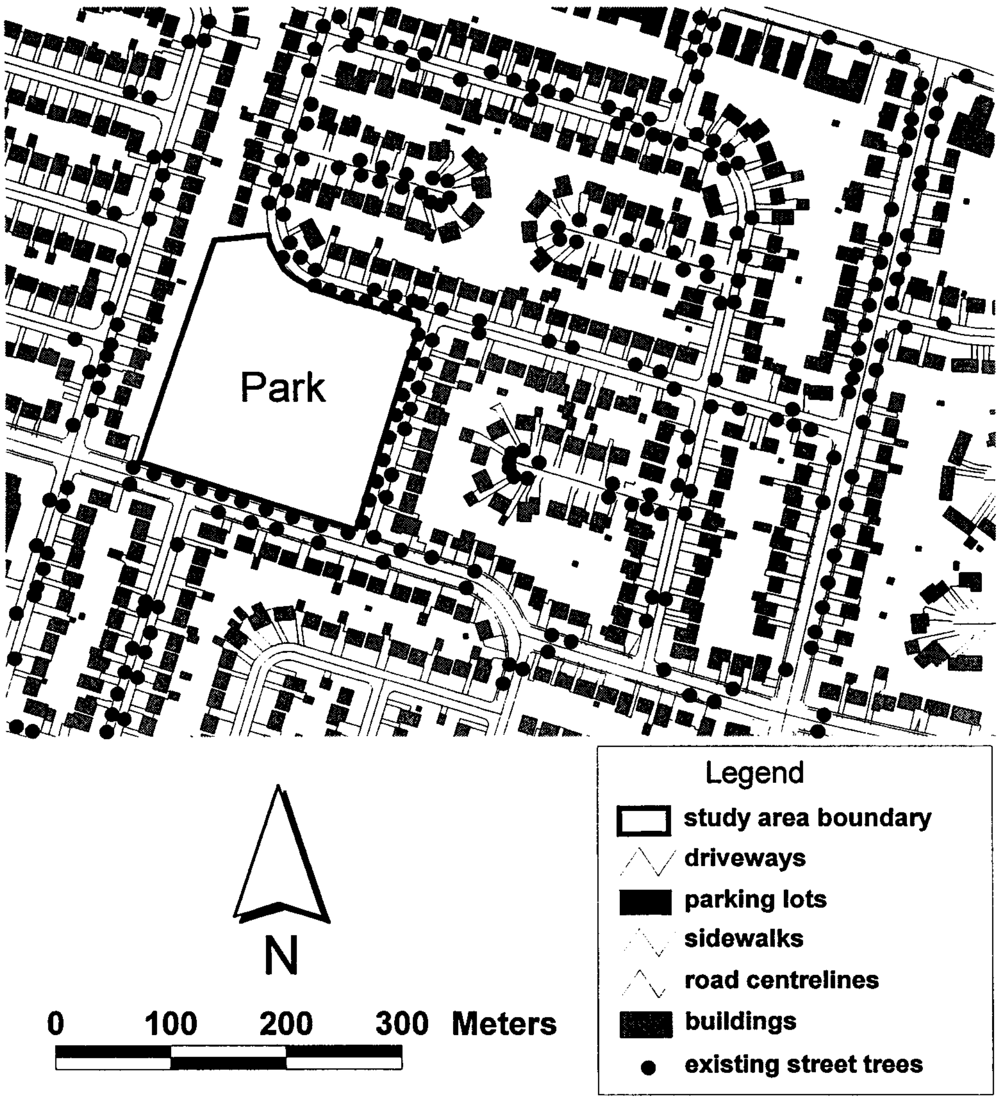


Figure 6.6: Map showing study area used in NG application 2

garden. The installed community garden has 85 plots - each with an area of 16 m^2 - covering approximately 6% of the park area. The remaining conventional lawn has been converted in equal proportions to low maintenance lawn and woodland shade. The final configuration (Alt4) considers the succession of the site to the native vegetative community (i.e., forest), in which 100% is devoted to the woodland shade garden type.

Table 6.10: Percentage allocations to garden type for the neighbourhood park

garden type	Percent Allocated to each Garden Type				
	current	**Alt 1**	**Alt2**	**Alt3**	**Alt4**
xeriscape	0	0	0	0	0
woodland shade	10	55	10	52	100
wildflower	0	45	0	0	0
conventional lawn	90	0	0	0	0
low maintenance lawn	0	0	90	42	0
ornamental tree / shrub	0	0	0	0	0
ornamental flower	0	0	0	6	0
vegetable garden	not available				
greenhouse	not available				

The actual consumption of the various materials, time and cost, based on estimated consumption rates from CMHC (2000a), is shown for the current landscaping configuration and Alt1 in Table 6.11. Percentage reductions, from the current case, are shown for each of the four alternative configurations. The least drastic of the four, Alt2 (change to low maintenance lawn), provides considerable reductions for all 6 variables shown in Table 6.11. Water, fertilizer and pesticide use all drop by more than 84 percent, and there are very significant savings in gas, time and cost, achieved by less frequent mowing and the use of slower growing grass species.

Table 6.11: Potential changes in landscaping variables measured for the neighbourhood park

	Actual Rates		Percent Change from the Current Case			
variable	**current**	**Alt 1**	**Alt 1**	**Alt2**	**Alt3**	**Alt4**
water consumption (m^3/yr)	860	500	-42	-92	-30	-22
gasoline consumption (m^3/yr)	680	10	-98	-47	-75	-100
pesticide use (kg/yr)	110	0	-100	-100	-95	-98
fertilizer use (kg/yr)	1880	0	-100	-84	-91	-100
time inputs (days/yr)	68	84	23	-40	30	32
cost ($/yr)	10,900	4,830	-56	-75	-34	-38

The remainder of the configurations considered are more drastic changes in landscaping (than Alt2), and represent significant departures in the current utilization of the park. For Alt1 (passive recreation), reductions in most variables exceed 50%. There is an increase in the time to maintain such a site, at least initially, to assist the establishment of the woodland shade areas. Alt3 produces a similar result as Alt1, although reductions in water, time and cost are not as large, due to the introduction of a community garden. The community garden has higher consumption rates for each variable. Consumption rates are not available for vegetable gardens. Therefore, in this example, the community garden area has been allocated to the "ornamental flower" garden type. Community gardens may have similar estimates for water, gas, time and cost as ornamental flower gardens. However, since organic farming is to be practised on the community garden plots (i.e., no fertilizer or pesticide), the amount of fertilizer and pesticide used has been over-estimated. Reversion of the site back to a forest clearly provides benefits in terms of the effective cessation in use of gas, pesticides, and fertilizers, but also has an increase in time for management over conventional landscaping. This is likely due to the need for enhanced succession, as described in Hough (1995), to help speed up the process of natural succession.

- *NG Application 3*

The third application of the NG extension considers the selection of the best location(s) for a community garden in the neighbourhood. The beneficiaries of the community garden, as discussed earlier in this chapter, are assumed to be the residents of multi-unit dwellings. In this application, four potential facility locations are considered, as shown on Figure 6.7. Two of these locations (numbers 3 and 4) are located in a neighbourhood park, one (number 1) is adjacent to the community centre, and the final one (number 2) is on the SE corner of a field south of the school. These sites exhaust the available parcels of publicly-owned land large enough for a community garden facility.

Two runs have been completed to demonstrate the selection of the best facility (Table 6.12). In Run 1, two facilities are to be selected (from the available 4), subject to a minimum number of 100 plots. This will provide a gardening plot for approximately 1 in 8 residents, given that the estimated number of multi-unit dwellings in the neighbourhood is 773. It is likely that interest in the community garden plots may not be that high initially, or there may be a limited budget to fund such an installation. Hence, a second run (Run 2), considers the installation of just a single community garden facility of 50 plots. The results are shown in Table 6.13. If two facilities are to be constructed (Run 1), facility numbers 2 and 3 are the best facilities to choose, as they provide the smaller weighted route distance (607 m) to be travelled

Table 6.12: Constraints for the selection of facility locations for community gardens

	Number of Potential Sites	**Number of Sites to Build**	**Number of Plots Required**	**Area Per Plot**
Run 1	4	2	100	16 m^2
Run 2	4	1	50	16 m^2

from the multi-unit dwellings. If only one facility is to be constructed (Run 2), the best facility is number 4 with a weighted route distance of 819 m, considerably higher than Run 1.

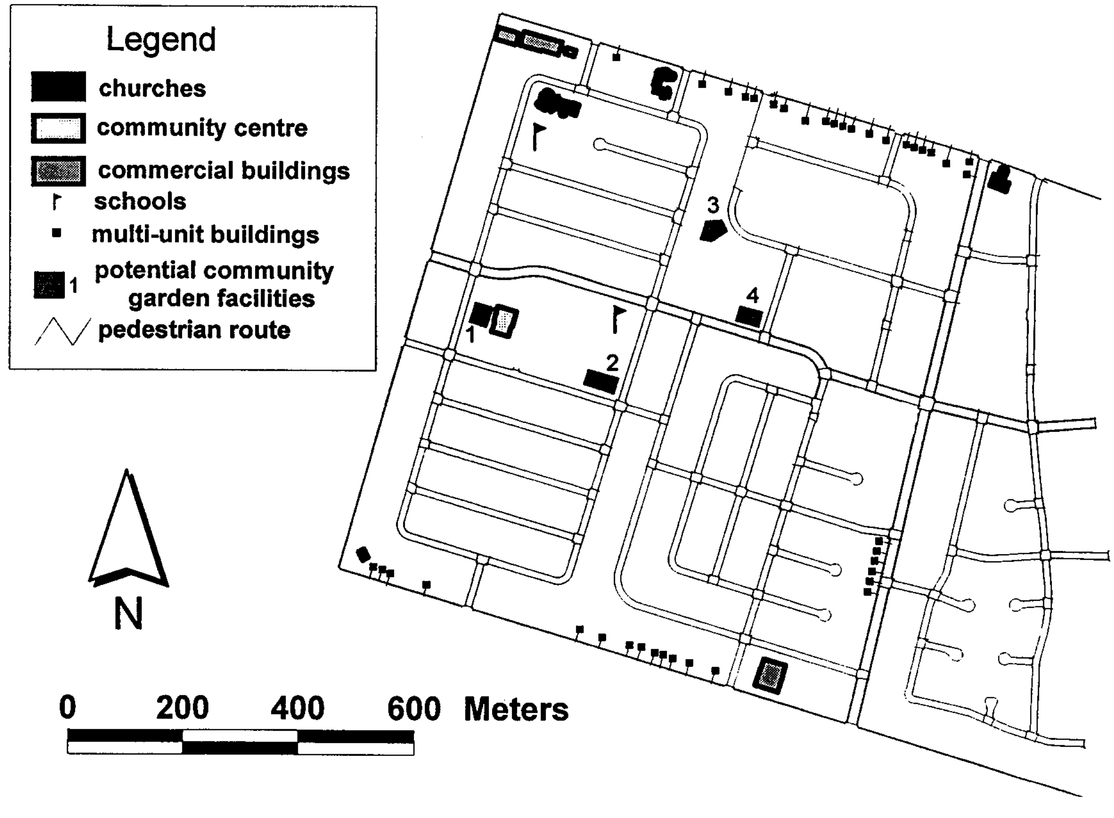


Figure 6.7: Map showing four potential facility locations for community gardens

Table 6.13: Results from the selection of facility locations for community gardens

		Chosen Facility Locations	**Weighted Route Distance**	**Number of Plots Provided**
Run 1	Best Configuration	2, 3	607 m	177
	2nd Best Configuration	1, 3	666 m	153
Run 2	Best Configuration	4	819 m	71
	2nd Best Configuration	3	824 m	78

- *NG Application 4*

The fourth application of the NG extension generates a street tree planting schedule, with the overall objective of greening the streetscape. A planting schedule is developed for a portion of the Huntington neighbourhood, as shown in Figure 6.8. This study area is approximately 13.1 hectares, and contains 226 single family homes, 14 multi-unit buildings, and 224 existing street trees. The number of street trees to be planted is based on a number of user-inputted constraints. In this example, the following constraints were used:

- desired spacing of street trees is 20 m;
- installation cost is $300 per tree;
- planting budget is $10,000 per year.

A spacing distance of 20 m approximately mimics the spacing of the single family homes in the study neighbourhood. Hence, the outputted greened streetscape should, in theory, have approximately one tree in front of every home, and a corresponding number in front of other structures depending upon their lot frontages. Installation costs of street trees vary by age, size and type of tree. Nurseries contacted in the Hamilton area provided a range of costs for Maple and Oak trees. For a 2-inch calliper, 7 to 8 year-old Maple, the approximate cost (including installation) ranged from $275 to $330. The same size and age of Oak was approximately $20 more expensive. The planting budget is an assumed value. The number of street trees to be planted, to meet the above constraints, is 144. These are to be planted over a 5-year period, at a rate determined by the tree cost and annual planting budget. A 5-year planting schedule (colour corresponding to the year of planting) for these 144 trees is provided on Figure 6.9. This planting schedule could be further subdivided into planting maps for year 1, year 2, year

3, etc., which could then be provided to the actual crews doing the planting. The planting locations suggested by these maps, however, are approximate only. Locations in front of dwellings and other structures would need to be adjusted once on-site, to account for the location of under- and above-ground utilities and driveways. As well, planting locations that may compromise traffic safety, by reducing sight distances at intersections, should be assessed by a transportation engineer.

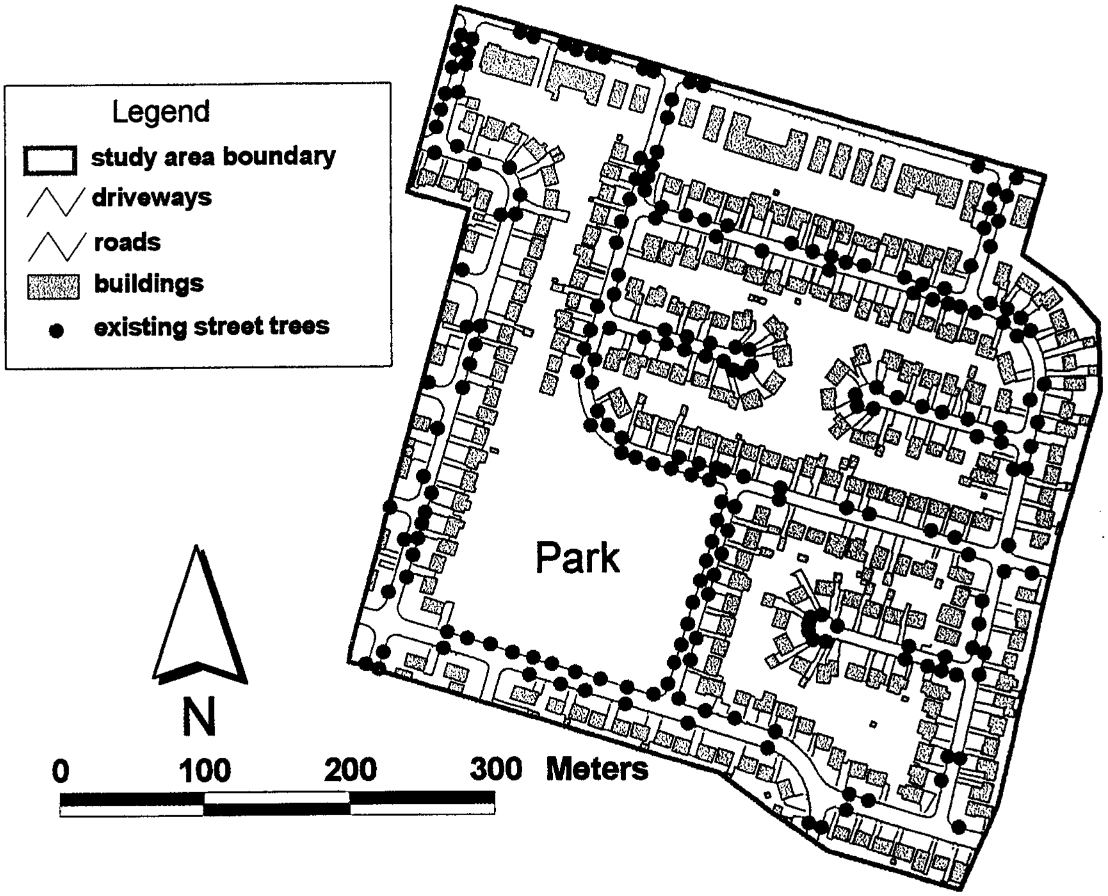


Figure 6.8: Map showing the locations of existing street trees for a portion of the Huntington neighbourhood, as surveyed April 2001

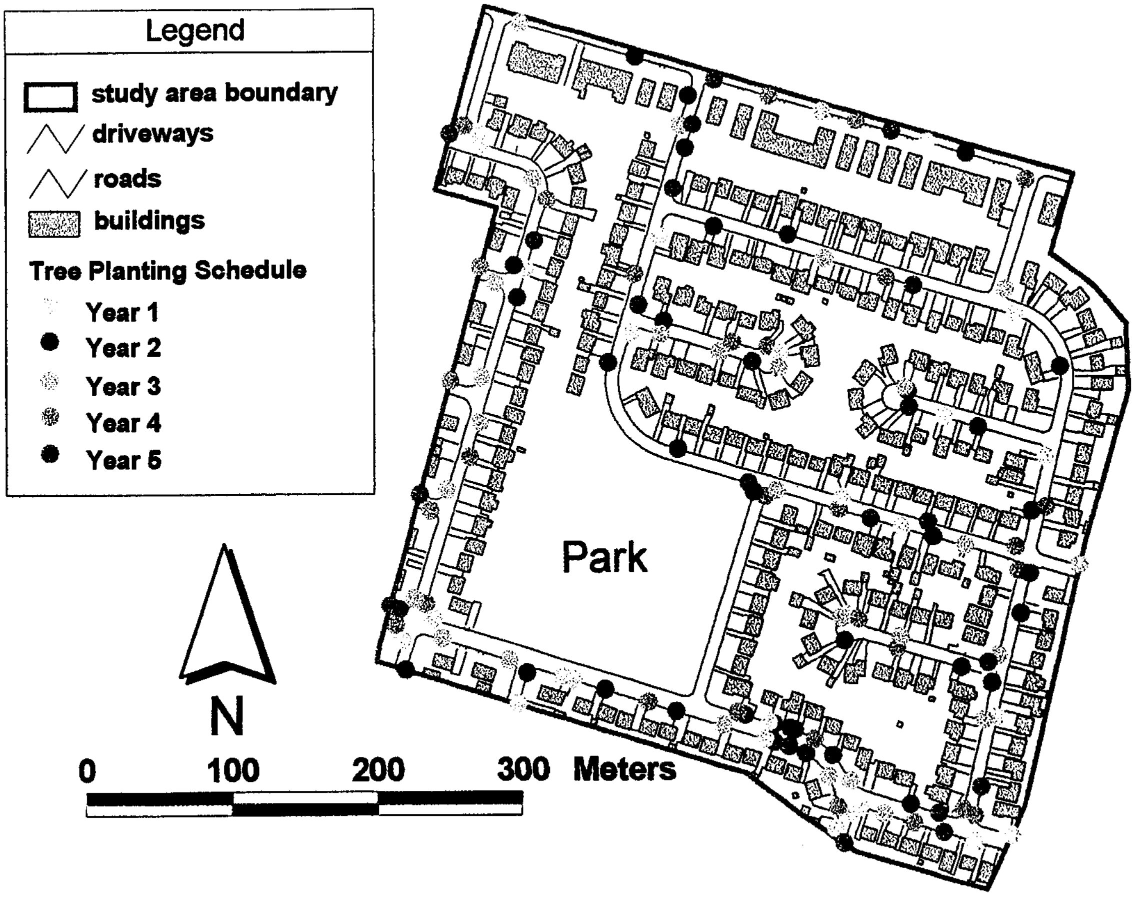


Figure 6.9: A 5-year planting schedule generated for the area shown in Figure 6.8

- *NG Application 5*

In the final application, the extension's ability to generate maps of comprehensive neighbourhood greening programs is demonstrated. These maps are generated using the menu option "View and Place NG Features", in which the user can digitize the locations of the neighbourhood greening features. Figure 6.10 is an example of a greening program that could be implemented for that particular portion of Huntington neighbourhood. This program incorporates various aspects of neighbourhood greening which have been considered in the four applications (of the NG extension) already discussed. In the second application, land areas in the park were allotted in the following percentages: 52% to woodland shade (i.e., naturalization); 42% to low maintenance lawn; and 6% to a community garden (see Alt3 on Table 6.10). The map reflects, in a schematic manner, areas devoted to community gardens and natural areas within the park (Figure 6.10). The peninsula-shaped natural area in the figure encompasses a pre-existing ridge in the park, which is already partially treed. The selected community garden (north part of the park) was facility #3, ranked as one of two "best" facility locations shown in Table 6.13. Other natural and quasi-natural areas are proposed for sites adjacent to schools and other public buildings. Naturalization projects on school sites are being promoted in Canada by the Evergreen Foundation (2001). Two small sites for naturalization are indicated on the neighbourhood's two school properties (Figure 6.10). There is considerable conventional landscaping surrounding the community centre in the western part of the neighbourhood, which is not utilized as playing fields. This area could certainly be a candidate for quasi-naturalization in which wildflowers could be planted, and subject only to periodic mowing and watering. The playing fields, south of the school at the bottom of Figure 6.10, are left intact to be used for school and community sporting activities. The final feature indicated on the figure are the greened streetscapes, which have been addressed in the generation of a planting scheme for the north-central portion of the Huntington neighbourhood.

This map (Figure 6.10) is an example of a neighbourhood greening program. It provides a useful summary of a plan for greening, depicting changes in the implementation and management of a neighbourhood's green spaces. A broad overview of a program afforded by this map could be presented to the neighbourhood's residents at a public meeting at the time of planning and re-development. Details on specific neighbourhood greening features could then be presented using maps shown earlier (e.gs., Figures 6.7 and 6.9).

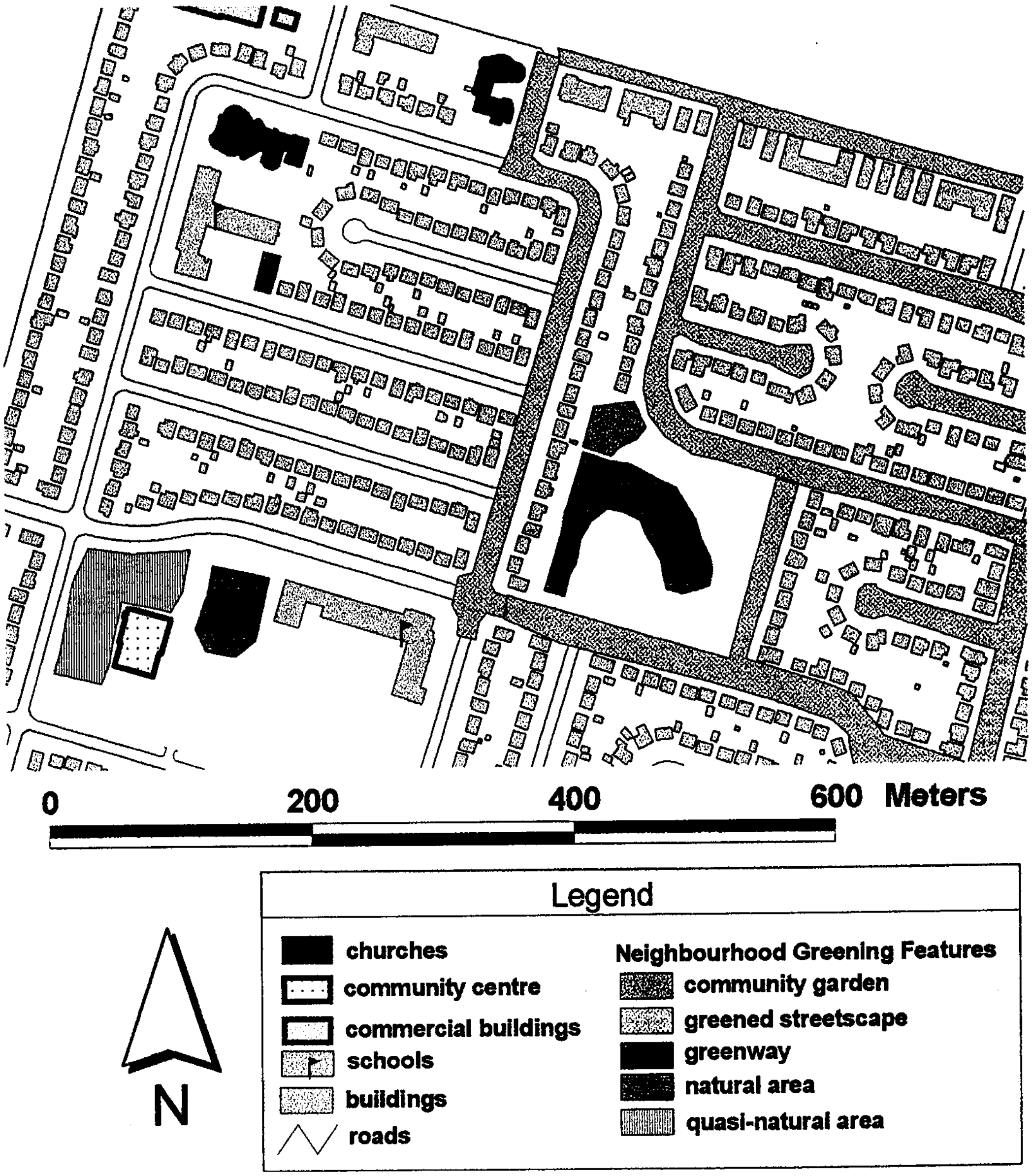


Figure 6.10: Greening program for the northwest corner of Huntington neighbourhood

6. 6 Conclusion

This chapter has covered a broad range of neighbourhood greening features available at both the neighbourhood and household scales. The primary objective in greening a neighbourhood, under the umbrella of sustainability, is to encourage green space management that uses techniques well-aligned with nature. These "naturalization" techniques rely less on commercial pesticides and fertilizers and regular mowing or pruning. These have been shown to provide substantial cost and time benefits in addition to their ecological benefits, which can be used to argue for the greater use of naturalized landscaping in our communities. As well, the neighbourhood greening methodology is aligned to sustainable community strategies in that it provides means to encourage local food production, through the addition of community gardens, and to stimulate more pedestrian travel, through the enhancement of streetscapes by planting street trees.

The prototype decision support tool borne out of the greening methodology - *NG extension* - provides government agencies, private groups and individuals with a number of useful options in generating and evaluating plans for neighbourhood greening. In particular, options are available for selecting the best locations for community gardens and playgrounds and for generating street tree planting schedules. Maps of greening plans, as developed in section 6.5, would be useful to include within reports and presentations to the public.

There is still further work to be done on quantifying other benefits of neighbourhood greening. Trees, in particular, have capabilities of reducing atmospheric pollution and urban heat island amelioration, although by how much is not well known. In addition, considerable savings in energy can be realized through the strategic placement of vegetation around buildings. If urban air quality continues to deteriorate in the future, as it has in the recent past, there is likely to be demand for these neighbourhood greening strategies which could reduce energy consumption and air pollution.

7. CONCLUSIONS AND RECOMMENDATIONS

The main objective of this dissertation was to develop a conceptual model and related methodologies to ameliorate a number of the deficiencies of conventional suburban neighbourhoods. These neighbourhoods have long been criticized as contributing to the automobile dependence and socio-economic segregation of communities in Canada and the U.S. These characteristics have led others to describe the conventional suburban form as unsustainable (Tomalty *et al.*, 1994; Van Vliet, 1994). The term "sustainability" owes its origins to the widely quoted book, *Our Common Future* (WCED, 1987), a landmark publication in which the limits of human population and economic growth were questioned. The concept of sustainability has evolved considerably from this book's definition of "sustainable development", and is now considered to be comprised of three equally weighted components: 1) economic; 2) social; and 3) environmental, each representing the leg of a three-legged stool (Tomalty *et al.*, 1994). Sustainability requires a careful balancing of these three components.

In response to criticisms of the conventional suburban neighbourhood (Rees and Roseland, 1991; Christoforidis, 1994; Van Vliet, 1994) and to the growing adoption of urban sustainability principles in city and regional planning strategies (Regional Municipality of Hamilton-Wentworth, 1992; Sustainable Seattle, 1993; British Columbia RTEE, 1994), a need was identified to consider how existing conventional suburban developments could be altered to a more sustainable form. New suburban communities and neighbourhoods (i.e., greenfield developments) can be constructed with sustainability principles in mind and there are computer-based decision support tools available to help in the development and evaluation of such community designs (Churchill, 1997; Criterion, 1998; Meyn, 1999). There are, however, no similar decision support tools available to generate retrofitting alternatives for enhancing the sustainability of existing conventional suburban neighbourhoods. This dissertation had the aims of developing methodologies to retrofit conventional suburban neighbourhoods and to compile these methodologies into an ArcView GIS-based decision support framework.

This dissertation has identified nine individual aspects of the conventional suburban neighbourhood to be retrofitted, addressing everything from land use to traffic calming, from green space naturalization to pedestrian connectivity, from neighbourhood density to water usage (as depicted in Table 1.1). The conceptual model for suburban retrofitting, described in chapter 3, has associated methodologies for each of these nine aspects. Of the nine methodologies, three have been compiled into distinct (rather than integrated) ArcView GIS extensions and were discussed at length in their particular chapters: pedestrian connectivity (chapter 4), neighbourhood traffic calming (chapter 5), and neighbourhood greening (chapter 6). Development of ArcView extensions for the remaining six aspects, equally important to the overall objectives of suburban retrofitting, and the integration of all nine aspects in a complete decision support system are envisioned to be completed in future research (see section 7.2). The major contribution of this research is the conceptual model for suburban retrofitting, which provides a framework through which one could explore possible reconfigurations of existing conventional suburban neighbourhoods.

This concluding chapter is structured in two sections. In the first section (7.1), material relating to the suburban retrofitting conceptual model is provided, followed by material for each of the three expanded methodologies. Specific conclusions are highlighted for each in a bulleted list. The final section (7.2) outlines some recommendations for future work on suburban retrofitting.

7.1 Conclusions

Suburban Retrofitting

The conceptual model provides retrofitting methodologies for nine neighbourhood aspects (as shown in Table 1.1). The entire success of suburban retrofitting for greater urban sustainability would appear to be tied to increasing residential density, as discussed in section 3.2.4. Achieving density higher than that typical of conventional suburban developments may provide sufficient concentration to make transit services economically viable (Pushkarev and Zupan, 1982); provide sufficient population to support local commercial activities (Berry and Garrison, 1958); and reduce development pressure on neighbouring agricultural areas. It is not suggested that high densities such as those found in southeast Asian cities be adopted, but rather some intermediate level similar to that found in European cities that have lesser automobile dependence than cities in the U.S., Canada or Australia (Newman and Kenworthy, 1989). The following material summarizes the general conclusions from, and contributions of, the conceptual model for suburban retrofitting.

- The nine aspects of the conventional suburban neighbourhoods to be retrofitted are physical characteristics that could be altered to a more sustainable condition. They primarily address the environmental component of urban sustainability, by attempting to provide retrofitting solutions that lower automobile dependence, and lessen the usage of water, energy and other materials. Lowered automobile dependence should provide communal health benefits with regards to air quality and increased personal health (i.e., heightened by greater walking and cycling).

- Lowering automobile dependence is a multi-faceted problem, as there are numerous reasons our society is automobile-dependent. Retrofitting methodologies provided in this dissertation, with the aim of reducing automobile dependence, recognize the importance of:
    - integrated land uses (addition of local commerce, employment)
    - promotion of other modes of transportation (street re-design for traffic calming and multi-modal use; enhancing pedestrian and cycling connectivity); and
    - raising residential densities to levels that would support regional transit systems.

- The work coded and compiled into ArcView extensions has provided prototype tools to address automobile dependence (*PRD Evaluate* and *NTC* extensions).

- As shown in the above point on lowering automobile dependence in suburban neighbourhoods, the nine aspects to be retrofitted have numerous interdependencies between one another, and two or more aspects often work together to achieve specific goals. Figure 3.1 and Table 3.1 show a list of these interdependencies to be considered when making decisions for suburban retrofitting.

- The use of GIS for this application makes the processes of scenario generation and evaluation easier for the decision maker, given the volume of information and data needed in suburban retrofitting.

- The spatial configuration of suburban retrofitting at the regional or metropolitan scales, as outlined in the conceptual model, will be governed by the location and form of regional public transit facilities. Transit stations (or hubs) will become neighbourhood centres around which increased density, commerce and employment are to be concentrated in the model.

- The proposed reconfiguration of commercial activities within residential neighbourhoods will involve a decentralization of activities in space and scale from power centres and regional malls. Furthermore, the literature on sustainable communities advocates principles relating to the production of durable goods, repair and recycling of goods rather than disposal, loyalty to the local retailer/producer and human-scale commercial enterprises. These principles do not bode well for the present-day economy that aims to increase economic prosperity and development through growth in consumer spending, nor for regional malls and power centres that rely heavily on access by automobile.

- A key objective of introducing local employment into the conceptual model for suburban retrofitting is to reduce (and ultimately eliminate) the need for commuting long distances to work. Two short term solutions were identified: 1) creating better transit linkages between key nodes in a particular metropolitan area, and 2) encourage the population to live closer to work, reducing personal costs and time for transportation. Longer term solutions should diversify land uses to a mixed use pattern in both current employment-focussed areas (CBDs and edge cities) and current residential-focussed areas (suburbia).

- The promotion of local food production in the conceptual model aims to encourage people to become more self- and community-reliant, rather than dependent on the agricultural productivity of a distant state or country. Elements of a local food production strategy include: 1) provision of community gardening plots; 2) planting of fruit and nut trees as landscaping; 3) encourage residents to use backyards for vegetable gardens and greenhouses, and 4) encourage grocery stores to promote locally-produced goods.

- A number of strategies have been proposed for reductions in water use and wastewater generation. Reductions in water use are achieved through changed personal habits and a shift towards the use of more naturalized landscaping techniques (e.g., xeriscapes). The amount of wastewater generated can be reduced through the use of porous paving materials, construction of drainage swales or infiltration basins, and the construction of cisterns to collect rainwater.

- With regards to the implementation of retrofitting of individual neighbourhoods, the conceptual model addresses three fundamental points: 1) the planning horizon over which retrofitting activities are to take place; 2) the necessity of the coordination of planning efforts done at a regional scale together with individual neighbourhood-scale efforts; and 3) the timing (or order) for retrofitting activities. Each of these points is discussed separately in a subsequent bullet.

- On the issue of planning horizon, there are retrofitting aspects which can be implemented with relative ease over a short time period (e.g., pedestrian connectivity, initiation of neighbourhood greening, traffic calming, streetscape aesthetics), while other aspects speak to more fundamental changes that may take several decades to reach objectives (e.g., addition of viable commercial and employment components, increased density to support transit). These contrasting time periods for planning and implementation need to be recognized and incorporated into community plans, so that neighbourhood alterations, which are likely to be small in any given year, reflect an incremental improvement towards overall goals.

- On the issue of scale, the developed conceptual model has embraced the neighbourhood as the preferred planning scale for suburban retrofitting. However, it will be important to ensure that any changes at the neighbourhood level are aligned with broader regional-scale objectives. As was argued in chapter 3, it is impossible to discuss issues of sustainable transportation, wildlife habitat or hydrology without considering the regional planning scale. The developed conceptual model therefore recognizes, in the context of transportation planning, the need for the planner / municipal engineer to clearly identify the current and future corridors for a regional transportation scheme, along which a series of neighbourhood and industrial hubs could be developed.

- On the issue of timing, there is a distinct order for the various retrofitting activities. For example, the identification of a regional transportation network and neighbourhood hubs, mentioned in the previous point, needs to be done prior to any concentration of density, commerce or employment. Once a network of hubs is identified, the short term aspects for retrofitting can be implemented, particularly those that are somewhat independent of the others (e.g., pedestrian connectivity, neighbourhood greening). Implementation of some aspects (e.g., traffic calming) may be lengthier if installation of certain traffic calming measures is to be coordinated with scheduled street renovations. It is expected that these short term aspects could be implemented within a 10-year period. The achievement of the longer term aspects will likely be determined by the insulation of the envisioned community from the political process, whereby a change in government would not radically shift away from a course mapped out in the initial framework. There should be flexibility and opportunity for review in the process, but not for abandonment or reversal of a plan that may take 20 to 40 years or more to realize.

- And finally, the conceptual model for suburban retrofitting has implications for the way in which communities are currently planned, built and serviced. Zoning restrictions and transportation design standards will certainly need revisions in light of proposed retrofits such as: densification, diversification and mixing of housing types along streets, reduction of setbacks in added commercial developments, and lane number and width reductions to achieve calming (especially along arterial streets). Some jurisdictions have altered their standards to permit New Urbanism suburban developments, although these are still the exception to the standard ways in which sprawl developments are built. Similarly, transportation engineers will need to be convinced of the benefits of calming arterial streets to see that calming measures are incorporated into future versions of TAC and CITE (1998) or Ewing (1999).

Pedestrian Connectivity

The need to retrofit improvements to a neighbourhood's pedestrian network, such as sidewalks or pedestrian paths linking isolated cul-de-sacs, is based on a general level of inaccessibility to local neighbourhood destinations within a reasonable walking distance of the suburban home. This reasonable walking distance is generally agreed to be approximately 400 m (Atash, 1994; Aultman-Hall *et al*, 1997). Because of the curvilinear street patterns of conventional suburban neighbourhoods, residents tend to be discouraged to walk within or across their neighbourhoods. A walk to the local elementary school can often be a surprisingly long and convoluted route. The term "pedestrian connectivity" was introduced as a measure of both the directness of route and the route distance for each home-destination trip. The methodology for retrofitting pedestrian connectivity evaluates alternative additions of pedestrian paths (to an existing pedestrian network) to determine what linkages would be required to improve walking accessibility to neighbourhood destinations for a sizeable majority of a neighbourhood's residents. Improvements to the pedestrian environment, through the provision of more direct and shorter routes than previously available to the neighbourhood residents, may provide an incentive to reduce neighbourhood car trips and to stimulate walking trips. Increased pedestrian travel and better connections to a regional transportation network will ultimately lead to more sustainable and responsible transportation alternatives. A decision support tool - *PRD Evaluate* extension - has been developed in ArcView GIS to generate and evaluate alternatives with improved pedestrian connectivity. The conclusions from the developed methodology and associated decision support tool for pedestrian connectivity are as follows:

- The methodology has been developed for retrofits to existing communities. As well, it could be utilized for the planning of new communities or comparing conventional suburban layouts with neo-traditional neighbourhood plans.

- The methodology provides a means to assess network route distance for origin-destination pairings, so that constraints on acceptable walking distances can be incorporated into the design of more sustainable suburban developments.

- The primary benefit of improving pedestrian connectivity of neighbourhoods is to encourage greater use of walking for local trips. A second benefit, through increased pedestrian travel, is the fostering of a sense of community through interaction of neighbours and pedestrians.

- A pedestrian route directness (PRD) ratio (of Hess, 1997) is utilized with developed connectivity cases to evaluate neighbourhood pedestrian connectivity.

- Four connectivity cases have been developed: two acceptable ones and two unacceptable ones. Acceptable connectivity occurs in neighbourhoods where route distances between origin-destinations are as direct as possible (do not exceed the critical value) but route distances may or may not exceed the critical value. If they exceed the value, people will not likely walk and something more fundamental will have to change in the neighbourhood (e.g., will have to consider adding a closer destination or moving the origin). Unacceptable connectivity occurs if the routes are more convoluted, exceeding a user-defined critical value for the PRD ratio. Connectivity can be improved by retrofitting paths or sidewalks to straighten the route.

- The decision support tool evaluates user-defined locations of added pedestrian paths and yields information to the user to assist in the determination of the preferred locations. The actual retrofitting of such connectors (pedestrian paths between isolated cul-de-sacs) then becomes a political process for the planner seeking the approval of impacted residents.

Retrofitted pedestrian paths should incorporate the list of design elements provided in chapter 4.

- In the example shown in chapter 4, a small investment to create 1.1 km of paved pedestrian paths provided substantial improvements in the number of neighbourhood residents having acceptable connectivity to the local elementary school (87% versus 47% prior to the modelled retrofits - refer to Table 4.4). The average PRD ratio in this example dropped from 1.70 to 1.37. These results could be used to develop "target design values" (see section 7.2).
- The example mentioned in the previous point is only one of many analyses that could be done to evaluate the best way to improve a neighbourhood's pedestrian connectivity. A full assessment of a neighbourhood's pedestrian connectivity would consider how route distance and the PRD are lowered by the addition of one or more pedestrian paths, to a number of different destinations.

Neighbourhood Traffic Calming

The implementation of traffic calming, unlike other to-be-retrofitted aspects in the conceptual model, is currently widespread in Canada and the U.S. The use of traffic calming measures in urban areas has evolved in response to resident complaints about traffic volume and speed along neighbourhood streets and how these affect safety for children and pedestrians. There are a variety of measures used to achieve the various goals of traffic calming: reduce speed, reduce volume, or increase the level of safety for pedestrians, cyclists or motorists. Good summaries of traffic calming measures currently in wide application are available in TAC and CITE (1998) and Ewing (1999). The bulk of these measures are applicable for local and collector streets only, as they would impart too severe a restriction on arterial streets (Robinson, 1999). Neighbourhood traffic calming programs typically focus on local and collector streets, as these are the streets along which the majority of people in suburban neighbourhoods live. Less common are applications of traffic calming to arterial streets, as there are few tested measures that would be appropriate for these streets with higher design speeds. Traffic calming is best applied at the neighbourhood scale, calming several streets at a time to avoid diversion of traffic onto nearby parallel routes.

Neighbourhood traffic calming programs are implemented in existing neighbourhoods because of traffic problems that arose following initial development and subsequent growth. Traffic engineers, prior to the widespread acceptance of traffic calming, were commonly more focussed on increasing roadway capacity, safety issues and operational issues (e.g., signal timing). This emphasis led by and large to the suburban street being designed primarily for the car. Road widths are unnecessarily large, with enough room for two travel lanes and on-street parking, despite the reduced need for on-street parking due to adequate driveway and garage vehicle capacity. These existing road design standards are likely the cause of high speeds observed on neighbourhood streets. There are initiatives underway to rethink street design guidelines for neighbourhood streets, that would be done at the time of initial development (see Table 5.2 for examples). The new standards would constitute "built-in traffic calming" and may avoid the need to retrofit streets in the future. A prototype decision support tool - *NTC* extension - was developed in ArcView GIS to assist transportation engineers and planners in the generation of a neighbourhood traffic calming plan for existing neighbourhoods. Options are available to treat local and collector streets, in ways similar to previous work on traffic calming. In addition, measures for arterial streets developed in this work are part of the comprehensive tool for neighbourhood traffic calming. The conclusions from the developed methodology and associated decision support tool for neighbourhood traffic calming are as follows:

- Using the NTC extension, the user can evaluate a neighbourhood's need for traffic calming, based on observed traffic speeds and volumes, and prepare a map showing areas in need of calming.

- Knowledge of a neighbourhood's special management zones is assumed. These zones are used by the tool to guide the selection of certain traffic calming measures. Certain zones (e.g., school zones and playgrounds) may have unique traffic calming management objectives for speed and safety, while others (transit and emergency vehicle routes) are not receptive to large vertical deflections or substantial delay times caused by certain calming measures.

- Decision making for neighbourhood traffic calming must accommodate comments of affected parties (residents, emergency service vehicles, transit operators) during planning, design and implementation stages.

- An extensive database on traffic calming measures has been created within the NTC extension. This database contains specific information about measures such as: 1) its description; 2) its intended benefits (and actual data on effectiveness if available); 3) its negative impacts; 4) other traffic calming measures it is typically installed with; 5) locations which should be avoided; and 6) its cost. Each measure also has visual information available, in the form of photographs, design sketches and tabulated benefits. Knowledge of these measures then allows the user of the NTC extension to create a map of a comprehensive neighbourhood traffic calming plan.

- As stated earlier, traffic calming is a relative new comer to transportation engineering in the U.S. and Canada. The effectiveness of many measures has been demonstrated in numerous reports, however, further testing on the success of existing traffic calming measures is on-going, as well as testing of new measures. The NTC extension can be regularly updated as new data or measures become available.

- A second major contribution of this work on traffic calming, in addition to the development of the NTC extension, is the synthesis of measures to calm arterial streets. There has been little experience, to date, in calming arterial streets in Canada or the U.S. The prototype version of the tool contains eight potential calming measures for arterial streets, although their effectiveness for speed reduction remains to be determined. Many of these incorporate specific features that encourage modes of travel other than the automobile (e.g., bike, transit, HOV).

- Canadian and American transportation engineers have been reluctant to calm arterial streets because of their primary function to move traffic through metropolitan areas. In support of calming arterial streets, projects implemented by Macbeth (1998a) in Toronto have shown that an arterial street can be calmed - with significant lane reconfigurations - with no impact on daily traffic volumes.

- This research on traffic calming measures for arterial streets encourages further re-thinking of our streets. Planners and engineers previously designed effective pedestrian-friendly thoroughfares and boulevards, such as those from Europe described in Jacobs *et al.* (1997). Major arterial streets of these forms are described for use in Australia (see WAPC, 2000).

It is suggested that there is opportunity in North America to construct or to retrofit arterial streets with designs different than the conventional model, incorporating a number of the characteristics of similar higher order streets from abroad.

Neighbourhood Greening

The amount of green space in conventional suburban neighbourhoods is quite significant. For example, more than 60 percent of the total area in the Huntington neighbourhood considered in chapter 6 is "landscapeable" area (Table 6.7). This landscapeable area includes both public green spaces (parks, greenways) and private green spaces - yards and gardens of all homes and other buildings in the neighbourhood. Suburban neighbourhood green spaces are typically highly manicured areas, with the homeowner or municipality using substantial amounts of chemical fertilizers and pesticides and employing frequent mowing and watering, all to keep the lawns green and free from weeds and pests. The use of such chemicals is potentially hazardous to human health, with warning signs commonly posted on lawns for several days following chemical applications.

The neighbourhood greening methodology proposed in this dissertation provides decision support to investigate a number of green space management options promoting the greater use of naturalization and organic gardening techniques. These kinds of activities consume less material resources while relieving a homeowner or parks department of the time and associated costs of maintaining the manicured suburban landscape. Other potential benefits achieved through a program of neighbourhood greening are: re-established connections between humans and nature; air quality improvements and energy conservation; and addition of a productive component to green space areas (e.g., community gardens). A decision support tool - *Neighbourhood Greening (NG)* extension - has been developed in ArcView GIS to create comprehensive neighbourhood greening plans comprised of a number of features and management techniques as yet under-utilized in most suburban neighbourhoods. These include natural areas; quasi-natural areas; greenways; greened streetscape; and community gardens. The conclusions from the developed methodology and associated decision support tool for neighbourhood greening are as follows:

- Information about each of the neighbourhood greening features listed in the above paragraph and in Table 6.3 has been compiled into the database of the developed decision support tool. The database summarizes feature descriptions and benefits, recommended locations, maintenance and management issues and photographs of sample installations, and is accessible to the user through a series of dialog boxes.

- The main capabilities of the NG extension are as follows:

    1. Analysis of retrofitting options for neighbourhood greening to provide direct environmental benefits and more sustainable communities. The use of techniques employing indigenous plant species and natural fertilizing options can result in significant savings in cost as well as in the use of water, energy (fuel) and other materials (fertilizer, pesticide). Examples of potential reductions were shown in Tables 6.9 and 6.11.

    2. Analogous to the NTC extension, the NG extension provides the ability to develop comprehensive neighbourhood greening plans comprised of a number of greening features. The associated maps can then be used in a public meeting to facilitate understanding of the proposed greening strategy.

    3. The NG extension, using techniques available in GIS, determines the planting locations for street trees to model a uniformly greened streetscape. Based on tree costs and annual planning budgets, a street tree planting schedule is then determined.

    4. The NG extension also evaluates the best locations of to-be-added neighbourhood greening features, through the use of a simplified p-median location-allocation model. These models are rarely coded in ArcView because of its limited computational capabilities. Coding of this model in ArcView for the current application was successful since the number of potential facility locations was limited to four, a simplification deemed acceptable for the application to community gardens and playgrounds.

- With regards to street tree planting schedules, locations generated by ArcView GIS are relatively crude and do not take into account the location of driveways or utilities. The user of these maps is therefore required, at the time of planting, to adjust the locations for these features once in the field, so that trees are not installed in locations which might compromise the integrity or function of the particular utility. As well, a traffic engineer should be consulted to ensure that proposed locations do not impact the safe operation of intersections.

- Street tree planting should be accompanied by regular maintenance and, when necessary, replacement. Tree populations should be comprised of a variety of species and age classes to withstand the effects of disease and to space replacement times, so that streetscape function and aesthetics afforded by the trees are maintained in perpetuity.

7.2 Recommendations for Future Research

This section provides an overview of recommendations for future research arising out of this work on the development of decision support tools for suburban retrofitting. The majority of these recommendations refer to the overall process of suburban retrofitting developed in the conceptual model. The remainder of the recommendations relate to specific details within the methodologies for the three primary aspects (pedestrian connectivity, neighbourhood traffic calming, and neighbourhood greening).

Suburban Retrofitting

- Prototype decision support tools have been developed and coded into ArcView GIS for three of the nine individual retrofitting methodologies. The remaining methodologies (for the six secondary aspects) could be coded into ArcView GIS in future work.

- The three coded extensions developed in this dissertation are largely independent of one another. Addition of the secondary aspects, and particularly "residential density", will bring numerous complex interdependencies into the decision making process (see Figure 3.1). Hence, future versions of a comprehensive suburban retrofitting tool will require the integration of the nine developed methodologies rather than leaving them as independent extensions.

- The GIS used in developing the prototype extensions was ArcView GIS version 3.1 (ESRI, 1998), which utilizes its own programming language, Avenue, for customizations. ESRI has recently released (spring 2001) a completely revamped version of ArcView (i.e., version 8.1). Key changes in ArcView 8.1 are the adoption of Microsoft's Visual Basic for Applications (VBA) as the customization language, and the provision of more advanced capabilities presently provided by more powerful GISs such as ARC/INFO. It is not currently clear if current extensions (those coded in Avenue) will be operational in the new ArcView. This will have to be explored prior to coding the remainder of the retrofitting methodologies as suggested in the two previous points.

- With regards to the staging of suburban retrofitting, a more prescribed implementation framework needs to be developed. The discussion of "timing" and "planning horizon" in section 7.1 was general in nature. A staging protocol is needed to fully establish an order for undertaking retrofitting activities.

- It was suggested in chapter 3 that wastewater treatment could be carried out for individual neighbourhoods, or groupings of 2 or 3 neighbourhoods, via the use of Living Machine technologies. This approach needs further investigation and verification, which would then be subject to regulatory approval by the appropriate levels of government.

- The scale of suburban retrofitting considered here is the neighbourhood. A logical next step is to consider what improvements could be made at the scale of the individual household. Some of these improvements have been alluded to in this dissertation, including reduced water use in the home, placement of vegetation around a structure to achieve energy use reductions, and options for water and energy collection systems. There is a decision support system, waiting to be developed, that would assist people in the retrofitting of their homes with a number of more sustainable technologies and practices. A model of a more sustainable home, Toronto's "Healthy House", is discussed in CMHC (2000b) and could serve as a starting point for this future research.

- Further to the previous point about scale, there is certainly opportunity to explore the implications of suburban retrofitting at the regional scale. For example, realization of reduced automobile use will be achieved through coordination and development of alternative and effective regional transportation schemes (e.g., transit). A number of other aspects of sustainable community planning are best considered in a broader view than just that of the neighbourhood (e.g., agricultural land preservation, habitat and wildlife biodiversity, and hydrological issues).

Pedestrian Connectivity

- The prototype tool for pedestrian connectivity is currently limited to considering only ten possible destinations, for an unlimited number of origins (see example in chapter 4). Future versions of the PRD Evaluate extension should rectify this limitation so that the number of destinations considered can exceed ten. This could be useful in problems determining optimum siting for destinations such as mail boxes or transit stops, in which more than ten facility locations might be involved.

- Traditional street patterns (i.e., grid) have been shown in this study to have better pedestrian connectivity than conventional suburban street patterns (curvilinear). Further to the point in section 7.1 on results achieved for the PRD ratios, it would be useful to determine a desired "target value" for the PRD ratio which could then be used to guide the retrofitting of pedestrian networks in conventional suburban developments.

- The *PRD Evaluate* extension has been developed to improve pedestrian connectivity. Similar analysis could be done to evaluate "bike connectivity", as there are benefits in having direct and shorter bike routes through the neighbourhood. Research will be needed to determine a critical value for acceptable biking distance, a distance beyond which a person would not cycle for a local trip. In neighbourhoods, separate on-street cycling routes (e.g., painted bike lanes) are not generally provided because of low automobile traffic volumes. Thus, the level of comfort and safety (of individual cyclists) will have an influence on how successful diversion from automobile to bike can be for these local trips.

- The choice of pedestrian paths and sidewalks to be retrofitted to the pedestrian network is currently the choice of the user. The user makes changes to the network and then uses the *PRD Evaluate* extension to re-evaluate the PRD ratios and route distances. A future version of the tool might consider the development of an optimization procedure that would search out the best locations for these paths and sidewalks. The user would then be given a choice of the location(s) to implement (from a list of optimal and near-optimal paths).

Neighbourhood Traffic Calming

- The prototype tool for neighbourhood traffic calming is based largely on the Canadian experience, as summarized in TAC and CITE (1998). To appeal to a wider audience of transportation engineers in the U.S., greater use of U.S. examples and data on effectiveness (than is done in the prototype version) should be completed. The design of the tool is such that additions of new material may be readily made.

- The recommendations provided by the prototype extension on which traffic calming measure(s) to apply in a given situation are still fairly broad. This is a result of the true nature of the breadth of measures appropriate in a given circumstance. Future versions of the NTC extension would aim to provide more focussed recommendations of specific measures based on greater experience with the application of such measures in suburban settings.

- A total of eight measures have been synthesized for application as traffic calming measures on arterial streets. Several of these address transportation issues beyond speed and volume reductions, such as the enhancement of pedestrian and cycling modes. Whether or not such designs can reduce automobile dependence through the prioritization of other modes (e.g., HOV, transit and bike lanes) needs to be determined. The magnitude of such impacts needs to be evaluated, as well as any impacts for speed or volume reduction.

- A series of "buttons" on the ArcView toolmenu were developed to allow the user to digitize specific traffic calming measures. In the current prototype version of the NTC extension, the symbols digitized using these buttons are text symbols only (e.g., L2, L3, C6, A2, ...).

A future version of the extension will have these buttons digitize actual symbols ("icon images") for traffic calming measures. The reason this work was not done for the prototype extension was that it was not apparent if ArcView was capable of handling such icon images on its View window. The new ArcView (version 8.1) mentioned earlier may be capable of rectifying this point.

Neighbourhood Greening

- The prototype tool for neighbourhood greening develops and evaluates green space management objectives at the scale of the neighbourhood. As implied above, future work of retrofitting for sustainability objectives at the scale of the home has a number of greening components. These include: vegetation placement around structures to achieve energy conservation; water use reductions achieved by landscaping changes and collection of rainwater; and, diversion of water away from storm sewers through landscaping and driveway options. These components have received only an overview treatment in this thesis, and would be part of a decision support system for retrofitting a more sustainable home, as mentioned earlier.

- Amongst other benefits, it is conceivable that neighbourhood greening could provide significant air quality and climatic benefits in cities. These benefits include the absorption of air pollutants by trees (Dwyer *et al.*, 1992) and the amelioration of urban heat islands (City of Chicago, 1998). These benefits have not been quantified in the prototype version of the NG extension, but would be interesting additions to be completed in future work.

- Consumption rates for water, materials, gas, time and cost were not available for the vegetable garden and greenhouse garden types. These types were included within the NG extension since they represent important uses of landscapeable area to provide local food sources. Data should be collected, in a manner similar to the other garden types summarized in CMHC (2000a), and incorporated into a future version of the NG extension.

- The tree planting schedule algorithm in a future version of the NG extension could be modified to account for the locations of utilities and driveways (refer also to point made in section 7.1).

- The NG extension does provide general information about each of the proposed neighbourhood greening features. Future supporting files could be developed to provide specific information about the appropriate species to plant in a naturalized area, xeriscaping or other neighbourhood greening features. These details are dependent upon the geographic location in which the tool is used, thus these details would be site-specific information rather than generic information that could be applied across a wide geographic region.

- Gaining public acceptance for the greater use of more naturalized landscaping is no small issue, since the conventional suburban manicured lawn and garden is well entrenched in our culture. People like the ideas of less chemical additives (to food, to land) and saving money, as long as they agree with the outcome. Future research may involve questions surrounding the perceptions of introduced neighbourhood naturalization concepts and what it could mean in terms of re-introduced insects and other animals.

This dissertation provides an initial thrust into the development of computer-based decision support tools for retrofitting conventional suburban developments. Three ArcView GIS-based extensions have been created which provide prototype tools for urban planners and municipal engineers to explore and evaluate a number of retrofitting scenarios. Retrofitting the conventional suburban neighbourhood has been deemed important to achieve society's objective of achieving more sustainable community designs. These suburban neighbourhoods, constructed for much of the last 55 years, have used patterns that have fostered dependence of these areas on the automobile as the primary mode of transportation, and have created socio-economic segregation across our cities.

The achievement of communities suggested by the conceptual model developed in chapter 3 depends on two main factors. Firstly, it is important to recognize that the process of suburban retrofitting is not something that can be achieved over a short time period. Some of the proposed transformations of suburban neighbourhoods will require several decades to realize. With political agendas geared more to 3 to 5 year mandates, the process of suburban retrofitting needs some insulation from changes in government and associated changes in community development philosophy. Secondly, many of the retrofitting procedures suggested in this dissertation are likely to be met with significant public resistance (e.g., NIMBYism). Long existing cultural habits in Canada and the U.S., such as automobile usage and overly consumptive lifestyles, may be difficult to overcome. Many of the processes outlined in the conceptual model will require a significant educational campaign to convince the public of the merits and need for suburban retrofitting, especially in the context of achieving more sustainable communities. Some examples are:

- reducing personal water consumption;
- adopting in-house grey water recycling techniques;
- using more naturalized landscaping techniques;
- supporting neighbourhood commercial enterprises; and
- using public transit.

As well, education will need to accompany the process itself to ensure that the retrofitting objectives and benefits are in fact realized. The process of suburban retrofitting, while likely initiated by staff in community and regional planning departments, will need the full support of politicians. It will be important for politicians to take a leading role in demonstrating to their constituents the benefits of creating more sustainable suburban developments.

Although this dissertation has promoted the concept of sustainable suburban neighbourhoods, it is recognized that suburban neighbourhoods are often components of a larger metropolitan region. Some of the greatest ills in our current urban patterns in North America such as excessive automobile commuting and air pollution, will not be alleviated by considering only neighbourhood-scale retrofitting options. Therefore, urban sustainability needs to be addressed at a variety of scales: home, neighbourhood and region. It is hoped that this work will stimulate considerable efforts at enhancing sustainability at the neighbourhood scale.

REFERENCES

Adler, J., 1995. Bye-bye suburban dream: 15 ways to fix the suburbs, *Newsweek*, (May 15 '95): 40-53.

AirCare, 2001. Homepage for Greater Vancouver's and Lower Fraser Valley's vehicle emission testing program, source: http://www.aircare.ca/, retrieved May 23, 2001.

Alexander, D. and Tomalty, R., 1994. *Urban Policy for Sustainable Development: Taking a Wide-Angle View*. Issues in Urban Sustainability - 6, Institute of Urban Studies, University of Winnipeg, pp. 1-42.

Alexander, E.R., 1993. Density measures: a review and analysis, *Journal of Architectural and Planning Research*, 10 (3): 181-202.

Altshuler, A., 1977. Review of the costs of sprawl, *Journal of the American Institute of Planners*, 43: 207-209.

American Association of State Highway and Transportation Officials (AASHTO), 1994. *A Policy of Geometric Design of Highways and Streets*, Washington, DC, 1006 pp.

Arendt, R., 1994. *Rural By Design: Maintaining Small Town Character*, Planners Press, American Planning Association, Chicago, Illinois, 441 pp.

Atash, F., 1994. Redesigning suburbia for walking and transit: emerging concepts, *Journal of Urban Planning and Development*, 120 (1): 48-57.

Atkins, C. and Coleman, M., 1997. The influence of traffic calming on emergency response times, *ITE Journal*, 67 (8): 42-46.

Aultman-Hall, L., Roorda, M., and Baetz, B.W., 1997. Using GIS for evaluation of neighbourhood pedestrian accessibility, *Journal of Urban Planning and Development*, 123 (1): 10-17.

Bates, D.V., 1994. *Environmental Health Risks and Public Policy: Decision Making in Free Societies*, University of British Columbia Press, Vancouver, 117 pp.

Baetz, B.W., 1994. Creation of landowner compacts for sustainable community development, *Journal of Urban Planning and Development*, 120 (4): 174-182.

Beavis, M.A. and Patterson, J., 1992. *A Select, Annotated Bibliography on Sustainable Cities*, Bibliographica 4, Institute of Urban Studies, University of Winnipeg.

Berry, B.J.L., and Garrison, W.L., 1958. Functional bases of the central place hierarchy, *Economic Geography*, 34: 145-154.

Bicknell, D., 1993. Traffic calming, *Proc. Instn Civ. Engrs Mun. Engr*, 98 (March): 13-19.

Bonczek, R.A., Holsapple, C.W., and Whinston, A.B., 1984. Developments in decision support systems, *Advances in Computers*, 23: 141-173.

Brabec, E., 1994. The economics of preserving open space, In: Arendt, R., *Rural By Design: Maintaining Small Town Character*, American Planning Association Press, Chicago, pp. 280-288.

BC Hot House Foods Inc., 2000. BC Hot House Foods web page, source: http://www.hothouse.com, material dated December 2000, retrieved March 22, 2001.

British Columbia RTEE, 1994. *State of Sustainability: Urban Sustainability and Containment*, British Columbia Round Table on the Environment and the Economy, Victoria, BC.

California Electric and Magnetic Fields (EMF) Program, 2000. "Electric and Magnetic Fields: measurements and possible effect on human health - what we know and what we don't know in 2000", source: http://www.dnai.com/~emf/longfactsheet.PDF, material dated December 2000, retrieved May 16, 2001.

Calthorpe, P., 1993. *The Next American Metropolis: Ecology, Community and the American Dream*, Princeton Architectural Press, New York, 175 pp.

Canada Mortgage and Housing Corporation (CMHC), 2000a. *Definitely in my Backyard: Making the Best Choices for You and the Environment*, source: http://www.cmhc-schl.gc.ca/publications/en/definitely, retrieved November 20, 2000.

Canada Mortgage and Housing Corporation (CMHC), 2000b. "The Toronto Healthy House: Facts and Figures", source: http://www.cmhc-schl.gc.ca/rd-dr/en/hh-lms/toronto/facts.htm, retrieved February 29, 2000.

Chou, Y-H., 1997. *Exploring Spatial Analysis in Geographic Information Systems*, First Edition OnWord Press, Sante Fe, New Mexico, 474 pp.

Christoforidis, A., 1994. New alternatives to the suburb: neo-traditional developments, *Journal of Planning Literature*, 8 (4): 429-440.

Churchill, C.J., 1997. *Decision Support for Sustainable Community Design*, Unpublished M.Eng. Thesis, Department of Civil Engineering, McMaster University, 301 pp.

City of Calgary, 1995. *Sustainable Suburbs Study: Creating More Fiscally, Socially and Environmentally Sustainable Communities*, Planning and Building Department, City of Calgary, 102 pp.

City of Chicago, 1998. "The City of Chicago's Guide to Urban Tree Care", Department of Environment, source: http://www.cityofchicago.org/Environment/CityTrees, retrieved November 2, 2000.

City of Portland, 1999. Traffic Calming Homepage. source: http://www.trans.ci.portland.or.us/Traffic_Management/Trafficcalming/reports/chapter 11.htm, retrieved February 19, 1999.

City of Portland, 2001. "Rainwater Recycling Approved for Limited Use in One and Two Family Homes", Office of Planning and Development Review, Portland, Oregon, source: http://www.opdr.ci.portland.or.us/, retrieved May 1, 2001.

City of Stoney Creek, 1997. *Official Plan*, dated November 17, 1997.

City of Toronto, 1994. *City of Toronto's Traffic Calming Policy*, City Works Services.

City of Toronto, 1997. *Installation of Speed Humps on City Streets: Policy Report*, City Works Services, 19 pp.

City of Toronto, 1998. *Smog: Make It or Break It.*

City of Vancouver, 2000a. "TreeCare - The Vancouver Park Board's Street Tree Management Program", City of Vancouver Parks Board, source: http://www.city.vancouver.bc.ca/parks/fyi/trees/treebro1.htm, retrieved November 2, 2000.

City of Vancouver, 2000b. "Vancouver's Community Gardens Policy", source: http://www.city.vancouver.bc.ca/parks&gardens/comgarden.htm, retrieved November 2, 2000.

Congress for the New Urbanism (CNU), 1998. *Charter of the New Urbanism.*

Cottrell, B.H. Jr., 1997. Using All-Way Stop Control for Residential Traffic Management. In: *Transportation Research Record 1605*, Transportation Research Board, National Research Council, Washington, D.C., pp 22-27.

Criterion Planners and Engineers, 1998. *Index Software: A Planning and Decision Support Tool*, source: http://www.crit.com, demo version retrieved June 1998.

Curtis, F.A., Neilsen, L., and Bjornsor, A., 1984. Impact of residential street design on fuel consumption, *Journal of Urban Planning and Development*, 110 (1): 1-8.

Dave, B., and Schmitt, G., 1994. Information systems for urban analysis and design development, *Environment and Planning B: Planning and Design*, 21: 83-86

De Chiara, J. and Koppleman, L., 1975. *Manual of Housing Planning and Design Criteria*, Prentice-Hall, Englewood Cliffs, NJ.

Des Rosiers, F., 1992. Urban sprawl and the central city, *Plan Canada*, (Nov.): 14-18.

Downing, P. and Gustely, R.D., 1977. The public service costs of alternative development patterns: a review of the evidence, In: Downing, P. (editor), *Local Service Pricing Policies and Their Effect on Urban Spatial Structure*, pp. 63-83, University of British Columbia, Vancouver.

Drive Clean, 2001. Homepage for Ontario's vehicle emission testing program, source: http://www.driveclean.com, retrieved May 23, 2001.

Duany, A. and E. Plater-Zyberk, 1992. The second coming of the American small town, *Plan Canada*, 32 (3): 6-13.

Dwyer, J.F., McPherson, G.E., Schroeder, H.W., and Rowntree, R.A., 1992. Assessing the benefits and costs of the urban forest, *Journal of Arboriculture*, 18 (5): 227-234.

Environment Canada, 1992 (Sept.). *Update on Environmental Issues*.

Environmental Council of Alberta, 1988. *Environment By Design: The Urban Place in Alberta*, ECA88-PA/CS-S3.

Environmental Systems Research Institute, Inc. (ESRI), 1994. *Understanding GIS: The ARC/INFO Method, Version 7 for UNIX and OpenVMS*, Redlands, CA.

Environmental Systems Research Institute, Inc. (ESRI), 1998. ArcView GIS, Version 3.1, Redlands, CA.

Environmental Systems Research Institute, Inc. (ESRI), 1999. View.CalculateDistance script, downloaded from ESRI's ArcScripts Main Page, source: http://andes.esri.com/arcscripts/scripts.cfm, retrieved June 15, 1999.

Evans, D., 1994. Traffic calming: the first five years and the Oxfordshire experience, *Proc. Instn Civ. Engrs Mun. Engr,* 103 (March): 9-15.

Evergreen Foundation, 2001. "Bringing Nature Back to Our Cities", source: http://www.evergreen.ca/en/index.html, retrieved April 27, 2001.

Ewing, R., 1997. Is Los Angeles-style sprawl desirable? *Journal of the American Planning Association*, 63 (1): 107-126.

Ewing, R.H., 1999. *Traffic Calming: State of the Practice*, Prepared for the U.S. Department of Transportation, Federal Highways Administration by Institute of Transportation Engineers, Washington, D.C., 244 pp.

Ewing, R. and Kooshian, C., 1997. U.S. experience with traffic calming, *ITE Journal*, 67 (8): 28-33.

Ferguson, B.K., 1998. *Introduction to Stormwater: Concept, Purpose, Design*, John Wiley & Sons, New York, 255 pp.

Fernandez, J.M., 1994. Boulder brings back the neighbourhood street, *Planning*, (June): 21-26.

Fowler, E.P., 1991. Land use in the ecologically sensible city, *Alternatives*, 18, (1): 26-35.

Frysinger, S.P., Copperman, D.A., and Levantino, J.P., 1996. Environmental decision support systems (EDSS): an open architecture integrating modeling and GIS, pp. 357-361, In: Goodchild, M.F., and others (editors.), *GIS and Environmental Modeling: Progress and Research Issues*. GIS World Books, Fort Collins, Colorado, USA, 486 pp.

Gabor, A., and Lewinberg, F., 1997. New Urbanism! New zoning! *Plan Canada*, 38 (4): 12-17.

Garreau, J., 1991. *Edge City: Life on the New Frontier*, Doubleday, New York, 546 pp.

Gates, C., 1994. The potential for improving water efficiency in existing housing: implications for municipal DSM programming, pp. 325-346, in Shrubsole, D. and Tate, D. (editors), *Every Drop Counts*, Canadian Water Resources Association, Cambridge, ON.

Gattis, J.L. and Watts, A., 1999. Urban street speed related to width and functional class, *Journal of Transportation Engineering, ASCE*, 125 (3): 193-200.

Ghosh, A. and Ruston, G. (editors), 1987. *Spatial Analysis and Location-Allocation Model*, van Nostrand Reinhold Company, New York, 373 pp.

Gordon, P. and Richardson, H.W., 1997. Are compact cities a desirable planning goal? *Journal of the American Planning Association*, 63 (1): 95-106.

Gurstein, P. and J. Curry, 1993. Implementing concepts of sustainable community planning, *Plan Canada*, 31 (3): 15-26.

Hamilton Spectator, The, 2001a, "Smog Watch Triggers Health Precautions", June 13, 2001.

Hamilton Spectator, The, 2001b, "Smog Raises Risk of Heart Attack", by C. Cox, June 12, 2001.

Hardoy, J.E., Mitlin, D. and Satterthwaite, D., 1992. *Environmental Problems in Third World Cities*, Earthscan Publications, London.

Harris, R., 1996. *Unplanned Suburbs: Toronto's American Tragedy, 1900 to 1950*, John Hopkins University Press, Baltimore, 356 pp.

Hartshorn, T.A., 1992. *Interpreting the City: An Urban Geography*. 2nd Edition, John Wiley & Sons, Inc., 484 pp.

Hartshorn, T.A., and Muller, P.O., 1986. *Suburban Business Centers: Employment Implications*, Final Report, Project No. RED-808-6-84-5(99-7-13616), Department Administration, U.S. Department of Economic Commerce, Washington, D.C.

Hawthorne, W., 1989. Why Ontarians walk, why Ontarians don't walk more, *A Study into the Walking Habits of Ontarians*, Energy Probe, Toronto.

Heisler, G.M., 1986. Energy savings with trees, *Journal of Arboriculture*, 12: 113-125.

Herr, P.B., 1993. The case of the northeastern village: broadening the preservationist's definition, *Historical Preservation Forum*, 6 (5): 20-28.

Hess, P.M., 1997. Measures of connectivity, *Places*, 11 (2): 59-65.

Hill, D.R., 1992. Sustainability, Victor Gruen, and the cellular metropolis, *Journal of the American Planning Association*, 58 (3): 312:326.

Hodge, G., 1991. *Planning Canadian Communities: An Introduction to the Principles, Practice, and Participants*, Second Edition, Nelson, Scarborough, ON.

Holtzclaw, J., 1991. *Explaining Urban Density and Transit Impacts on Auto Use*, Natural Resources Defence Council/Sierra Club, Sacramento.

Hough, M., 1995. *Cities and Natural Process*, Routledge, New York, 326 pp.

Howard, E., 1945. *Garden Cities of Tomorrow*, edited with a preface by F.J. Osborn, Faber and Faber, London, 168 pp. (originally published in 1898).

Hudson, M., 2000. *Ground Work: Investigating the Need for Nature in the City*, Evergreen Foundation, Toronto, 25 pp.

International Union for the Conservation of Nature (ICUN), 1980. *World Conservation Strategy: Living Resource Conservation for Sustainable Development*. IUCN-UNEP-WWF, Geneva.

Jacobs, A.B., Yodan, Y.R. and Macdonald, E., 1997. Guidelines for the design of multiple roadway boulevards, *Places*, 11 (2): 41-47.

Jacobs, J., 1961. *The Death and Life of Great American Cities*, Random House, New York, NY, 458 pp.

Katz, G.E., 1995. Natural areas in city, suburb and town and the practical application of landscape ecology, *Plan Canada*, (Nov. '95): 18-21.

Kirnbauer, M., and McCaig, B., 2000. "Sustainable Building Guidelines", source: http://www.eng.mcmaster.ca/civil/sustain/building/intro.html, material dated summer 2000, retrieved October 2000.

Knack, R.E., 1991a. The one-acre habit is hard to break, *Planning*, 57 (8): 8-11.

Knack, R.E., 1991b. Tony Nelessen's do-it-yourself neo-traditionalism, *Planning*, 57 (12): 18-22.

Knack, R.E., 1994. Dig these gardens, *Planning*, 60 (7): 20-24.

Krueger, R., 2000. Trials and tribulations of the Canadian fruit-growing industry, *The Canadian Geographer*, 44 (4): 342-354.

Kunstler, J.H., 1996. *Home From Nowhere: Remaking Our Everyday World for the Twenty-First Century*, Simon and Schuster, New York, 319 pp.

Kunstler, J.H., 2000. Presentation about Suburban Sprawl, given at McMaster University, March 16th, 2000.

La Barra, T. and Rickaby, P., 1987. An approach to the assessment of the energy efficiency of urban built form, In: Hawkes, D., Owers, J., Rickaby, P., and Steadman, P. (editors), *Energy and Urban Built Form*, pp. 43-62, Butterworths, London.

Leonard, J.D. and Davis, W.J., 1997. Urban traffic calming treatments: performance measures and design conformance, *ITE Journal*, 67 (8): 34-40.

Lerner-Lam, E., Celniker, S.P, Halbert, G.W., Chellman, C., and Ryan, S., 1992. Neo-traditional neighbourhood design and its implications for traffic engineering, *ITE Journal*, 62 (1): 17-25.

Levy, J.M., 1991. *Contemporary Urban Planning*, Second Edition, Prentice-Hall, Englewood Cliffs, NJ.

Litman, T., 1997. *Evaluating Traffic Calming Benefits, Costs and Equity Impacts*, Victoria Transport Policy Institute, Victoria, BC, 21 pp.

Litman, T., 1998. Driving out subsidies: how better pricing of transportation options would help protect our environment and benefit consumers, *Alternatives Journal*, 24 (1): 36-42.

Little, C.E., 1990. *Greenways for America*, John Hopkins University Press, Baltimore, 237 pp.

Living Machines Inc., 2001. "Case Study I for South Burlington, Vermont", Living Machines Inc. web site, source: http://www.livingmachines.com/htm/study1.htm, retrieved May 23, 2001.

Lockwood, I.M., 1997. ITE traffic calming definition, *ITE Journal*, 67 (7): 22-24.

Macbeth, A., 1998a. Calming arterials in Toronto, Paper presented to the Annual Meeting of the Institute of Transportation Engineers, Toronto, August 9-12, 1998.

Macbeth, A., 1998b. Bicycle lane design at intersections and traffic calming, Professional Development Seminar on Planning and Design of Bikeways endorsed by the Institute of Transportation Engineers, Hamilton, Ontario, November 28, 1998.

MacBurnie, I., 1992. Reconsidering the dream: alternative design for sustainable suburban development, *Plan Canada*, 32 (5): 19-23.

MacDonald, D. and Clark, B., 1995. New Urbanism in Calgary: McKenzie Towne, *Plan Canada*, (Jan. 1995): 20-21.

Maclaren, V., 1992. *Sustainable Urban Development in Canada: From Concept to Practice*, Intergovernmental Committee on Urban and Rural Research (ICURR) Press, Toronto.

Maclaren, V., 1996. *Developing Indicators of Urban Sustainability: A Focus on the Canadian Experience*, Intergovernmental Committee on Urban and Regional Research (ICURR) Press, Environment Canada, 149 pp.

Maddaus, W.O., 1987. *Water Conservation*, American Water Works Association, Denver.

Malakoff, D., 2000. "What Good is Community Greening?", source: http://www.communitygarden.org/pubs/whatgood.htm, American Community Gardening Association, retrieved November 2, 2000.

Meyn, O.N., 1999. *Application of Artificial Neural Networks to the Evaluation of Sustainable Community Design*, Unpublished M.Eng. Thesis, Department of Civil Engineering, McMaster University, 95 pp.

Moore, Paul, 1998. Personal communications with this planner, Planning Department, City of Stoney Creek, ON, July 1998.

Murdie, R.A., Rhyne, D. and Bates, J., 1992. *Modelling Quality of Life Indicators in Canada: A Feasibility Analysis*, Canada Mortgage and Housing Corporation, Ottawa.

Naroff, H. and Ostro B.D., 1982. Urban development and pollution control, *Urban Analysis*, 7: 87-103.

Negahban, B., and others, 1996. A GIS-based decision support system for regional environmental planning, pp. 277-282, In: Goodchild, M.F., and others (editors.), *GIS and Environmental Modeling: Progress and Research Issues*. GIS World Books, Fort Collins, Colorado, USA, 486 pp.

Nelessen, A. and L. Howe, 1995. Flexible friendly neighbourhood transit: a solution for the suburban transportation dilemma, *Plan Canada,* (Sept): 14-16.

Neuman, M., 1991. Utopia, dystopia, diaspora, *American Planning Association Journal*, 57 (3): 344-47.

New Urban News, 1998. New Urbanism in Canada: 1) hotbed of neotraditional development; 2) activity from BC to Ontario; and 3) new city on a runway. *New Urban News*, 3 (2): 7-11.

New Urban News, 1999. New Urbanist retail gathers momentum, *New Urban News*, 4 (6): 1-6.

New Urban News, 2001. A banner year for New Urbanist home sales, *New Urban News*, volume 6 (issue 3), source: http://www.newurbannews.com/whatsnew.html, retrieved June 18, 2001

Newman, P. and Kenworthy, J.R., 1989. *Cities and Automobile Dependence: An International Sourcebook*, Aldershot, Gower, 388 pp.

Noble, M.S., *et al.*, 1976. In: Rams, E.W. (editor), *Analysis and Evaluation of Retail Locations*, Reston Publishing, Reston, VA.

Oke, T.R., 1987. *Boundary Layer Climates*, Second Edition, Methuen, New York, 435 pp.

Ontario Ministry of Municipal Affairs and Housing (Ont. MMAH), 1982. *Handbook for Energy Efficient Residential Subdivision Planning*, MMAH, Toronto.

Ontario Ministry of Municipal Affairs and Housing (Ont. MMAH), 1997. *Breaking Ground: An Illustration of Alternative Development Standards in Ontario's New Communities*, Queen's Printer for Ontario, 34 pp.

Owens, S., 1986. *Energy Planning and Urban Form*, Council for the Protection of Rural England, London.

Patterson, J., 1992. Transport to work: eight selected cities, *Sustainable Cities*, 1: 1-5.

Platt, R.H., Rowntree, R.A., and Muick, P.C. (editors), 1994. *The Ecological City: Preserving and Restoring Urban Biodiversity*, University of Massachusetts Press, Amherst, 291 pp.

Preston, R.E., 1977. A perspective on alternative settlement forms, In: Russworm, L.H., Preston, R.E., and Martin, L.R.H. (editors), *Essays on Canadian Process and Form*, Volume 1, pp. 41-172, Department of Geography, University of Waterloo, Waterloo.

Pushkarev, B.S. and Zupan, J.M., 1982. Where transit works: urban densities for public transportation, In: Levinson, H.S., and Weant, R.A., (editors), *Urban Transportation: Perspectives and Prospects*, Eno Foundation, Westport, CT.

Randall, T.A., and Baetz, B.W., 2001. Evaluating pedestrian connectivity for suburban sustainability, *Journal of Urban Planning and Development*, ASCE, 127 (1): 1-15.

Razavi, A.H., 1997. *ArcView GIS: Avenue Developer's Guide*, Second Edition, OnWord Press, Sante Fe, New Mexico, 407 pp.

Real Estate Magazine (REM), 1998 (July). Sustainable communities provide homes at lower cost, *The Real Estate Magazine*.

Rees, W.E., 1990. The ecology of sustainable development, *The Ecologist*, 20 (1): 18-23.

Rees, W.E., 1992. Ecological footprints and appropriated carrying capacity: what urban economics leaves out, *Environment and Urbanization*, 4 (2): 121-130.

Rees, W.E., and Roseland, M., 1991. Sustainable communities: planning for the 21st Century, *Plan Canada*, 31 (3): 15-25.

Regional Municipality of Hamilton-Wentworth, 1992. *Vision 2020: The Sustainable Region*, Regional Chairman's Task Force on Sustainable Development, Regional Municipality of Hamilton-Wentworth.

Regional Municipality of Hamilton-Wentworth, 1995. *Signposts on the Trail to Vision 2020: Sustainability Indicators for the Hamilton-Wentworth Region - Participants Handbook*, Regional Municipality of Hamilton-Wentworth.

Register, R., 1987. *Ecocity Berkeley: Building Cities for a Healthy Future*, North Atlantic Books, Berkeley, California, 140 pp.

Remington, K., 1999. Shortest Network Paths (SNR) extension, *Environmental Systems Research Institute Inc. ArcScripts Main Page*, source: http://www.andes.esri.com/arcscripts/scripts.cfm, retrieved July 6, 1999.

Replogle, M, 1990. Sustainable transportation strategies for world development, Paper presented to the World Congress for a Sustainable Future, United Nations, New York, September 7th, 1990.

Richardson, N.H., 1989. *Land Use Planning and Sustainable Development in Canada*, Canadian Environmental Advisory Council, Ottawa.

Richardson, N.H., 1996. What is a "sustainable city"? *Plan Canada*, 36 (5): 34-38.

Robinson, C.C., 1999. Traffic calming on arterials - CON, Paper presented to the Annual Meeting of the Institute of Transportation Engineers, Las Vegas, August 1-4, 1999.

Roseland, M. 1992. *Towards Sustainable Communities*, National Round Table on the Environment and the Economy, Ottawa.

Roseland, M., 1997. Dimensions of the eco-city, *Cities*, 14 (4): 197-202.

Russell, P., Tobin, R., Robertson, W., Thomas, B. and Townsend, A., 1994. Domestic water conservation: 'the light grey option', pp. 303-316, in Shrubsole, D. and Tate, D. (editors), *Every Drop Counts*, Canadian Water Resources Association, Cambridge, ON.

Rybczynski, W., 1991. Living smaller, *Atlantic Monthly*, (Feb): 64-78.

Saltzman, A., 1979. The decline of transit, In: Gray, G. and Hoel, L. (editors), *Public Transportation*, Prentice-Hall, Englewood Cliffs, NJ.

Sarkar, S., Nederveen, A.A.J., and Pols, A., 1997. Renewed Commitment to Traffic Calming for Pedestrian Safety, In: *Transportation Research Record 1578*, Transportation Research Board, National Research Council, Washington, D.C., pp 11-19.

Seneviratne, P.N., 1985. Acceptable walking distances in central areas, *Journal of Transportation Engineering, ASCE*, 111 (4): 365-376.

Sharratt, K., Wardle, B., and Fiotakis, G., 1994. Ontario's water efficiency strategy, pp. 77-83, in Shrubsole, D. and Tate, D. (editors), *Every Drop Counts*, Canadian Water Resources Association, Cambridge, ON.

Shriver, K., 1997. Influence of environmental design on pedestrian travel in four Austin neighbourhoods, *Transportation Research Record 1578*, Transportation Research Board, NRC, Washington, D.C., pp. 64-75.

Skene, M., 1999. Traffic calming on arterial roadways?, Paper presented to the Annual Meeting of the Institute of Transportation Engineers, Las Vegas, August 1-4, 1999.

Southworth, M., 1997. Walkable suburbs? An evaluation of neotraditional communities at the urban edge, *Journal of the American Planning Association*, 63 (1): 28-44.

Steyn, D.G., Bottenheim, J.W., and Thomson, R.B., 1997. Overview of tropospheric ozone in the Lower Fraser Valley, and the Pacific '93 field study, *Atmospheric Environment*, 31 (14): 2025-2035.

Sussman, R. and Hall, B., 1993. Municipal planning and GIS, *Plan Canada*, (July 1993): 8-12.

Sustainable Seattle, 1993. *Sustainable Seattle Indicators of Sustainable Community: A Report to Citizens on Long Term Trends in Their Community*, Seattle, WA.

Taylor, M., 1994. The new suburban village, In: Aberley, D., *Futures By Design: The Practice of Ecological Planning*, New Society Publishers, Gabriola Island, BC, Canada.

Thomsen, C.H., 1994. Design and maintenance of water efficient landscaping, pp. 295-302, in Shrubsole, D. and Tate, D. (editors), *Every Drop Counts*, Canadian Water Resources Association, Cambridge, ON.

Timmermans, H. (editor), 1997. *Decision Support Systems in Urban Planning*, Routledge, 352 pp.

Tomalty, R., Hendler, S., and Flick, K., 1994. *Planning for Sustainable Urban Development. Issues in Urban Sustainability 6*, Institute of Urban Studies, University of Winnipeg.

Transportation Association of Canada (TAC), 1999. *Geometric Design Guide for Canadian Roads*, Transportation Association of Canada, Ottawa.

Transportation Association of Canada (TAC) and Canadian Institute of Transportation Engineers (CITE), 1998. *Canadian Guide to Neighbourhood Traffic Calming*, Transportation Association of Canada, Ottawa.

Troy, P., 1992. The new feudalism, *Urban Futures Journal*, 2: 36-44.

US Department of Housing and Urban Development, 1980. *Metropolitan Development Patterns: What Difference Do They Make?*, Housing and Urban Development, Office of Policy Development and Research.

Urban Ecology, 1996. "Mission Statement and Accomplishments", source: http://www.urbanecology.org.

Van der Ryn, S. and Calthorpe, P., 1986. *Sustainable Communities: a New Design Synthesis for Cities, Suburbs, and Towns*, Sierra Club Books, San Francisco, 238 pp.

Van Order, M.J., 1993. CADD, GIS and MIS: a backgrounder for planners. *Plan Canada*, (July): 5-7.

Van Vliet, D.R., 1994. *Sustainable Subdivision Planning and Design: Analysis, Literature Review and Annotated Bibliography*. Institute of Urban Studies, University of Winnipeg, 113 pp.

Wackernagel, M. and Rees, W.E.,, 1996. *Our Ecological Footprint: Reducing Human Impact on the Earth*. New Society Publishers, Gabriola Island, BC, 160 pp.

Walter, C.E., 1995. Suburban residential traffic calming, *ITE Journal*, 65 (9): 44-48

Warner, S.B., 1978. *Streetcar Suburbs: The Process of Growth in Boston: 1870-1900*, Second Edition, Harvard University Press, Cambridge, 208 pp..

West, J.E., 2000. Arterial traffic calming - is it an oxymoron?, Paper presented at the Annual Meeting of the Institute of Transportation Engineers, Nashville, August 6-9, 2000.

Western Australian Planning Commission (WAPC), 2000. *Liveable Neighbourhoods: A Western Australian Government Sustainable Cities Initiative*, Western Australian Planning Commission, Perth, Australia, 88 pp.

Wight, I., 1995. New urbanism vs. conventional suburbanism, *Plan Canada*, (Sept): 20-22.

World Commission on Environment and Development (WCED), 1987. *Our Common Future*, Oxford University Press, Oxford, 400 pp.

World Resources Institute (WRI), 1997. "World Resources 1996-1997: A Guide to the Global Environment", source: http://www.wri.org/wri/wr-96-97/em_txt2.html, retrieved May 25, 2001.

Yiftachel, O. and D. Hedgcock, 1993. Urban social sustainability: the planning of an Australian city, *Cities*, (May): 139-157.

Young, A., 1995. Bamberton: public input and process. *Plan Canada*, 35 (1): 22.

Zein, S.R., Geddes, E., Hemsing, S, and Johnson, M. , 1997. Safety Benefits of Traffic Calming. In *Transportation Research Record 1578*, Transportation Research Board, National Research Council, Washington, D.C., pp 3-10.

APPENDIX A

Computer Code and Structure in Developed ArcView Extensions

This appendix contains a list of computer code used in the development of the three ArcView GIS extensions described in chapters 4, 5 and 6. Code is almost entirely written using ArcView's programming language, Avenue (as "scripts"); one "function" for use in Excel was written using Visual Basic for Applications (VBA). A distinction is made between "original" or "modified" scripts. Original ones are those created by the author of this dissertation; modified ones are taken from previous researchers and altered to fit the particular application developed. The Neighbourhood Traffic Calming (*NTC*) and Neighbourhood Greening (*NG*) extensions utilize dialog boxes, which became available in ArcView 3.1. The pedestrian connectivity extension (*PRD Evaluate*) was developed in ArcView 3.0a, which did not support dialog boxes. Table A.1 contains a summary of the number of scripts, functions and dialogs created and used in this research.

Table A.1: Summary of code created or used in the three ArcView extensions

Extension	**Number of Dialog Boxes**	**Number of Original Avenue Scripts**	**Number of Modified Avenue Scripts**	**Number of Original VBA Functions**
PRD Evaluate	0	4	7	1
NTC	21	137	8	0
NG	12	78	4	0
Totals	**43**	**219**	**19**	**1**

There are too many pages of code written for these extensions to include a hard copy of the complete code listings within this dissertation. A list of the created and modified scripts and functions are included for each extension in Tables A.2, A.3, and A.4. A Microsoft Word 97 file is provided for each unique script and function on the CD enclosed in the envelope at the end of the dissertation (see directory "D:\dssFiles\phdCode").

Table A.2: Avenue scripts and VBA function used in the *PRD Evaluate* extension

AV Script Name	Author(s)	Date Last Modified
DDECreateSpreadsheet	ESRI	Jul 29, 1999
DDECreateSpreadsheet.Modified	ESRI + TR	Oct 1, 1999
PRD.EditNewTheme	TR	Sep 28, 1999
PRD.Evaluate	TR	Oct 1, 1999
PRD.PostExcel	TR	Oct 1, 1999
SNR.ResultsModified	Remington(1999)+ TR	Aug 23, 1999
Table.DeleteFieldModified	ESRI + TR	Aug 27, 1999
Table.DeleteFieldAndJoins	TR	Aug 27, 1999
Table.MakeFromExcel	ESRI	Jul 29, 1999
View.CalculateDistanceModified	ESRI + TR	Aug 19, 1999
View.ExportModified	ESRI + TR	Sep 29, 1999
VBA Function Name	**author(s)**	**Date Last Modified**
Sub Main()	TR	Dec 29, 1999

Table A.3: Avenue scripts used in the *NTC* extension, listed by dialog

Dialog or Script Name	Author(s)	Date Last Modified
NTC About Dialog		
NTC.AboutDialog	TR	Jun 21 '00
NTC.AboutDialog.Open	TR	Oct 18 '00
NTC.AboutDialog.Close	TR	Jul 27 '00
NTC.lbt_OK1.Click	TR	Jul 27 '00
NTC Arterials Dialog		
NTC.ArterialsDialog.Open	TR	Aug 11 '00
NTC.lbt_A1.Click	TR	Jul 18 '00
NTC.lbt_A2.Click	TR	Jul 18 '00
NTC.lbt_A3.Click	TR	Jul 18 '00
NTC.lbt_A4.Click	TR	Jul 18 '00
NTC.lbt_A5.Click	TR	Jul 18 '00
NTC.lbt_A6.Click	TR	Jul 18 '00
NTC.lbt_A7.Click	TR	Jul 18 '00
NTC.lbt_A8.Click	TR	Jul 18 '00
NTC.lbt_Back11.Click	TR	Jul 21 '00
NTC.lbt_Exit7.Click	TR	Aug 11 '00
NTC Benefits Dialog		
NTC.BenefitsDialog.Open	TR	Oct 5 '00
NTC.BenefitsDialog.Close	TR	Aug 11 '00
NTC.lbt_Back15.Click	TR	Aug 11 '00
NTC Benefits Choice Dialog		
NTC.BenefitsChoiceDialog.Open	TR	Aug 11 '00
NTC.lbt_Back17.Click	TR	Aug 11 '00
NTC.lbt_SpeedRed.Click	TR	Aug 11 '00
NTC.lbt_VolumeRed.Click	TR	Aug 11 '00

Table A.3: continued...

NTC Collectors Dialog		
NTC.CollectorsDialog.Open	TR	Aug 11 '00
NTC.lbt_Back12.Click	TR	Jul 21 '00
NTC.lbt_C1.Click	TR	Jul 18 '00
NTC.lbt_C2.Click	TR	Jul 18 '00
NTC.lbt_C3.Click	TR	Jul 18 '00
NTC.lbt_C4.Click	TR	Jul 18 '00
NTC.lbt_C5.Click	TR	Jul 18 '00
NTC.lbt_C6.Click	TR	Jul 18 '00
NTC.lbt_C7.Click	TR	Jul 18 '00
NTC.lbt_C8.Click	TR	Jul 18 '00
NTC.lbt_C9.Click	TR	Jul 18 '00
NTC.lbt_C10.Click	TR	Jul 18 '00
NTC.lbt_C11.Click	TR	Jul 18 '00
NTC.lbt_C12.Click	TR	Jul 18 '00
NTC.lbt_Exit6.Click	TR	Aug 11 '00
NTC DesignDetails Dialog		
NTC.DesignDetailsDialog.Open	TR	Oct 5 '00
NTC.DesignDetailsDialog.Close	TR	Aug 11 '00
NTC.lbt_Back16.Click	TR	Aug 11 '00
NTC Evaluate Dialog		
NTC.EvaluateDialog.Open	TR	Oct 2 '00
NTC.Evaluate.Display	TR	Oct 16 '00
NTC.Evaluate.LabelView	TR	Aug 17 '00
NTC.Evaluate.Main	TR	Aug 17 '00
NTC.Evaluate.QuerySpeed	TR	Jun 14 '00
NTC.Evaluate.QueryTable	TR	Aug 17 '00
NTC.Evaluate.QueryVolume	TR	Jun 14 '00
NTC.lbt_Back3.Click	TR	Aug 2 '00
NTC.lbt_Back18.Click	TR	Aug 16 '00
NTC.lbt_Next2.Click	TR	Aug 2 '00
NTC.lbt_Next3.Click	TR	Nov 27 '00
NTC.View.ExportModified	ESRI + TR	Jun 29 '00
NTC.View.ExportModified2	ESRI + TR	Oct 13 '00
NTC Installation Dialog		
NTC.InstallationDialog.Open	TR	Oct 5 '00
NTC.InstallationDialog.Close	TR	Jul 19 '00
NTC.lbt_Back10.Click	TR	Jul 19 '00
NTC.lbt_Installation2.Click	TR	Jul 19 '00
NTC Locals Dialog		
NTC.LocalsDialog.Open	TR	Aug 11 '00
NTC.lbt_Back13.Click	TR	Aug 11 '00
NTC.lbt_Exit5.Click	TR	Aug 11 '00
NTC.lbt_L1a.Click	TR	Aug 8 '00
NTC.lbt_L1b.Click	TR	Aug 8 '00
NTC.lbt_L1c.Click	TR	Aug 8 '00
NTC.lbt_L2.Click	TR	Jul 18 '00
NTC.lbt_L3.Click	TR	Jul 18 '00
NTC.lbt_L4.Click	TR	Jul 18 '00
NTC.lbt_L5.Click	TR	Jul 18 '00
NTC.lbt_L6.Click	TR	Jul 18 '00
NTC.lbt_L7.Click	TR	Jul 18 '00
NTC.lbt_L8.Click	TR	Jul 18 '00
NTC.lbt_L9.Click	TR	Jul 18 '00

Table A.3: continued...

NTC Measures Dialog		
NTC.MeasuresDialog.Open	TR	Oct 5 '00
NTC.lbt_Back4.Click	TR	Jul 14 '00
NTC.lbt_Back5.Click	TR	Oct 5 '00
NTC.lbt_Exit4.Click	TR	Aug 11 '00
NTC.lbt_Next4.Click	TR	Aug 11 '00
NTC.lbt_Arterial.Click	TR	Jul 14 '00
NTC.lbt_Collector.Click	TR	Jul 14 '00
NTC.lbt_Local.Click	TR	Jul 14 '00
NTC Options Dialog		
NTC.OptionsDialog	TR	Jul 14 '00
NTC.OptionsDialog.Open	TR	Sep 29 '00
NTC.lbt_Exit3.Click	TR	Jul 14 '00
NTC.lbt_Options.Click	TR	Jul 14 '00
NTC.lbt_ShopList.Click	TR	Jul 14 '00
NTC.lbt_Speed.Click	TR	Aug 9 '00
NTC.lbt_SpeedVolume.Click	TR	Aug 9 '00
NTC.lbt_Volume.Click	TR	Aug 9 '00
NTC Photo Dialog		
NTC.PhotoDialog.Open	TR	Oct 5 '00
NTC.PhotoDialog.Close	TR	Jul 19 '00
NTC.lbt_Back9.Click	TR	Jul 19 '00
NTC.lbt_Photo2.Click	TR	Jul 19 '00
NTC Photo2 Dialog		
NTC.Photo2Dialog.Open	TR	Oct 5 '00
NTC.Photo2Dialog.Close	TR	Jul 31 '00
NTC.lbt_Back14.Click	TR	Jul 31 '00
NTC Placement Dialog		
NTC.PlacementDialog.Open	TR	Sep 19 '00
NTC.lbt_EditMeasures.Click	TR	Oct 3 '00
NTC.lbt_Exit10.Click	TR	Oct 3 '00
NTC.lbt_RefreshView.Click	TR	Sep 28 '00
NTC.lbt_ViewCost.Click	TR	Sep 28 '00
NTC.PlaceAndCostMeasures	TR	Nov 28 '00
NTC.View.PointToolModified	ESRI + TR	Sep 26 '00
NTC.View.PointToolUpdateModified	ESRI + TR	Sep 19 '00
NTC.View.PointToolModifiedArterial	ESRI + TR	Oct 19 '00
NTC.View.PointToolModifiedCollector	ESRI + TR	Oct 19 '00
NTC.View.PointToolModifiedLocal	ESRI + TR	Oct 19 '00
NTC Reset to Default Settings, menu option		
NTC.ResetToDefaults	TR	Oct 18 '00
NTC Select Dialog		
NTC.SelectDialog.Open	TR	Aug 9 '00
NTC.lbt_AnotherSelection.Click	TR	May 18 '00
NTC.lbt_Done1.Click	TR	May 18 '00
NTC.lbt_Exit2.Click	TR	May 18 '00
NTC.lbt_CreateTheme.Click	TR	Oct 11 '00
NTC.Tool_Select.Apply	TR	May 11 '00
NTC.ViewChoice	TR	May 9 '00
NTC.View.ExportModified	ESRI + TR	Jun 29 '00
NTCView.CreateThemes	TR	May 18 '00
View.ExportModified.NTC	ESRI + TR	Oct 11 '00

Table A.3: continued...

NTC Set Working Directory, menu item		
NTC.SetWorkingDirectory	TR	Oct 12 '00
NTC Shopping Dialog		
NTC.ShoppingDialog.Open	TR	Oct 2 '00
NTC.ShoppingDialog.Change	TR	Aug 7 '00
NTC.lbt_Back19.Click	TR	Oct 2 '00
NTC.lbt_Exit9.Click	TR	Aug 11 '00
NTC Sketch1 Dialog		
NTC.Sketch1Dialog.Open	TR	Oct 5 '00
NTC.Sketch1Dialog.Close	TR	Jul 19 '00
NTC.lbt_Back6.Click	TR	Jul 19 '00
NTC.lbt_CrossSection.Click	TR	Jul 18' 00
NTC Sketch2 Dialog		
NTC.Sketch2Dialog.Open	TR	Oct 5 '00
NTC.Sketch2Dialog.Close	TR	Jul 19 '00
NTC.lbt_Back8.Click	TR	Jul 19 '00
NTC Street Data Dialog		
NTC.StreetDataDialogOpen	TR	Oct 18 '00
NTC.StreetDataDialog	TR	May 4 '00
NTC.cbx_Local.Click	TR	May 9 '00
NTC.cbx_Collector.Click	TR	May 9 '00
NTC.cbx_Arterial.Click	TR	May 9 '00
NTC.lbt_Next1.Click	TR	Jul 17 '00
NTC.lbt_Back1.Click	TR	May 9 '00
NTC.lbt_Exit1.Click	TR	Jul 17 '00
NTC Suggest Dialog		
NTC.SuggestDialog.Open	TR	Oct 3 '00
NTC.lbt_OK2.Click	TR	Oct 3 '00
NTC TCM Info Dialog		
NTC.TCMInfoDialog.Open	TR	Aug 11 '00
NTC.lbt_Back7.Click	TR	Jul 19 '00
NTC.lbt_Benefits.Click	TR	Aug 11 '00
NTC.lbt_DesignDetails.Click	TR	Aug 11 '00
NTC.lbt_Exit8.Click	TR	Aug 11 '00
NTC.lbt_Installation.Click	TR	Jul 18 '00
NTC.lbt_Photo.Click	TR	Jul 18 '00
NTC.lbt_Sketch.Click	TR	Jul 18 '00

Table A.4: Avenue scripts used in the *NG* extension, listed by dialog and menu option

Dialog, Menu Option or Script Name	Author(s)	Date Last Modified
NGE Digitize Feature Dialog		
`NGE.DigitizeFeatureDialog.Open`	TR	Mar 29 '01
`NGE.lbtExit6.Click`	TR	Jan 31 '01
`NGE.lbtFinish1.Click`	TR	Mar 1 '01
`NGE.lbtOK2.Click`	TR	Mar 1 '01
NGE Existing LU Dialog		
`NGE.ExistingLUDialog.Open`	TR	Mar 15 '01
`NGE.lbtConvPark.Click`	TR	Mar 15 '01
`NGE.lbtExit8.Click`	TR	Mar 15 '01
`NGE.lbtHomeYard.Click`	TR	Mar 20 '01
`NGE.lbtSchoolYard.Click`	TR	Mar 15 '01
`NGE.lbtStreetscape.Click`	TR	Mar 15 '01
`NGE.lbtUtilROW.Click`	TR	Mar 15 '01
`NGE.lbtVacantLot.Click`	TR	Mar 15 '01
NGE Feature Choice Dialog		
`NGE.lbtCommGard.Click`	TR	Mar 1 '01
`NGE.lbtExit5.Click`	TR	Jan 31 '01
`NGE.lbtPlayGrd.Click`	TR	Mar 1 '01
NGE Garden Fraction Dialog		
`NGE.GardenFractionDialog.Open`	TR	Jan 19 '01
`NGE.GardenCP.Apply`	TR	Apr 11 '01
`NGE.GardenCP.Change`	TR	Jan 17 '01
`NGE.GardenAP.Change`	TR	Jan 17 '01
`NGE.GardenTotal.Change`	TR	Jan 17 '01
`NGE.lbtExit2.Click`	TR	Jan 19 '01
`NGE.lbtNext1.Click`	TR	Jan 17 '01
NGE HomeAndYard Dialog		
`NGE.HomeAndYardDialog.Open`	TR	Apr 9 '01
`NGE.HomeAndYardDialog.Close`	TR	Apr 9 '01
`NGE.lbtBack4.Click`	TR	Apr 9 '01
`NGE.lbtDwyOpts.Click`	TR	Apr 9 '01
`NGE.lbtExit11.Click`	TR	Apr 9 '01
`NGE.lbtLandscOpts.Click`	TR	Apr 9 '01
`NGE.lbtPhotos2.Click`	TR	Apr 11 '01
`NGE.lbtRoofOpts.Click`	TR	Apr 9 '01
`NGE.lbtVegPlace.Click`	TR	Apr 9 '01
NGE Info Dialog		
`NGE.InfoDialog.Open`	TR	Apr 9 '01
`NGE.lbtBack3.Click`	TR	Mar 20 '01
`NGE.lbtDigitLocations.Click`	TR	Mar 29 '01
`NGE.lbtExit10.Click`	TR	Mar 29 '01
`NGE.lbtOK3.Click`	TR	Mar 29 '01
`NGE.lbtPhotos.Click`	TR	Apr 11 '01
NGE Photo Dialog		
`NGE.PhotoDialog.Open`	TR	Apr 11 '01
`NGE.PhotoDialog.Close`	TR	Mar 26 '01
`NGE.lbtAnPhoto.Click`	TR	Mar 26 '01
`NGE.lbtClose1.Click`	TR	Mar 26 '01

Table A.4: continued...

NGE Potential LU Dialog		
NGE.PotentialLUDialog.Open	TR	Mar 20 '01
NGE.lbtBack2.Click	TR	Mar 20 '01
NGE.lbtCommGard2.Click	TR	Mar 20 '01
NGE.lbtExit9.Click	TR	Mar 29 '01
NGE.lbtGreenStrScape.Click	TR	Mar 20 '01
NGE.lbtGreenways.Click	TR	Mar 20 '01
NGE.lbtNatAreas.Click	TR	Mar 20 '01
NGE.lbtQuasiNatAreas.Click	TR	Mar 20 '01
NGE Potential Reduction Dialog		
NGE.PotentialReductionDialog.Open	TR	Apr 19 '01
NGE.lbtBack1.Click	TR	Jan 19 '01
NGE.lbtExit4.Click	TR	Jan 19 '01
NGE Selection Output Dialog		
NGE.SelectOutputDialog.Open	TR	Mar 12 '01
NGE.lbtAnotherSelection.Click	TR	Mar 1 '01
NGE.lbtExit7.Click	TR	Mar 1 '01
NGE.lbtViewLocations.Click	TR	Mar 12 '01
NGE Study Area Dialog		
NGE.SADialog.Open	TR	Apr 12 '01
NGE.AreaPerimCalcs	TR	Feb 19 '01
NGE.CreateSABdyTheme	TR	Dec 28 '00
NGE.lbtOK1.Click	TR	Jan 3 '01
NGE.lbtExit1.Click	TR	Dec 29 '00
Delimit Study Area for Landscapeable Fraction, menu option		
NGE.EvaluateNGPotential.Start	TR	Jan 4 '01
NGE.EvaluateNGPotential.Main	TR	Apr 17 '01
NGE.FormatThemes	TR	Apr 17 '01
NGE.GeoProc.Clip.Finish.Modified	ESRI + TR	Jan 3 '01
Evaluate Landscapeable Area and NG Potential, menu option **(NGE LandscArea Dialog)**		
NGE.LADialog.Open	TR	Apr 19 '01
NGE.LADialog.Close	TR	Jan 19 '01
NGE.CalcLandscArea	TR	Apr 17 '01
NGE.lbtExit3.Click	TR	Jan 19 '01
NGE.lbtGarden.Click	TR	Jan 16 '01
NGE.lbtStreetTree.Click	TR	Apr 17 '01
NGE.StreetTree.Main	TR	Apr 19 '01
NGE.View.ExportModified2	ESRI + TR	Mar 1 '01
Select Locations for NG Features, menu option		
NGE.SelLocations	TR	Mar 1 '01
NGE.SelLocations.Start	TR	Mar 1 '01
NGE.SelLocations.Main	TR	Mar 12 '01
NGE.CreateFeatureTheme	TR	Mar 29 '01
NGE.LocAlloc.Evaluate	TR	Mar 12 '01
NGE.View.ExportModified	ESRI + TR	Mar 1 '01
NGE.View.ExportModified2	ESRI + TR	Mar 1 '01
SNR.resultsModified2	Remington + TR	Mar 1 '01
View and Place NG Features, menu option		
NGE.ViewAndPlace.Start	TR	Mar 15 '01

APPENDIX B

User Manual for the *PRD Evaluate* Extension

PRD Evaluate Extension

User Manual

prepared by:

Todd Randall
Sustainable Communities Research Group
Department of Civil Engineering
McMaster University
Hamilton, Ontario, Canada.

July 2001

Objective of the Tool

The ArcView Extension, *PRD Evaluate*, has been prepared as part of the doctoral research of the author[1]. *PRD Evaluate* has been designed to provide decision support to those involved in the investigation of modelling and evaluating improvements to a neighbourhood's pedestrian environment. A sample application of this extension has been published as Randall and Baetz (2001)[2]. This manual is intended to assist with the use of this tool. The manual is divided into the following sections: Extension Installation; Project Set Up and Data Requirements; and Extension Operation. All files needed for running the extension are found on the accompanying CD; not included are files for which a separate site licence is required (e.g., ArcView's *Network Analyst* extension).

PRD refers to a pedestrian route directness ratio, a ratio between the measured network distance and the geodetic distance between for an origin-destination pairing. PRD values tending towards 1 suggest more efficient routes (good values are 1.2 to 1.4), while those in excess of 2 suggest the route is overly long and convoluted. Four connectivity cases are developed which represent both acceptable and unacceptable connectivity. These cases are determined by user-inputted critical values for the PRD ratio and acceptable walking distance.

This decision support tool is a prototype version only. I encourage you to contact the author should you discover a bug in the tool, so that it can be corrected in future versions. I would also appreciate feedback on the tool's applicability in your company or division. Please send your comments to the address below.

Todd Randall
Department of Civil Engineering
McMaster University
1280 Main St. West
Hamilton, Ontario, L8S 4L7
email: randall@mcmaster.ca

---

[1] Randall, T.A., 2001. *Decision Support for Suburban Retrofitting*, Unpublished Ph.D. Thesis, Department of Civil Engineering, McMaster University.

[2] Randall, T.A. and Baetz, B.W., 2001. Evaluating pedestrian connectivity for suburban sustainability, *Journal of Urban Planning and Development*, ASCE, 127 (1): 1-15.

Installation of the ArcView Extension

PRD Evaluate is designed for use in ArcView GIS versions 3.2 and earlier, since it has been written and compiled using Avenue. In addition, a portion of *PRD Evaluate* has been compiled using Visual Basic for Applications (VBA), hence the user will also need a licensed version of Microsoft Excel, 1997 version or later.

The *PRD Evaluate* extension is housed in the .avx file indicated below. In addition, two additional extensions are needed in using *PRD Evaluate*: 1) *Network Analyst* (available from ESRI); and 2) *Shortest Network Path* (written by K. Remington, University of South Carolina). An .avx file is provided here for *SNP*, since it is a shareable extension available from ESRI's ArcScripts Main Web Page.

Step 1: Copy .avx files to appropriate directory

COPY d:\prdExt\PRD_v2.avx
d:\prdExt\Snp.avx
TO DIRECTORY c:\esri\Av_gis30\ArcView\ext32

PRD Evaluate utilizes Microsoft Excel for some calculation steps. The following file, containing VBA functions, should be copied from the CD to your project's working directory.

Step 2: Copy .xls file from CD to working directory

COPY d:\prdExt\prd1.xls TO DIRECTORY *your project directory*

A number of ArcView legend files (.avl files) are used late in the extension when creating layouts displaying the results of the connectivity analysis. One legend file is available for each of the three dwelling categories. These are listed below and should be copied from the CD to your project's working directory.

Step 3: Copy .avl files from CD to working directory

COPY d:\prdExt\conncase_leg_dup.avl
d:\prdExt\conncase_leg_mu.avl
d:\prdExt\conncase_leg_sfh.avl
TO DIRECTORY *your project directory*

No other support files are necessary for *PRD Evaluate*. However, a number of data files needed are discussed in the next section.

ArcView Project Set Up and Data Requirements

This section describes how one needs to set up an ArcView project to analyze a chosen study neighbourhood for pedestrian connectivity. Details are provided regarding data types and attributes required; data preparation steps; and other ArcView extensions required.

Two other ArcView extensions are required to carry out some of the data preparation steps. These are *Geoprocessing* and *Digitizer* extensions, both of which are included with a site license for ArcView 3.1. Additional extensions needed for operation of *PRD Evaluate* are discussed in the section "Extension Operation".

It is expected that the digital data for the study neighbourhood will already be housed within ArcView shape files (.shp). Shape files are to be available for each of the following neighbourhood features; note that the type of shape file (theme) is indicated in parentheses:

- buildings (polygon)
- building centroids (point)
- road centrelines (polyline)
- sidewalks (polyline)
- pedestrian paths (polyline)

The building themes are to be further sub-divided into categories of origins and destinations, and the polyline themes are to be conglomerated to create networks representing the network available to pedestrian (see below). If the study neighbourhood has neither sidewalks nor pedestrian paths (connecting isolated cul-de-sacs), then it is up to the decision maker to assign an appropriate pedestrian network. In extreme situations, this could consist of the street network, but this is generally not acceptable.

A naming convention for created ArcView themes and Views is followed in this and other associated manuals. The theme names often incorporate an abbreviated portion of the study neighbourhood. The initial view is often in the format "Study Neighbourhood Start View".

In the event that data are not provided in ArcView shape files, but are available in some other format, conversion procedures are available using GISs other than ArcView. For example, in developing the *PRD Evaluate* extension, data in Micro Station Format (.dgn files) were used. These files were converted to ArcView shape files using command statements available in ARC/INFO. Please refer to ARC/INFO for instructions on converting ARC/INFO coverages to ArcView shape files.

Step 4: Data Preparation Notes

The following points describe the steps for preparing the shape files.

a) For the building theme (polygons only), all ancillary structures should be removed. This includes garages, portables, greenhouses, and outbuildings. The remaining building polygons are to be classified by building type and primary use, creating a unique theme for each. Create a new theme while in the View by using the menu option Theme / Convert to Shape File. A list of building theme names is provided in Table 1 (column 2).

b) Generate centroids (i.e., points) for each building theme by intersecting the polygon building themes created in a) with the theme for building centroids. Centroids are the "nodes" to be used by *PRD Evaluate* when the network distances are determined. The intersection step is to be done using the Geoprocessing extension, on click: View / Geoprocessing Wizard (*Clip One Theme Based on Another* option). For this procedure: the input theme is centroid (point) theme; the overlay theme is building (polygon) theme; specify the output file (themes) to appropriate directory. Specify the names for the building centroids as in Table 1 (column 3).

Table 1: Building themes created for *PRD Evaluate* extension

theme (1)	polygon theme name (2)	centroid theme name (3)
single family homes	*sfh.shp*	*sfh_nd.shp*
schools	*sch.shp*	*sch_nd.shp*
multi-unit dwellings	*mu.shp*	*mu_nd.shp*
duplexes	*dup.shp*	*dup_nd.shp*
commercial buildings	*comm.shp*	*comm_nd.shp*
churches	*chu.shp*	*chu_nd.shp*
community centre	*ctr.shp*	*ctr_nd.shp*
hospital	*hos.shp*	*hos_nd.shp*

c) For analysis of pedestrian connectivity, an appropriate travel network suitable to pedestrians must be created. It is suggested that the combination of sidewalks and existing pedestrian paths is the most appropriate.

Pedestrian Network = sidewalks + ped_connectors
e.g., ped_rte.shp = ber_side.shp + ber_pc.shp (ber = Berrisfield neighbourhood)

The addition step in this "equation" is carried out using View / Geoprocessing Wizard (*Merge* option). Select the attributes of sidewalks to be carried through.

d) The network analysis requires each origin and destination centroid (or node), discussed in step b), to be physically on the network created in step c). To achieve this, I suggest editing the network theme (once created) by adding short "driveway" segments so that nodes are connected to the sidewalks, roads, and paths. Furthermore, it is necessary to add connecting segments across intersections so that the full network is accessible to all nodes. These segments should be digitized using the line split tool, available on ArcView's toolmenu (assuming the *Digitizer* extension is activated).

The following is a checklist to make sure connections are made for the network theme for:

access segments to network for:		**network connectors for:**
• single family homes	• schools	• sidewalks
• duplex	• commercial bldgs	• intersections
• multi-unit bldgs	• civic bldgs	
	• industrial facilities	

e) **Important Note:** Each network line theme, created in steps c) and d), contains a "length" field which is used by *PRD Evaluate* to determine the route distances between origins and destinations. The use of the line split tool adds segments to the theme which have a ZERO value in their length field. The following procedure below describes how to update values in the length field[3]. This procedure must be done at the following times: 1) after the ped_rte theme has been initially created; and 2) any time that a modification is made to the route theme where a segment with a zero value is created. This latter instance occurs following the addition of a new path in each alternative considered (see "Extension Operation" section below).

Determine the length of new segments by:
- in the View window, set line theme to edit mode Theme / Start Editing;
- go to attribute table and highlight length field header;
- select all records in the table if there are numerous length records to be updated, OR select only the new additions as individual records (Shift key);
- in Table window, click Field / Calculate to activate Field Calculator Dialog box;
- in box labelled [Length] =, type in *[Shape].ReturnLength* and click OK;
- take theme out of edit mode Theme/Stop Editing

f) The final point on shape file preparation refers to formatting. It is suggested the following formats for symbol, size, label and colour be adopted, in order to standardize the maps created by *PRD Evaluate*.

symbol	size	theme label	colour
●	6	single family home	red
flag	14	schools	black
—	-	pedestrian route	black
■	8	multi-unit buildings	mint green
▲	8	duplexes	royal blue
■	14	commercial buildings	pale blue

The *PRD Evaluate* extension provides an analysis of pedestrian connectivity that is weighted to neighbourhood population. Thus, the presence of higher residential density in one portion of the study neighbourhood may weight retrofitted improvements to that area. There are three dwelling classifications considered in the tool: single family, duplex and multi-unit dwellings. The first two have fixed occupancy numbers and require no additional information. However, for multi-unit dwellings, the user is required to create a database file that contains attributes relating to building type and the number of dwelling units present. For instance, an apartment containing 180 units has a much different impact than a townhouse with 6 units.

---

[3] Procedure summarized from ESRI, 1996. *ArcView GIS: Using ArcView GIS*, Environmental Systems Research Institute, Inc., pp.261-2.

Step 5: create .dbf file for multi-unit dwellings

CREATE mu.dbf WITH ATTRIBUTES *"dwelling_id", "type", "no_of_du"*

PRD Evaluate uses the following figures for per dwelling unit occupancy rates: 3 persons per dwelling (ppd) for single family; 2 ppd for duplex; 1.25 ppd for apartment; and 2 ppd for townhouse and rowhouse. These are summarized from Baetz (1994)[4].

Extension Operation

This section discusses the operation of *PRD Evaluate*. It is necessary to evaluate pedestrian connectivity in the initial configuration of the pedestrian network. This will serve as a "base case", and is used to compare subsequent configurations considered in a number of alternatives. In most applications, it will be best to create a new View window for each pedestrian connectivity alternative considered. This will assist with the management of a series of possible configurations. In addition to *PRD Evaluate* and the Excel code mentioned earlier, four other ArcView extensions are required. These are:

- *Digitizer*
- *Geoprocessing*
- *Network Analyst*
- *Shortest Network Path v1.1*

The operation of the extension is described in three "operational" steps, followed by some comments on how to carry out subsequent analyses to evaluate any changes to the pedestrian network (see "Subsequent Iterations"). The first and third steps are to be completed in ArcView, while the second step is to be completed in Excel. Detailed instructions for these steps are included below. Two data forms (Data Sheets 1 and 2) are provided at the end of this manual to facilitate recording information generated in each of the three steps.

---

[4] Baetz, B.W., 1994. Creation of landowner compacts for sustainable community development, *Journal of Urban Planning and Development*, ASCE, 120 (4): 174-182.

- *Operational Step 1*

Operating Environment	Instructions
AV	Open ArcView and prepare shapefiles as described in section above entitled "ArcView Project Set Up and Data Requirements". In the initial view for the connectivity analysis (e.g., the "Neighbourhood Start View"), there should only be one line theme present (e.g., the theme for pedestrian route).
AV	Load Extensions. *Digitizer, Geoprocessing, Network Analyst, PRD Evaluate* and *Shortest Network Paths v1.1* extensions must all be activated.
EXCEL	Open Excel file, named "prd1.xls", saying 'yes' at the enable macros prompt. Leave Excel open upon return to ArcView.
AV	From initial View window in ArcView, on-click the menu option Connectivity / Calculate PRD. Depending upon the number of origins, this step may take several minutes to complete.

OUTPUT STEP 1: For each of the selected origin(s), a table is generated and sent to Excel for computation described in Operational Step 2 below.

- *Operational Step 2*

Operating Environment	Instructions
EXCEL	User must physically move to Excel spreadsheet to see the "books" generated by the ArcView script *DDECreateSpreadsheet.Modified.* A book is created for each dwelling type (origin) selected in Operational Step 1.
EXCEL	Open the VBA code in named file from Operational Step 1 (i.e., prd1.xls) by selecting Tools/Macro/Visual Basic Editor. This will then show the main subroutine "*Sub Main()*"
EXCEL	Select book with pertinent data on which you want PRD calculations to be done. Run Sub Main() routine by clicking the run arrow. *****An important exception** is for the multi-unit dwelling files, in which the type and number of dwellings per building will have to be copied from the multi-unit attribute .dbf file created earlier (see Step 5).
EXCEL	Repeat the previous step for each book created by Operational Step 1. Each book must be selected manually.

OUTPUT STEP 2: For each of the Excel tables analyzed, PRD calculations and assignment of results to connectivity cases 1, 2, 3, or 4 will have been done. The final step in *Sub Main()* automatically selects the entire table, so that Operational Step 3 (see below) can identify what material needs to be transferred back to ArcView. If you have had to manually enter or add any data values to the spreadsheet, you must re-select ranges using the mouse. **DO NOT SELECT the first row of the spreadsheet containing cell A1 "Attributes of ...".**

- ***Operational Step 3:*** [*** This step must be done for one origin at a time due to overwriting of theme attribute tables. Before executing subsequent file imports from Excel, make sure that all tables in ArcView are not in edit mode.]

Operating Environment	Instructions
EXCEL/AV	*User physically returns to ArcView. View window will be active (if not, activate it). Make note of the spreadsheet name you left active in Excel, since that will be the one you will work with.
AV	From the ArcView Table window, click menu option Connectivity / Receive Table FROM Excel to bring the active table from Excel to ArcView. New table will be "Table1" found in ArcView's Project window.
AV	From View window, activate dwelling theme on table of contents and then click menu option Connectivity / Display PRD Results. Do your own file management so that these are put in non-temporary directories. This step displays the results for the selected origin as a new shapefile. One is able to specify critical values for both PRD and route distance here.
AV	On-click the origin's original attribute table, select all, table edit and then save all edits to create a new attribute table (.dbf format). Then, once you have no use for original attribute table, click on Connectivity / Delete Connectivity Fields to reset the attribute table, then de-select all records.
AV	To get summary statistics about a particular field in a table (such as c4pop, c3pop, ...), select all records in Original Attribute table and activate the field header. Then choose the menu item from Table window Field / Statistics. You are interested in the sum.
AV	To query a table for particular results, choose from Table window Table / Query and enter an appropriate expression. For example, ([ped_conn] = 4) returns x of n records having pedestrian connectivity case 4. ([cost] < 200) returns y of n records having route distance less than 200 m. Record the results of the querying steps on Data Sheet 2.
AV	For the newly created shape file(s), load the appropriate legend file described earlier in Step 3. To do so, double-click the theme to activate ArcView's legend editor, select Load and negotiate to stored .avl file.
AV	With the newly created shape file(s), new layouts can be created by selecting View / Layout from the View window.

OUTPUT STEP 3: The output from this step is the data recorded on Data Sheet 2. This analysis corresponds to critical values for PRD and walking distance entered early in Operation Step 3 by the user.

- ***Subsequent Iterations:***

In successive iterations (or analyses), one may hope to add sidewalks and pedestrian paths to improve the pedestrian connectivity of the neighbourhood. Conditions of improved connectivity include lower PRD ratios and lower average walking distances to destinations. Based on the maps generated in *Operational Step 3*, areas of unacceptable connectivity can be identified. The user can then make modifications to the pedestrian network theme by adding sidewalk or path segments (between isolated cul-de-sacs). Remember to add these segments using the Line / Split tool as discussed earlier in *Step 4*. If attempting to evaluate independent additions to the network, be sure to remove any previously added sidewalks or path segments. It is also important to remember to calculate the length of any added network segments and update the theme's attribute table (see *Step 4e*). Save the newly created pedestrian route as an unique theme and return to *Operational Step 1*.

PRD EVALUATE - DATA SHEET 1

Project File (.apr):____________ Date: ________________ Observer: _________
Neighbourhood Name: _______ Destination: ____________ Dwelling Types: ___________

	Analysis Number →		
STEP 1	Origin Type		
STEP 2	Initial Excel Filename (.xls)		
	Critical PRD/Distance	/	/
	Dest Bldg #		
	Run Sub Main()		
	Enter Bldg Pop'n (if nec.)		
	Add'l Nghd Data Table (.dbf)		
	new Excel name (.xls)		
STEP 3: JOINING	Original Attribute Table		
	Source Table		
	field common to both		
STEP 3: QUERYING	PRD Critical Value		
	Distance Critical Value		
	newly created shapefile (.shp)		

PRD EVALUATE - DATA SHEET 2

Project File (.apr):_____________ Date: _________________ Observer: ___________
Neighbourhood Name: _________ Destination: _____________ Dwelling Types: ______________

Summary of results. Upper half of the table shows frequency of route distances (in m) in specified ranges, plus the average route distance. Bottom half of the shows a frequency distribution for the 4 connectivity cases plus an average Pedestrian Route Directness (PRD) ratio.

ROUTE DISTANCE (Cost)	**alternative**			**alternative**			**alternative**		
	n	**%**	**Δ**	**n**	**%**	**Δ**	**n**	**%**	**Δ**
<200 m									
200-400 m									
400-500 m									
500-600 m									
>600 m									
total									
average distance (m)									
standard deviation									
CONNECTIVITY	**alternative**			**alternative**			**alternative**		
PRD/Distance Critical Values	/			/			/		
acceptable connectivity:	**n of bldgs**	**popn**	**Δ**	**n of bldgs**	**popn**	**Δ**	**n of bldgs**	**popn**	**Δ**
conn. case 1									
conn. case 2									
unacceptable connectivity:									
conn. case 3									
conn. case 4									
totals:									
average UltPRD									
standard deviation									
PRD range									
Route Network File(.shp)									
New Shape File with ALL attributes									
New VIEW									
Excel File									

APPENDIX C

User Manual for the *NTC* Extension

NTC Extension

User Manual

prepared by:

Todd Randall
Sustainable Communities Research Group
Department of Civil Engineering
McMaster University
Hamilton, Ontario, Canada.

July 2001

Objective of the Tool

The ArcView extension, *Neighbourhood Traffic Calming (NTC)*, has been prepared as part of the doctoral research of the author[1]. The *NTC* extension has been designed to provide decision support to those involved with the investigation and implementation of Neighbourhood Traffic Calming. This manual is intended to assist with the use of this tool. The manual is divided into the following sections: Extension Installation; Project Set Up and Data Requirements; and Extension Operation. All files needed for running the extension are found on the accompanying CD.

There are numerous devices used for implementing traffic calming programs in North America. The vast majority have been applied to local and collector streets. Comparatively few are considered for use on arterial streets. The *NTC* extension is a tool has largely been developed to assist the transportation engineer with sorting through the volume of information about traffic calming and deciding upon which measure(s) to install. It provides decision support for selecting traffic calming measures for local, collector and arterial streets. Measures utilized by the tool are listed in the section entitled "Extension Operation".

This decision support tool is a prototype version only. I encourage you to contact the author should you discover a bug in the tool, so that it can be corrected in future versions. I would also appreciate feedback on the tool's applicability in your company or division. Please send your comments to the address below.

Todd Randall
Department of Civil Engineering
McMaster University
1280 Main St. West
Hamilton, Ontario, L8S 4L7
email: randall@mcmaster.ca

---

[1] Randall, T.A., 2001. *Decision Support for Suburban Retrofitting*, Unpublished Ph.D. Thesis, Department of Civil Engineering, McMaster University.

Installation of the ArcView Extension

The *NTC* extension is designed for use in ArcView GIS versions 3.2 or earlier, since it has been written and compiled using Avenue. It is housed in the .avx file indicated below, and should be copied from the CD.

Step 1: Copy .avx file to appropriate directory

COPY d:\ntcExt\ntc4.avx TO DIRECTORY c:\esri\Av_gis30\ArcView\ext32

Information on each of the traffic calming measures utilized by the *NTC* extension is contained in a number of directories. The extension has been coded to access files stored on the E drive. Copy the following directories and their contained files to your E drive. If the E drive is not used, *NTC* extension will report a "file not found" message.

Step 2: Copy NTC extension's directories and files to E drive

	d:\dssFiles\ntcExt\benTabs		e:\dssFiles\ntcExt\benTabs
COPY	d:\dssFiles\ntcExt\captions	TO E	e:\dssFiles\ntcExt\captions
from CD	d:\dssFiles\ntcExt\designD	DRIVE	e:\dssFiles\ntcExt\designD
	d:\dssFiles\ntcExt\photos		e:\dssFiles\ntcExt\photos
	d:\dssFiles\ntcExt\sketches		e:\dssFiles\ntcExt\sketches

No other support files are necessary for the *NTC* extension. The data files to operate the extension are discussed in the next section.

ArcView Project Set Up and Data Requirements

This section describes how one needs to set up an ArcView project to generate a neighbourhood traffic calming program. Details are provided regarding data types and attributes required, and data preparation steps. Most notably, the user requires data (measured or assumed) for traffic volumes and 85th percentile speeds on the neighbourhood's streets.

A naming convention for created ArcView themes and Views is followed in this and other associated manuals. The theme names often incorporate an abbreviated portion of the study neighbourhood. The initial View is often in the named "Study Neighbourhood" + "Start View".

It is expected that the digital data for the study neighbourhood will already be housed within ArcView shape files (.shp). A (polyline) shape file is required only for a street centreline theme. A naming convention is used in *NTC* extension for street centreline theme (see step 3 below). This shape file should have a unique identification number assigned to each roadway segment; these numbers are then used to link the shape file to its attributes (stored in a separate database file) discussed in step 4. Most polyline themes created in ArcView will also have a segment length field "Length".

In the event that data are not provided in ArcView shape files, but are available in some other format, conversion procedures are available using GISs other than ArcView. For example, in developing the *NTC* extension, data in Micro Station format (.dgn files) were used. These files were converted to ArcView shape files using command statements available in ARC/INFO. Please refer to ARC/INFO for instructions on converting ARC/INFO coverages to ArcView shape files.

Step 3: Naming the street centreline theme

Create "hun_rdct.shp" theme, where "hun" is short for Huntington (neighbourhood); and "rdct" is short for road centreline

The bulk of the data preparation for using the *NTC* extension is in creating the attributes to accompany the created road theme. These attributes are to be housed in a database file (.dbf format) which are to be joined to the road centreline theme later. It is important that the .dbf file have the same "identification numbers" (in the SEG_ID field, see Table 1 below).

Step 4: Create a .dbf file containing attributes of the neighbourhood's road segments, and record the name

The attributes for the road centrelines are mostly measured characteristics. A complete list is provided in Table 1 below. Field names created in the .dbf file must be those indicated here, otherwise the extension will not function properly. An example of a .dbf file with fictional data is provided on the accompanying CD (see D:\ntcExt\hun_road_data.dbf).

Table 1: Attributes of road segments to be compiled as fields in a .dbf file

attribute	**field name**	**notes on data source for attributes**	**data type**
segment identity number	SEG_ID	consult ArcView shape file	integer
segment type	SEG_TYPE	local, collector, or arterial	character
segment width	SEG_WIDTH	measured or TAC (1999)[2]	real
segment ROW width	SEG_ROW	measured or TAC (1999)[2]	integer
number of travel lanes	TRAV_LANE	measured	integer
number of parking lanes	PKG_LANE	measured	integer
85th percentile speed	SPEED_85	measured	real
traffic volume	TRAFF_VOL	measured	integer
request received for calming from public	PUB_REQ	public complaint records	character (insert a 'y' or 'n')

---

[2] Transportation Association of Canada (TAC), 1999. *Geometric Design Guide for Canadian Roads*, Transportation Association of Canada, Ottawa.

Extension Operation

This section discusses the operation of the *NTC* extension. The initial evaluation of the neighbourhood's need for traffic calming is based on the available traffic speed and volume data (see Step 4 above), and on the user's inputted constraints for desired "design speed" and "design volume" for the neighbourhood's street segments. The *NTC* extension evaluates the existing traffic condition of a study neighbourhood, and then recommends certain measures. The recommendation of measures is constrained by special management zones (SMZs) in the study neighbourhood. The individual decision-maker is presumed to have knowledge of these SMZs, and will be prompted to create these during the generation of a neighbourhood traffic calming program (see *Operational Step 1* below).

The operation of the extension is discussed in the following two sub-sections. The first sub-section lists the traffic calming measures available to the extension. The second sub-section describes the menu options available within the extension.

Available Traffic Calming Measures:

A total of 29 traffic calming measures (TCMs) are provided in the decision support tool for neighbourhood traffic calming (Table 2). These measures can be applied to local, collector or arterial streets. Much of the information for local and collector measures have been derived from Canadian sources, particularly TAC and CITE (1998)[3]. Future versions of the *NTC* extension will incorporate a greater amount of US content (e.g., Ewing, 1999)[4]. Measures for arterial streets have been created by the author (Randall, 2001)[1].

---

[3] Transportation Association of Canada (TAC) and Canadian Institute of Transportation Engineers (CITE), 1998. *Canadian Guide to Neighbourhood Traffic Calming*, Transportation Association of Canada, Ottawa.

[4] Ewing, R.H., 1999. *Traffic Calming: State of the Practice*, Prepared for the US Department of Transportation, Federal Highays Administration by Institute of Transportation Engineers, Washington, D.C., 244 pp.

Table 2: List of traffic calming measures (TCM) used on the three road classes; symbols used on tool buttons within the *NTC* extension are indicated are right

TCM Shorthand	Brief Description of TCM	Symbols on Tool Buttons
Local Streets		
L1	Base Case Configuration	n/a[1]
L2	Raised Crosswalks	L
L3	Raised Intersections	3
L4	Speed Hump (parabolic)	4
L5	Chicane (1-Lane)	5
L6	Curb Extension	6
L7	Traffic Circle	7
L8	Intersection Channelization	8
L9	All-Way Stop Control (AWSC)	9
Collector Streets		
C1	Base Case Configuration	n/a[1]
C2	Raised Crosswalks	C
C3	Raised Intersection:	3
C4	Speed Hump (flat-topped)	4
C5	Textured Crosswalk	5
C6	Chicane (2-Lane)	6
C7	Curb Extension	7
C8	Raised, Landscaped Median Island	8
C9	Traffic Circle	9
C10	Intersection Channelization	I
C11	All-Way Stop Control (AWSC)	W
C12	Stripe Bike Lanes	B
Arterial Streets		
A1	Base Case Configuration	n/a[1]
A2	Add Continuous 2-Way Turn Lane and Bike Lanes to Arterials	A
A3	Add 1 Parking Lane, Bike Lanes and Landscaped Median Islands to Arterials	3
A4	Add 2 Parking Lanes and Shared Curb Lane to Arterials	4
A5	Add 2 Parking Lanes and Bike Lanes to Arterials	5
A6	Designate HOV/Transit/Bike Lane and Add Landscaped Median to Arterials	6
A7	Designate HOV/Transit Lane and Add Bike Lanes and Landscaped Median to Arterials	7
A8	Pedestrian Crosswalks with Flashing Light	8

Notes: 1) TCM Descriptors for L1, C1, and A1 refer to the initial base case conditions for each of the street types, and therefore, are not "traffic calming options" in the strictest sense. However, it is possible that some streets have not been designed to these standards, so these measures might be a "first step" for improvements for certain streets.

Menu Options for the NTC Extension

The *NTC* extension is organized into seven menu options that are briefly described in Table 3; the key ones are numbers 4, 5 and 6. The operation of the extension is described in more detail in four "operational" steps below.

Table 3: Menu options available in the *NTC* extension

Menu Option	Brief Description
1) Reset to Default Settings	resets input parameters such as design speed and design volume to built-in default values;
2) Create Themes	prompts the user to create new line themes for special management zones such as: school zones, or transit and emergency routes;
3) Set Working Directory	user can set a working directory for file management;
4) Display Critical Areas for NTC	evaluates road network to identify segments having identifiable traffic calming problems such as volume or speed in excess of design levels;
5) Preview Traffic Calming Measures	user is able to peruse information concerning traffic calming measures for local, collector and arterial streets;
6) Place and Cost Measures	user-selected traffic calming measures can be placed on a map to form a "neighbourhood traffic calming program"; an estimated cost of the created program is then displayed to the user;
7) About NTC Extension	provides pertinent information about the program.

- ***Operational Step 1: Create SMZ themes (OPTIONAL)***

As stated earlier, the process of determining locations to install traffic calming measures takes into account the locations of special management zones (SMZs) such as school zones and emergency vehicle routes. From the initial View window, on-click the menu option NTC / Create Themes to generate themes for the five SMZs. Potential SMZ themes include: school or playground zones; areas having high pedestrian volumes; and routes for transit, emergency and maintenance vehicles. These new themes are created from the existing theme for road centreline segments. It is not mandatory to create these themes to generate a neighbourhood traffic calming program, only a recommendation to do so.

- ***Operational Step 2: Display critical areas for NTC***

This menu option is activated from the initial View window by on-clicking NTC / Display Critical Areas for NTC. You are first prompted to set the critical speed and volume values that will be used to assess whether or not street segments are in need of traffic calming. Second, you are asked to specify themes for a number of features; you must specify a road centreline theme as well as its associated attribute data that is housed within the .dbf file created earlier (see *Step 4* above). Specification of themes for any SMZs is optional. You will be able to choose from a number of traffic calming objectives: (A) Speed Reduction; (B) Volume Reduction; (C) Planning for SMZs; or some combination thereof.

The output from this step is a new View window entitled 'ntcRun1', 'ntcRun2', ... , 'ntcRunX' that has themes highlighting segments with particular traffic calming problems.

- ***Operational Step 3: Preview TCMs***

This menu option is activated from the new View created in *Operational Step 2* - 'ntcRunX' by on-clicking NTC / Preview Traffic Calming Measures. Follow the series of dialogs to view traffic calming measures for solving particular traffic calming issues: Reduce Traffic Speed; Reduce Traffic Volume; and/or Enhance the Pedestrian and Cycling Environment. You are provided with the opportunity to peruse a wide variety of information for the traffic calming measures listed in Table 2. This includes textual information; photos and sketches of sample installations; and tables of tabulated speed and volume reduction benefits. Textual information includes descriptions of measures, their preferred installation locations, impacts, costs and synergies with other measures. The information provided in this step will assist you in the creation of a neighbourhood traffic calming program (see *Operational Step 4*).

- ***Operational Step 4: Place and cost TCMs***

This menu option follows the investigation of traffic calming measures (TCMs), as described in the previous step. On-click the menu option NTC / Place and Cost Measures while in the new View created in *Operation Step 2* - 'ntcRunX'. A "Placement Dialog" appears that allows you to add or remove measures to or from a newly created theme for traffic calming measures. Measures are digitized as points on the map in the View window by selecting a measure on one of the three toolmenu buttons on the ArcView console. One toolmenu is provided for each group of traffic calming measures for local, collector or arterial streets; refer to button symbols shown on Table 2 above. Digitized locations of TCMs constitute a neighbourhood traffic calming plan or program. Click the "Refresh View" and "View Cost" buttons on the "Placement Dialog" to obtain an estimated cost in Canadian dollars for the prescribed program. Costs for the arterial calming measures are currently unavailable.

- ***Subsequent Iterations:***

In successive iterations, one is able to return to various steps in the process and to refine the neighbourhood traffic calming program. The *NTC* extension serves as a useful tool to investigate a number of these programs in conceptual form and to provide an initial assessment on which road segments within a neighbourhood need traffic calming.

APPENDIX D

User Manual for the *NG* Extension

NG Extension

User Manual

prepared by:

Todd Randall
Sustainable Communities Research Group
Department of Civil Engineering
McMaster University
Hamilton, Ontario, Canada.

July 2001

Objective of the Tool

The ArcView extension, *Neighbourhood Greening (NG)*, has been prepared as part of the doctoral research of the author[1]. The *NG* extension has been designed to provide decision support to those involved with the investigation and installation of Neighbourhood Greening. This manual is intended to assist with the use of this tool. The manual is divided into the following sections: Extension Installation; Project Set Up and Data Requirements; and Extension Operation. All files needed for running the extension are found on the accompanying CD; not included are files for which a separate site licence is required (e.g., ArcView's *Network Analyst* extension).

Neighbourhood Greening refers both to the creation of new green spaces and to the management of existing ones. The neighbourhood greening methodology is concerned with the implementation of more naturalized landscaping techniques, through which lower amounts of water and other materials (e.g., gas, fertilizer, pesticides) would be needed. In addition, the methodology provides decision support to assist the planner in the installation of a number of neighbourhood greening features, including:

- Natural Areas
- Quasi-Natural Areas
- Greenways
- Greened Streetscape
- Community Gardens
- Yard, Garden, and Driveway Options.

This decision support tool is a prototype version only. I encourage you to contact the author should you discover a bug in the tool, so that it can be corrected in future versions. I would also appreciate feedback on the tool's applicability in your company or division. Please send your comments to the address below.

Todd Randall
Department of Civil Engineering
McMaster University
1280 Main St. West
Hamilton, Ontario, L8S 4L7
email: randall@mcmaster.ca

---

[1] Randall, T.A., 2001. *Decision Support for Suburban Retrofitting*, Unpublished Ph.D. Thesis, Department of Civil Engineering, McMaster University.

Installation of the ArcView Extension

The *NG* extension is designed for use in ArcView GIS versions 3.2 or earlier, since it has been written and compiled using Avenue. The extension is housed in the .avx file indicated below. Two additional extensions are needed in using *NG* extension: 1) *Network Analyst* (available from ESRI); and 2) *Shortest Network Path* (written by K. Remington, University of South Carolina). An .avx file is provided here for *SNP*, since it is a shareable extension available from ESRI's ArcScripts Main Web Page.

Step 1: Copy .avx files to appropriate directory

COPY	d:\ngExt\nge1.avx	TO DIRECTORY	c:\esri\Av_gis30\ArcView\ext32
	d:\ngExt\Snp.avx		

Information on each of the neighbourhood greening features utilized by the *NG* extension is contained in a number of directories. In addition, a number of ArcView legend files (.avl files) are used in the extension to display greening features and street tree symbols. The extension has been coded to access files stored on the E drive. Copy the following directories and their contained files to your E drive. If the E drive is not used, *NG* extension will report a "file not found" message.

Step 2: Copy NG extension's directories and files to E drive

COPY from CD	d:\dssFiles\ngExt\captions	TO E DRIVE	e:\dssFiles\ngExt\captions
	d:\dssFiles\ngExt\info		e:\dssFiles\ngExt\info
	d:\dssFiles\ngExt\photos		e:\dssFiles\ngExt\photos
	d:\dssFiles\ngExt\sketches		e:\dssFiles\ngExt\sketches
	d:\dssFiles\ngExt\legends		e:\dssFiles\ngExt*[1]

*1: note slightly altered destination directory for legend files.

No other support files are necessary for the *NG* extension. The data files to operate the extension are discussed in the next section.

ArcView Project Set Up and Data Requirements

This section describes how one needs to set up an ArcView project to utilize the *NG* extension. Details are provided regarding: data types and attributes required; data preparation steps; and other ArcView extensions required.

Two other ArcView extensions, beyond *SNP* and *Network Analyst*, are required to carry out some of the data preparation steps. These are *Geoprocessing* and *Digitizer* extensions, both of which are included with a site licence for ArcView 3.1. For more details, refer to section below, entitled "Extension Operation".

It is expected that the digital data for the study neighbourhood will already be housed within ArcView shape files (.shp). Shape files are to be available for each of the following neighbourhood features; note that the type of shape file (theme) is indicated in parentheses:

- buildings (polygon)
- building centroids (point)
- swimming pools (polygon)
- road centrelines (polyline)
- road edges (polyline)
- sidewalks (polyline)
- driveways (polyline)
- parking lots (polygon)
- pedestrian paths (polyline)
- existing street trees (point)

The building themes are to be further sub-divided by type and use, and the sidewalk and pedestrian path themes are to be conglomerated to create a pedestrian network theme. If the study neighbourhood has neither sidewalks nor pedestrian paths (connecting isolated cul-de-sacs), then it is up to the decision maker to assign an appropriate pedestrian network. In extreme situations, this could consist of the street network, but this is generally not acceptable.

A naming convention for created ArcView themes and Views is followed in this and other associated manuals. The theme names often incorporate an abbreviated portion of the study neighbourhood. An example for the "Huntington" study neighbourhood is shown below in Tables 1 and 2 (see *Step 3*). The initial View window for the project is assigned the name "Study Neighbourhood Start View".

In the event that data are not provided in ArcView shape files, but are available in some other format, conversion procedures are available in GISs other than ArcView. For example, in developing the *NG* extension, data in Micro Station format (.dgn files) were used. These files were converted to ArcView shape files using command statements available in ARC/INFO. Please refer to ARC/INFO for instructions on converting ARC/INFO coverages to ArcView shape files.

Step 3: Spatial Data Preparation Notes

The following points describe the steps for preparing the shape files.

a) The building theme (polygons only) should include all typical neighbourhood buildings (e.g., homes, commercial buildings, etc) and any ancillary structures (e.g., garages, portables, greenhouses, and outbuildings). Building polygon themes are then to be created for each of residential dwelling types. Select the appropriate building polygons and create a new theme while in the View by using the menu option Theme / Convert to Shape File. A list of theme names to be used is provided in Table 1 (column 2).

Table 1: Building themes created for *NG* extension for the Huntington neighbourhood. Note the three-letter abbreviation "hun" in the theme names.

theme (1)	polygon theme name (2)	centroid theme name (3)
all buildings	*hunbuild.shp*	*hun_cent.shp*
multi-unit buildings	*mu.shp*	*mu_nd.shp*
single family homes	*sfh.shp*	*sfh_nd.shp*
duplexes	*dup.shp*	*dup_nd.shp*

b) Generate centroids (i.e., points) for each created residential building theme by intersecting the polygon building theme created in a) with the theme for building centroids. Centroids are the "nodes" to be used by the *NG* extension when the network distances are determined. The intersection step is to be done using the *Geoprocessing* extension, on-click: View / Geoprocessing Wizard (*Clip One Theme Based on Another* option). For this procedure: the input theme is the centroid (point) theme; the overlay theme is the building (polygon) theme; specify the output file (themes) to appropriate directory. Specify the name for the building centroids as in Table 1 (column 3).

c) A number of other themes are required to utilize all of the options available in the *NG* extension. These and their required attributed are listed in Table 2.

Table 2: Themes created for *NG* extension for the Huntington neighbourhood. Note the three letter abbreviated "hun" in theme name.

themes required (1)	theme type (2)	theme name (3)	attributes required (3)
existing street trees	point	*exsttr.shp*	
parking lots	polygon	*hun_pkg.shp*	*area*
pedestrian route	polyline	*ped_rte.shp*	*length*
sidewalks	polyline	*hun_sid.shp*	*length*
pedestrian paths	polyline	*hun_pc.shp*	*length*
driveways	polyline	*hun_dwy.shp*	*length*
road centrelines	polyline	*hun_rdct.shp*	*see Step 4 below*
road edges	polyline	*hun_road.shp*	*length*
swimming pools	polygon	*hun_swim.shp*	*area*

d) For analysis of pedestrian access to a retrofitted community garden in the *NG* extension, an appropriate pedestrian travel network is needed. It is suggested that the combination of sidewalks and existing pedestrian paths is the most appropriate.

Pedestrian Network = sidewalks + ped_connectors
e.g., hun_rte.shp = hun_side.shp + hun_pc.shp (hun = Huntington neighbourhood)

The addition step in this "equation" is carried out using View / Geoprocessing Wizard (*Merge* option). Select the attributes of sidewalks to carry through.

e) The network analysis used to evaluate pedestrian access discussed in point c) requires that the multi-unit building nodes and potential garden facility locations be physically on the pedestrian network. To achieve this, I suggest editing the network theme (once created) by adding short "driveway" segments so that multi-unit nodes are connected to the sidewalks, roads, and paths. Furthermore, it is necessary to add connecting segments across intersections so that the full network is accessible to all nodes. These segments should be digitized using the line split tool, available on ArcView's toolmenu (assuming the *Digitizer* extension is activated).

f) **Important Note:** Each network line theme, created in steps c) and d), contains a "length" field which is used by the *NG* extension to determine the route distances between homes and facility locations. The use of the line split tool adds segments to the theme which have a ZERO value in their length field. The following procedure below describes how to update values in the length field[2]. This procedure must be done at the following times: 1) after the pedestrian route theme has been initially created; and 2) any time that a modification is made to the pedestrian route theme where a segment with a zero value is created (see "Extension Operation" section below).

Determine the length of new segments by:

- in the View window, set line theme to edit mode Theme / Start Editing;
- go to attribute table and highlight length field header;
- select all records in the table if there are numerous length records to be updated, <u>OR</u> select only the new additions as individual records (Shift key);
- in Table window, click Field / Calculate to activate Field Calculator Dialog box;
- in box labelled [Length] =, type in *[Shape].ReturnLength* and click OK;
- take theme out of edit mode Theme/Stop Editing

In addition to spatial data, the *NG* extension requires some additional attribute data for two of the shape files created above (*see Step 4*). These data are to be stored in .dbf file format and are later joined to the shape files during operation of the extension.

Step 4: Create .dbf files containing attributes of the neighbourhood's multi-unit buildings and road centrelines

CREATE	mu.dbf	with Attributes	*"dwelling_id", "type", "no_of_du"*
CREATE	hun_road_data.dbf	with Attributes	*"segment_ id", "seg_type"*

For the creation of the .dbf file for road centrelines, it is acceptable to use one that you may have already created when using the *Neighbourhood Traffic Calming (NTC)* extension. These attributes are fully described in Table 3 below. Field names created in the .dbf files must be those indicated here, otherwise the extension will not function properly. Example files are provided on the accompanying CD (see hun_road_data.dbf and hun_mu_data3.dbf located in the D:\ngExt directory).

---

[2] Procedure summarized from ESRI, 1996. *ArcView GIS: Using ArcView GIS*, Environmental Systems Research Institute, Inc., pp.261-2.

Table 3: Attributes of roads and multi-unit dwellings to be compiled in separate .dbf files

attribute	field name	notes on data source for attributes	data type
Road Centreline .dbf file			
segment identity number	SEG_ID	consult ArcView shape file	integer
segment type	SEG_TYPE	local, collector, or arterial	character
Multi-Unit .dbf file			
dwelling identification no.	HN_BUILD	consult ArcView shape file	integer
type of dwelling	TYPE	apt, townhouse, or rowhouse	character
number of dwelling units per building	NO_OF_DU	measured	integer

The *NG* extension uses standard road widths assigned to the three street types considered in order to calculate area. Paved widths for local, collector and arterial streets are assumed as 8.5, 12.2 and 14 m, respectively[3]. Driveways are assumed to have a standard width of 3 m.

Extension Operation

This section discusses the operation of the *NG* extension around its four key menu options (Table 4). A key output from the use of this tool is to develop strategies for greater use of naturalized landscaping techniques, the inclusion of community garden facilities within neighbourhoods, and the development of street tree planting schedules. The operation of the extension is described in more detail in the four "operational" steps below. Two data forms (NGE Data Forms 1 and 2) are provided at the end of this manual to facilitate recording information during the use of the *NG* extension.

Table 3: Menu options available in the *NG* extension

Menu Option	Brief Description
1) Delimit Study Area for Landscapeable Fraction	allows the user to create a distinct study area boundary to be considered in the calculation of landscapeable area;
2) Evaluate Landscapeable Area and NG Potential	determines the amount of landscapeable area in the study region; evaluation for neighbourhood greening potential is in terms of reduced use of water and other materials, as well as in terms of space available for planting street trees;
3) Select Locations for NG Features	employs a location-allocation algorithm to determine preferred facility locations for two neighbourhood greening features (e.g., community gardens and playgrounds);
4) View and Place NG Features	user is able to peruse information concerning neighbourhood greening features, and to then select and place measures on a map to create a neighbourhood greening program.

---

[3] Transportation Association of Canada (TAC), 1999. *Geometric Road Design for Canadian Roads*, Transportation Association of Canada, Ottawa.

The user is not restricted to following these menu options in order, with the exception that option 1) must be completed prior to option 2). Neither of the latter two options is dependent on the user having completed the first two options.

- ***Operational Step 1: Delimit Study Area for Landscapeable Fraction***

This menu option is activated from the initial View window ("Neighbourhood Name Start View") by on-clicking Neighbourhood Greening / Delimit Study Area for Landscapeable Fraction. This View window should contain all of the themes listed in Tables 1 and 2. You are first prompted to digitize a polygon representing the study area boundary. This boundary is then used to clip the existing themes which are copied to a newly created View window entitled: 'ngeAlt1', 'ngeAlt2', ... , 'ngeAltX'. This new View is used in subsequent analyses (see next step).

- ***Operational Step 2: Evaluate Landscapeable Area and NG Potential***

This menu option is activated from the View window - 'ngeAltX' - created in *Operational Step 1*, by on-clicking Neighbourhood Greening / Evaluate Landscapeable Area and NG Potential. You are first prompted to provide a .dbf containing road attribute data; this was discussed earlier in *Step 4*. The "identification" fields are used to link this file with the attribute table attached to the ArcView shape file. A "Landscapeable Area" dialog box is then generated and returns statistics concerning the areas devoted to various neighbourhood features. Record these results on NGE Data Form 1 or 2 found at the end of this user manual.

At this point, you have one of two options. You are prompted to investigate options for "Green Gardening" or for "Street Trees". In the former option, you can modify percentage allocations (of the available landscapeable area) to various garden types; details of these garden types are provided by on-clicking Neighbourhood Greening / View and Place Options (see *Operational Step 4* below). By indicating current and modelled allocations, you are able to investigate potential reductions in the consumption of various materials, water and cost. Record these results on NGE Data Form 1. In the latter option, you will generate a map depicting a street tree planting schedule. The extension locates gaps between existing trees, and then generates planting locations based on user inputted constraints for: desired tree spacing, tree cost and annual planting budget. A new theme ("Tree Planting Schedule) is generated in the View 'ngeAltX' for the planting schedule. Only the first five plant years are shown; you should consult the theme attribute table for tree locations to be planted in year 6 and beyond. Record results from a number of street tree schedules on NGE Data Form 2.

<u>Note:</u> It is important to recognize that the planting locations suggested are approximated only. After a planting schedule is drawn up, locations may have to be adjusted (once on-site) to account for utility and driveway locations. A traffic engineer may need to be consulted to evaluate potential street tree locations that may impact traffic safety, especially the safe operation of intersections.

- *Operational Step 3: Select Locations for NG Features*

This menu option is activated from the initial View window ("*Neighbourhood Name* Start View") by on-clicking Neighbourhood Greening / Select Locations for NG Features. This option provides a methodology to evaluate the best community garden or playground facilities to install. The potential "customers" for these facilities are assumed to be the residents of multi-unit dwellings, as they have little or no gardening or recreational space at home. Ensure that you have prepared an database file for multi-unit dwellings as discussed earlier in *Step 4*. It is assumed that people will consider accessing these facilities by walking, if route distances are relatively short. Hence a pedestrian network theme is used in the extension to evaluate route distances (see *Step 3*). You are required to digitize polygon and point locations for potential facilities. Note that the point locations MUST intersect the pedestrian route. In the prototype version, the maximum number of potential facilities considered is four. Additional constraints can be entered for the minimum number and size of gardening plots.

The output from this menu option consists of the best and second best configuration of facilities to install. These results are displayed in a "NGE Selection Output" dialog. A new View window is also created; in the example of community garden locations, the new View is entitled 'Community Garden Alternative X'.

- *Operational Step 4: View and Place NG Features*

The final menu option, Neighbourhood Greening / View and Place NG Features, provides an opportunity to investigate the various neighbourhood greening features listed earlier in the section "Objectives of the Tool". Upon on-clicking this menu option, you are prompted for the existing land use, since this governs the types of neighbourhood greening features possible. For each feature, you can peruse its description, benefits, recommended locations and management or maintenance issues. Photos of sample features are also available. You are then prompted to digitize locations of these features on a map to create a neighbourhood greening program. You can create a new program or modify an existing one. This type of map can also be utilized to display the locations of neighbourhood greening features that were investigated in *Operational Steps 1,2 and 3.*

NGE - DATA FORM 1		**PAGE 1 OF 2**
PROJECT:	**DATE:**	**ANALYST:**

Procedure:

- investigate benefits of changing landscaping type for a defined study area

Applicable Menu Option(s):

- Delimit Study Area for Landscapeable Fraction
- Evaluate Landscapeable Area and NG Potential [GREENING]

Generated Study Area Characteristics:

Initial View:		**Study Area Theme:**	
New View:		**Layout:**	
Study Area Characteristics			
Areas (in hectares)	**(ha)**	**Other**	
buildings		street frontage (km)	
roads			
driveways		# of single family homes	
parking lots		# of duplexes	
sidewalks		# of multi-unit buildings	
swimming pools			
		# of existing street trees	
total study area			
net landscapeable area			

Alternative Garden Configurations Considered:

- describe alternatives on the lines, below the table, and on the next page;
- system default is 80% conv.lawn, and 10% to each of orna.tree/orna.flwr.;

	Percent Allocated to each Garden Type							
garden type	**current**	**Alt 1**	**Alt2**	**Alt3**	**Alt4**	**Alt5**	**Alt6**	**Alt7**
xeriscape								
woodland shade								
wildflower								
conventional lawn								
low maintenance lawn								
ornamental tree / shrub								
ornamental flower								
vegetable garden	not available							
greenhouse	not available							

Alt 1:

Alt 2:

NGE - DATA FORM 1

Alt 3:

Alt 4:

Alt 5:

Alt 6:

Alt 7:

Potential Changes in the use of various materials, in each of the listed alternatives.

- results are based on data provided in CHMC (2000a)
- provide actual values for "current" and "Alt1"; record only the percent change for the remainder of the alternatives.

	Actual Rates		**Percent Change from the Current Case**						
variable	**current**	**Alt 1**	**Alt 1**	**Alt2**	**Alt3**	**Alt4**	**Alt5**	**Alt6**	**Alt7**
water consumption (m^3/yr)									
gasoline consumption (m^3/yr)									
pesticide use (kg/yr)									
fertilizer use (kg/yr)									
time inputs (days/yr)									
cost ($/yr)									

	NGE - DATA FORM 2	**PAGE 1 OF 1**
PROJECT:	**DATE:**	**ANALYST:**

Procedure:

- generate a street tree planting schedule (5 years) for a designated study area

Applicable Menu Option(s):

- Delimit Study Area for Landscapeable Fraction
- Evaluate Landscapeable Area and NG Potential [STREET TREES]

Generated Study Area Characteristics:

Initial View:		**Study Area Theme:**	
New View:		**Existing Tree Theme:**	
		Study Area Characteristics	
Areas (in hectares)	**(ha)**	**Other**	
buildings		street frontage (km)	
roads			
driveways		# of single family homes	
parking lots		# of duplexes	
sidewalks		# of multi-unit buildings	
swimming pools			
		# of existing street trees	
total study area			
net landscapeable area			

Planting Schedules Generated:

- use default parameters (or specify your own) to generate street tree planting schedules;
- default tree cost is estimated from local nursery and includes installation of a 2-inch calliper, Maple ($300) - Oak would be slightly more costly;
- RE: choice of printer; if b/w is selected, planting locations are symbols; if colour is selected, distinct colours are used;

parameter	**default values**	**Street Tree Planting Schedule**			
		1	**2**	**3**	**4**
desired tree spacing	15 m				
total number of trees to be planted	n/a				
average cost per tree	$300				
annual budget for planting	$10,000				
printer choice	b/w				
# of years to plant all trees	n/a				
new theme for plant schedule	n/a				
layout	n/a				

APPENDIX E

Devices and Techniques for Water Use Reduction in the Home

Context

The conceptual model for suburban retrofitting developed in this dissertation includes a discussion of devices and techniques for reducing water consumption and wastewater generation at the neighbourhood scale (see section 3.2.8). Further to these neighbourhood-scale retrofits, numerous retrofits could be implemented for individual homes to reduce personal water consumption and wastewater generation therein. This appendix provides some additional information about devices and techniques that could be implemented to reduce both water consumption and wastewater generation in and around the home. The included information could be incorporated into future work on retrofitting existing homes, to make these fit models of "green buildings" with lower overall environmental impact.

Home-Scale Devices and Techniques

Devices and techniques to be discussed include minor and major plumbing reconfigurations, the use of cisterns and landscaping techniques. Minor plumbing alterations, to save water in the home, include small devices that can be added to toilets, sinks and showers, as well as routine maintenance. According to Maddaus (1987), approximately 20 percent of all toilets leak as much as 30,000 L of water per year. Leaky faucets with a drip of one drop per second can waste as much as 10,000 L of water per year. With the average 1993 cost in Toronto for water/sewer services of $\$0.96/m^3$, a simple repair to a toilet or replacement of a washer in a faucet could save the homeowner as much as $38.40 on annual water costs.

Dishwashers and clothes washing machines are significant users of water, at 24 to 53 L/cycle and 96 to 212 L/cycle, respectively (Gates, 1994). Using appliances more sparingly could result in significant cost savings. For example, most dishwashers have a shorter, more efficient cycle that can be selected for "light" loads, in which the plates and cutlery have been rinsed briefly before being placed in the appliance.

Low cost measures, averaging about $40-50 per household, include toilet retrofit and showerhead and faucet adapters (Gates, 1994). These provide modest savings of water per flush (3 to 4 L). Higher cost measures, typically in the hundreds of dollars, involve fixture replacement. Replacement of an older 20 L/flush toilet with lower flow or ultra-low flow toilets, using approximately 3 to 6 L/flush, would provide significant water savings. For example, a 6 L/flush replacement for a 20 L/flush toilet can reduce water used for toilet flushing by 70%, and result in a reduction of indoor water consumption by approximately 20%. Potential savings on the annual water bill amount to nearly $100 (see Table E.1). Gates (1994) reports the replacement toilet might cost $150 to $400, but can be paid back through lower water and sewer bills in less than five years.

Table E.1: Potential water savings in terms of volume and cost. Assume average per capita water consumption of 350L/cap/day, and a family of 4 living in the home, with a water/sewer cost of 0.96 $/L (1993 value for City of Toronto; Gates, 1994).

	Water Consumption	**Family of 4 Consumption**		**Volume Reduction**	**Annual Water Bill**	**Potential Savings**
base case	350 L/c/d	511,000 L/yr	511 m^3/yr	-	$490.56	-
low flush toilet (20%)	280 L/c/d	408,800 L/yr	409 m^3/yr	70 L/c/d	$392.45	$98.11
low flow showerhead (33%)	235 L/c/d	343,100 L/yr	343 m^3/yr	115 L/c/d	$329.38	$161.18
both options	165 L/c/d	241,000 L/yr	241 m^3/yr	185 L/c/d	$231.26	$259.30

A second example of water reduction in the home would be the replacement of conventional showerheads, with flows of 15 to 20 L/minute. Showerheads with flows of at most 10 L/minute are now mandatory in Ontario (Gates, 1994), and faucets and showerheads with flows as low as 2 to 5 L/minute are also available. A change from a 15 L/minute to a 10 L/minute showerhead could reduce water consumption by 33%, and provide significant savings (Table E.1). Installation of both a low flush toilet and low flow showerhead could reduce an individual homeowner's annual water bill by more than $250. Many of these devices are now required by law in Ontario, due to changes to the Province's plumbing code in the 1990's (Sharratt *et al.*, 1994).

Cisterns and rain barrels are commonly used in rural areas to collect stormwater from roofs for use in the home or in landscaping. Many people use their cistern water (with limited treatment or filtration) for drinking and cooking. The use of cisterns could be applied in suburban areas, used to collect rainwater from roofs of homes and garages as well as stormwater from driveways. Cisterns could be constructed in basements or as a separate tank (buried or on the surface, like a rain barrel). Ideally there should be two separate cisterns: one, for "clean" water from the roof; and a second for the somewhat dirtier water collected off paved surfaces which might have some oil content. Clean water collected by one cistern could be used for a number of household uses including showering, bathing, toilet flushing, appliances, cleaning, cooking, and drinking; the latter two uses may require some treatment or filtration. But certainly, this water is safe for the former uses. The potentially contaminated water collected by a second cistern could be used as a "grey water" source in the home, safe (with necessary treatment/filtration) for uses such as: appliances, toilet flushing, cleaning and even showering. Water from either cistern would be appropriate for landscape application.

Developing a plumbing system capable of handling a number of different water streams in the house (potable, cistern waters, non-potable, grey water, black water) would be a major undertaking, but would also lead to reductions in water usage. It would require, however, significant modifications to the current plumbing networks within the typical home and is considered beyond the scope of the discussion here. Recycling grey water systems are demonstrated in Toronto's Healthy House (see CMHC, 2000b for details) and by Russell *et al.* (1994).

And finally, techniques for alternative landscaping should be considered to help reduce water consumption. Outdoor water use, for gardening and irrigation, is a significant component of water demand, particularly in the summer season. There are means of reducing outdoor water demands by at least 50%, but it will require a significant change in the way people value, and behave with, their water resources (Gates, 1994).

Managing water in the yard and driveway has the following objectives: 1) reduction of volume of water sent to a wastewater treatment plant (WWTP); 2) enhancement of groundwater table via infiltration through porous surfaces; and 3) reduction of watering needs through the use of vegetation types most suited to the local climate. Achieving the first of these objectives involves the diversion of stormwater away from the sewer (i.e., avoids the "combined sewer" approach). Water from roofs (using cisterns) and driveways, which would normally go to the storm sewer, would be collected. Runoff from driveways would be diverted from the storm sewer using a number of measures. As discussed above, cisterns could be built, and the water used for garden and landscaping. A second option would be the construction of drainage swales and infiltration ponds. These could be constructed adjacent to driveways or in low-lying areas of the neighbourhood's green spaces. The collected water would then slowly percolate to groundwater, or evaporate. Thirdly, the runoff generated by driveways could be reduced through the use of permeable paving materials and techniques, including porous asphalt, bricked driveways, "greened" driveways with grass strip between paved wheel tracks, and gravel driveways. The design and management of drainage swales and infiltration ponds would need care to ensure their long term success in capturing and holding large storms, while efficiently dissipating water to the atmosphere, groundwater or surface streams. It would be inappropriate, for example, for ponds to persist for long enough periods to develop algae blooms and create mosquito habitat, unless pond creation was to be used as part of a neighbourhood naturalization strategy. Each of these mentioned options works towards the second objective of recharging local groundwater tables. In particular, roof and driveway runoff diverted onto greened areas, will percolate into the soil. In addition to these options, the runoff from the roads themselves could also be diverted to low-lying areas for temporary storage or landscaping uses. From storage ponds, runoff could be used to feed local streams (as it likely did naturally) or to percolate into the groundwater table.

The third objective of managing water in the yard and driveway is important, in terms of reducing the outdoor demands for water around the house and neighbourhood. It is clearly linked to neighbourhood-scale retrofits considered for "neighbourhood greening" (see section 3.2.3). The fixation of North Americans with the “expected” greenscape (e.g., weed-free, chemically-treated lawn, exotic and often water-consumptive plant species) has led to our high per capita water consumption rates. The more-sustainable means to have green space in urban communities is through the practice of xeriscaping and naturalization. Xeriscaping involves the use of suitable native (and non-native) plant species that have proven themselves hardy and drought tolerant to a particular climate. A broad range of plants are available for all climatic regions, and the result can be quite diversified and unique (Thomsen, 1994). Naturalization involves the use of indigenous species to a particular area and has still lower maintenance requirements. These and other neighbourhood greening options were discussed in chapter 6.

APPENDIX F

Estimated Consumption Rates of Various Materials by Garden Type

Descriptions of the first 7 garden types listed on the subsequent table, and their corresponding consumption rates of the various materials and time and cost inputs, are taken from CMHC (2000a). Data for the final two types (vegetable gardens and greenhouses) are not currently available.

Table F.1: Estimated consumption rates by garden type (compiled from CMHC, 2000a)

garden type	description*¹	annual water consumption (Liter/m²)	annual gasoline consumption (mL/m²)	annual time inputs (minutes/m²)	annual costs ($/m²)	annual fertilizer inputs (grams/m²)	annual pesticide inputs (grams/m²)
xeriscape	made up of tree, shrub and perennial species adapted to suit local rainfall conditions and require almost no watering	7.3	0	18.4	0.8	16.7	0.5
woodland shade garden	composed of native trees, shrubs and ground covers that mimic natural forests	29.1	0	5.6	0.3	0	0.1
wildflower meadow	feature native grasses and wildflowers that mimic natural meadow or prairie landscapes	12.7	1.3	4.8	0.1	0	0.2
conventional lawn	made up of two or three turf grass species; neatly trimmed and regularly watered, fertilized and sprayed to achieve a consistent, manicured look	38.2	32.8	4.1	0.5	90.7	5.4
low-maintenance lawn	composed of hardy, drought-tolerant, slow-growing grass and broad-leafed species that do not require frequent mowing; resemble conventional lawns but are slightly taller and more diverse in appearance	0	17.3	2.2	0.1	14.1	0
ornamental trees and shrubs	feature primarily exotic species selected for brilliant displays and other visual characteristics; these are regularly pruned, weeded, watered and sprayed	78.2	0	20.6	1.3	167.8	6.2
ornamental flowerbeds	feature bulbs and perennials that are weeded, cut back and divided and annuals that are replanted every year	180	0	28.1	2.0	25.9	3.4
vegetable garden	vegetable gardens irrigated using rainwater collected in cisterns; organic farming techniques for pest control are encouraged	-	-	-	-	-	-
greenhouse	lengthens the growing season and allows a more diverse crop of vegetables	-	-	-	-	-	-

Notes: 1) descriptions are exact quotes from CMHC (2000a), except for vegetable garden and greenhouse types, which are descriptions by the author.

APPENDIX G

Database Files Used in Sample Applications

Filename: *ber_mu_data.dbf* (refer to Table G.1)
Description: Multi-unit dwelling attribute data for the Berrisfield neighbourhood used in the application of *PRD Evalute* in chapter 4. Field headings are identity number (BE_BUILD_); type of multi-unit dwelling (TYPE); number of dwelling units in each building (NO_OF_DU); and street by which the particular dwelling unit is accessed (ACCESS_ST).

Filename: *hun_road_data.dbf* (refer to Table G.2).
Description: Road centreline data for the Huntington neighbourhood used in the application of the NTC and NG extensions in chapters 5 and 6. Field headings are identity number (SEG_ID); road segment classification (SEG_TYPE); segment width (SEG_WIDTH); segment ROW width (SEG_ROW); number of travel lanes (TRAV_LANE); number of parking lanes (PKG_LANE); 85th percentile speeds (SPEED_85); traffic volume (in vpd)(TRAFF_VOL); and indicator if segments has received a public request for traffic calming (PUB_REQ).

Filename: *hun_mu_data.dbf* (refer to Table G.3)
Description: Multi-unit dwelling attribute data for the Huntington neighbourhood used in the application of the *NG* extension in chapter 6. Field headings are identity number (HN_BUILD_); type of multi-unit dwelling (TYPE); number of dwelling units in each building (NO_OF_DU); and street by which the particular dwelling unit is accessed (ACCESS_ST).

Table G.1: Multi-unit dwelling data for Berrisfield neighbourhood

BE_BUILD_	TYPE	NO_OF_DU	ACCESS_ST
8	apt	180	Up Gage Ave
44	apt	24	Up Gage Ave
66	rowhouse	5	Palmer Rd
98	rowhouse	4	Rosanne Cr
409	townhouse	6	Beryl St
454	townhouse	8	Beryl St
511	townhouse	7	Beryl St
621	townhouse	5	Larch St
631	townhouse	8	Larch St
634	townhouse	8	Larch St
661	townhouse	5	Larch St
670	townhouse	8	Birchview Dr
683	townhouse	8	Birchview Dr
692	townhouse	5	Larch St
696	townhouse	8	Birchview Dr
715	townhouse	7	Birchview Dr
718	townhouse	8	Birchview Dr
719	townhouse	3	Birchview Dr
720	townhouse	7	Bowden St
721	townhouse	8	Bowden St
736	townhouse	5	Bowden St
739	townhouse	5	Bowden St
745	townhouse	8	Birchview Dr
746	townhouse	8	Birchview Dr
767	townhouse	6	Birchview Dr
935	townhouse	4	Limeridge Rd
947	townhouse	3	Limeridge Rd
954	townhouse	8	Limeridge Rd
961	townhouse	3	Limeridge Rd
962	townhouse	9	Limeridge Rd
965	townhouse	8	Limeridge Rd
973	townhouse	8	Limeridge Rd
976	townhouse	7	Limeridge Rd
978	townhouse	8	Limeridge Rd
980	townhouse	9	Limeridge Rd
982	townhouse	8	Limeridge Rd
984	townhouse	2	Limeridge Rd
985	townhouse	8	Limeridge Rd
986	townhouse	7	Limeridge Rd
987	townhouse	4	Limeridge Rd
988	townhouse	2	Limeridge Rd
989	townhouse	5	Limeridge Rd
990	townhouse	6	Limeridge Rd
991	townhouse	2	Limeridge Rd
992	townhouse	5	Limeridge Rd
993	townhouse	4	Limeridge Rd
994	townhouse	4	Limeridge Rd
995	townhouse	8	Limeridge Rd
996	townhouse	5	Limeridge Rd
997	townhouse	4	Limeridge Rd
998	townhouse	4	Limeridge Rd
999	townhouse	4	Limeridge Rd

Table G.2: Road centreline data for Huntington neighbourhood

SEG_ID	SEG_TYPE	SEG_WIDTH	SEG_ROW	TRAV_LANE	PKG_LANE	SPEED_85	TRAFF_VOL	PUB_REQ
1	local	8.5	20	2	1	50	800	n
2	local	8.5	20	2	1	49	800	n
3	local	8.5	20	2	1	50	750	n
4	local	8.5	20	2	1	47	800	n
5	local	8.5	20	2	1	48	850	n
6	local	8.5	20	2	1	49	890	n
7	local	8.5	20	2	1	40	220	n
8	local	8.5	20	2	1	42	200	n
9	local	8.5	20	2	1	46	1200	n
10	local	8.5	20	2	1	54	1150	n
11	local	8.5	20	2	1	52	1100	y
12	local	8.5	20	2	1	47	700	y
13	local	8.5	20	2	1	50	800	n
14	local	8.5	20	2	1	46	600	n
15	local	8.5	20	2	1	40	1600	n
16	local	8.5	20	2	1	46	850	n
17	local	8.5	20	2	1	49	430	y
18	local	8.5	20	2	1	52	400	n
19	local	8.5	20	2	1	54	500	y
20	local	8.5	20	2	1	46	800	n
21	local	8.5	20	2	1	52	710	n
22	local	8.5	20	2	1	49	1200	n
23	local	8.5	20	2	1	49	910	n
24	local	8.5	20	2	1	40	220	n
25	local	8.5	20	2	1	48	900	n
26	local	8.5	20	2	1	46	900	n
27	local	8.5	20	2	1	48	890	n
28	local	8.5	20	2	1	46	975	n
29	local	8.5	20	2	1	48	680	n
30	local	8.5	20	2	1	46	710	n
31	local	8.5	20	2	1	40	300	n
32	local	8.5	20	2	1	44	210	n
33	local	8.5	20	2	1	46	200	n
34	local	8.5	20	2	1	48	600	n
35	local	8.5	20	2	1	40	200	n
36	local	8.5	20	2	1	40	310	n
37	local	8.5	20	2	1	42	120	n
38	local	8.5	20	2	1	41	200	n
39	local	8.5	20	2	1	42	200	n
40	local	8.5	20	2	1	49	1200	n
41	local	8.5	20	2	1	49	900	n
42	local	8.5	20	2	1	46	1400	n
43	local	8.5	20	2	1	48	1800	n
44	local	8.5	20	2	1	46	2000	n
45	local	8.5	20	2	1	50	2800	n
46	local	8.5	20	2	1	46	800	n
47	local	8.5	20	2	1	47	640	n
48	local	8.5	20	2	1	47	600	n
49	local	8.5	20	2	1	47	800	n

Table G.2: continued …

SEG_ID	SEG_TYPE	SEG_WIDTH	SEG_ROW	TRAV_LANE	PKG_LANE	SPEED_85	TRAFF_VOL	PUB_REQ
50	local	8.5	20	2	1	48	900	n
51	local	8.5	20	2	1	49	950	n
52	local	8.5	20	2	1	48	710	n
53	local	8.5	20	2	1	50	640	n
54	local	8.5	20	2	1	54	500	n
55	local	8.5	20	2	1	42	210	n
56	local	8.5	20	2	1	48	430	n
57	local	8.5	20	2	1	50	1500	n
58	local	8.5	20	2	1	49	680	n
59	local	8.5	20	2	1	49	720	n
60	local	8.5	20	2	1	50	850	n
61	local	8.5	20	2	1	48	1000	n
62	local	8.5	20	2	1	43	210	n
63	collector	12.2	26	2	2	48	3200	n
64	collector	12.2	26	2	2	52	3000	n
65	collector	12.2	26	2	2	47	3050	y
66	collector	12.2	26	2	2	49	2100	y
67	collector	12.2	26	2	2	56	2200	y
68	collector	12.2	26	2	2	55	2300	n
69	arterial	12.2	26	2	2	58	5400	n
70	arterial	12.2	26	2	2	57	5450	n
71	arterial	12.2	26	2	2	59	6100	n
72	local	8.5	20	2	1	42	260	n
73	local	8.5	20	2	1	46	1400	n
74	local	8.5	20	2	1	49	2800	n
75	arterial	14.0	26	4	0	50	10500	n
76	arterial	14.0	26	4	0	56	9800	n
77	arterial	14.0	26	4	0	55	9650	n
78	arterial	14.0	26	4	0	57	9500	n
79	arterial	14.0	26	4	0	50	8000	n
80	local	8.5	20	2	1	50	800	n
81	local	8.5	20	2	1	47	1000	n
82	local	8.5	20	2	1	48	800	n
83	local	8.5	20	2	1	49	690	n
84	local	8.5	20	2	1	48	700	n
85	local	8.5	20	2	1	49	750	n
86	local	8.5	20	2	1	48	2900	n
87	local	8.5	20	2	1	46	500	n
88	local	8.5	20	2	1	48	600	n
89	local	8.5	20	2	1	47	680	n
90	local	8.5	20	2	1	47	800	n
91	collector	12.2	26	2	2	50	2700	n
92	collector	12.2	26	2	2	47	2500	n
93	collector	12.2	26	2	2	46	2500	n
94	collector	12.2	26	2	2	48	2300	n
95	collector	12.2	26	2	2	49	2200	n
96	collector	12.2	26	2	2	48	2200	n
97	collector	12.2	26	2	2	44	2200	n
98	collector	12.2	26	2	2	48	3200	n

Table G.2: continued ...

SEG_ID	SEG_TYPE	SEG_WIDTH	SEG_ROW	TRAV_LANE	PKG_LANE	SPEED_85	TRAFF_VOL	PUB_REQ
99	collector	12.2	26	2	2	52	3150	n
100	collector	12.2	26	2	2	50	3000	n
101	collector	12.2	26	2	2	50	3500	n
102	collector	12.2	26	2	2	49	2900	n
103	collector	12.2	26	2	2	56	1750	n
104	collector	12.2	26	2	2	54	1800	n
105	collector	12.2	26	2	2	50	1900	n
106	collector	12.2	26	2	2	48	4200	n
107	local	8.5	20	2	1	50	600	n
108	local	8.5	20	2	1	50	700	n
109	local	8.5	20	2	1	49	600	n
110	local	8.5	20	2	1	47	550	n
111	local	8.5	20	2	1	49	950	n
112	local	8.5	20	2	1	50	800	n
113	local	8.5	20	2	1	50	800	n
114	local	8.5	20	2	1	47	890	n
115	arterial	14.0	26	4	0	55	9650	n
116	arterial	14.0	26	4	0	58	9600	n
117	local	8.5	20	2	1	49	720	n
118	local	8.5	20	2	1	49	800	n
119	arterial	12.2	26	2	2	56	6200	n
120	local	8.5	20	2	1	46	900	n
121	arterial	14.0	26	4	0	57	9500	n
122	local	8.5	20	2	1	42	100	n
123	local	8.5	20	2	1	50	1200	n
124	local	8.5	20	2	1	49	900	n
125	local	8.5	20	2	1	49	850	n
126	arterial	14.0	26	4	0	57	8400	n
127	arterial	14.0	26	4	0	57	8400	n
128	local	8.5	20	2	1	46	3000	n
129	local	8.5	20	2	1	46	1700	n
130	collector	12.2	26	2	2	48	2900	n
131	collector	12.2	26	2	2	46	2000	n
132	local	8.5	20	2	1	47	250	n
133	collector	12.2	26	2	2	50	4500	n
134	arterial	14.0	26	4	0	51	12000	n
135	arterial	14.0	26	4	0	56	11400	n
136	arterial	14.0	26	4	0	68	8200	n
137	arterial	14.0	26	4	0	56	7500	n
138	arterial	14.0	26	4	0	66	7200	n
139	arterial	14.0	26	4	0	68	6400	n
140	arterial	14.0	26	4	0	60	6000	n

Table G.3: Multi-unit dwelling data for Huntington neighbourhood

HN_BUILD_	TYPE	NO_OF_DU	ACCESS_ST
6	apt	120	Fennell Ave East
25	apt	20	Fennell Ave East
31	apt	23	Fennell Ave East
39	apt	6	Fennell Ave East
42	apt	6	Fennell Ave East
45	apt	6	Fennell Ave East
49	apt	9	Fennell Ave East
53	apt	42	Fennell Ave East
63	apt	12	Fennell Ave East
70	apt	9	Fennell Ave East
75	apt	9	Fennell Ave East
79	apt	9	Fennell Ave East
85	apt	36	Fennell Ave East
98	townhouse	3	Shirley St
113	apt	7	Shirley St
115	apt	9	Fennell Ave East
120	apt	6	Fennell Ave East
129	apt	6	Fennell Ave East
132	apt	37	Fennell Ave East
146	apt	6	Upper Kenilworth Ave
172	apt	6	Upper Kenilworth Ave
1361	apt	6	Upper Kenilworth Ave
1401	apt	6	Upper Kenilworth Ave
1433	apt	6	Upper Kenilworth Ave
1459	apt	12	Mohawk Rd East
1470	apt	12	Mohawk Rd East
1480	apt	6	Upper Kenilworth Ave
1488	apt	4	Mohawk Rd East
1500	apt	117	Mohawk Rd East
1510	apt	6	Upper Kenilworth Ave
1545	apt	6	Upper Kenilworth Ave
1649	apt	12	Mohawk Rd East
1667	apt	66	Mohawk Rd East
1694	apt	12	Mohawk Rd East
1695	apt	15	Mohawk Rd East
1707	apt	12	Mohawk Rd East
1712	apt	12	Mohawk Rd East
1717	apt	12	Mohawk Rd East
1720	apt	32	Mohawk Rd East
1732	apt	32	Mohawk Rd East

APPENDIX H

ArcView Extensions and Supporting Files

All files needed to install and operate the three developed ArcView extensions, as described in the user manuals (Appendices B, C, and D), are contained on the CD in the pocket on the back cover of this dissertation.