A Prototype Decision Support System for the Productive Reuse of Vacant and Underutilized Urban Land

A DECISION SUPPORT SYSTEM FOR THE PRODUCTIVE REUSE OF VACANT AND UNDERUTILIZED URBAN LAND

BY

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Abstract

Many cities around the world struggle with the presence of vacant and underutilized land in the urban environment. There is growing momentum across many municipal jurisdictions in North America to reuse public and privately held vacant and underutilized urban land on a temporary to potentially permanent basis for community-based projects; however, there are limited community-based tools available to assess the suitability of vacant land for potential reuse.

This thesis presents three papers (Chapters 2-4) that describe the development and application of a prototype community-based decision support tool (PDSS), developed in Microsoft Excel®. The PDSS provides a methodology for evaluating up to fifteen community-based reuse strategies across three green infrastructure categories: parks, urban food production, and stormwater/ecosystems management. The PDSS aids in deriving community-focused goals, objectives and solutions for the efficient reuse of vacant and underutilized land.

The PDSS includes a vacant and underutilized land inventory for identifying and inventorying the physical and spatial attributes (i.e. location and condition) of vacant and underutilized land across the urban environment (VULI); a methodology for quantifying the suitability of vacant land for a suite of reuse strategies (SSI); a multi-objective, binary-integer programming formulation for the allocation of reuse strategies across the urban environment (LOCAL), and a tool for municipal green infrastructure investment decision-making (DECO).

The information derived from VULI and SSI can be used by community groups to help articulate the inherent potential of these spaces for future reuse. If this methodology was adopted at the municipal level, the prototype tool has the potential to expedite applications to reuse city-owned lands on a temporary basis. LOCAL provides a methodology to facilitate the allocation of multiple reuse strategies to a single parcel, to achieve a mix of green infrastructure uses at each site, and provides users with the ability to readily generate "what-if" scenarios based on user-specified allocation constraints. DECO can be utilized to design and investigate material alternatives, maintenance schedules, and different cost regimes, which can be useful for construction and long-term preventative maintenance decision-making. Finally, the results of a tree growth-stormwater attenuation modeling exercise are presented (Chapter 5). The methodology and results presented aid in articulating the stormwater attenuating benefits of trees that are planted on a temporary basis on vacant land.

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Lastly, this thesis is for my mother (and dearest friend), Susanne, whom I lost 6 years ago – for her unending encouragement and love. I did it mom!

Nomenclature

SSI_i^j	Site Suitability Index (coefficient) for strategy *j* at site *i*
X_i^j	Binary decision variable for reuse strategy *j* at site *i*
X_k^j	Binary decision variable for reuse strategy *j* at site *k*
$X^{max,j}$	Maximum number of allocations allowable for each strategy *j*
$D_{i,k}$	Geodesic distance between site *i* and site *k*
$D_{min.sep.}^j$	Minimum separation distance required for reuse strategy *j*
PV	Present Value of life cycle costs
C_t	Sum of all costs occurring in year t (i.e. acquisition costs + capital costs + maintenance costs + renewal costs)
S_t	Sum of all salvage values occurring in year t
R_t	Sum of all revenue values occurring in year t
t	Number of years in the future when the cost will be incurred
n	Total number of years under analysis (life cycle length)
i	Real discount rate (nominal interest rate - expected inflation)
Y_L	Total canopy Leaf Area (LA)
Y_P	Tree growth parameters (tree height, crown diameter, crown height, diameter at breast height)
H	Crown height
D	Crown diameter

Sh	Average Shading Factor
S_c	Estimate of crown surface area
a, b, c	Regression coefficients for predicted tree growth parameters
C	Water storage on the canopy
C_{t-1}	Water storage on the canopy from the previous time step
P	Open-sky precipitation
R	Precipitation that contacts and falls through the wetted canopy
E	Evaporation from the wetted canopy
P_f	Rainfall that falls through the tree canopy without leaf contact
c_f	Tree canopy cover fraction
k	Light extinction coefficient
S	Maximum storage capacity of the canopy
S_L	Maximum depth of water that can be stored by leaves per unit leaf area
E_P	Evaporation potential
E_F	Evaporation flux
T	Temperature
p	Daytime hours coefficient
LAI_T	The total leaf area index when the canopy is in full-leaf (one sided leaf area per unit ground area in broadleaf canopies)
LAI_F	Fraction of the total leaf area index

F_L	Fraction of the canopy in leaf
Q	Runoff depth
I_a	Initial abstraction
CN	SCS Curve Number
S_s	Potential maximum soil moisture retention after runoff begins

Publication List

This thesis consists of the following papers:

Paper I
Kirnbauer, M.K. and Baetz, B.W. A prototype community-based planning tool for evaluating site suitability for the temporary reuse of vacant lands. Submitted to the Journal of the American Planning Association (August 2011).

Paper II
Kirnbauer, M.K. and Baetz, B.W. Allocating urban agricultural reuse strategies to inventoried vacant and underutilized land. Accepted for publication (in press) in the Journal of Environmental Informatics (April 2012).

Paper III
Kirnbauer, M.K. and Baetz, B.W. A prototype decision support system for the designing and costing of municipal green infrastructure. Submitted to the Journal of Urban Planning and Development (April 2012).

Paper IV
Kirnbauer, M.K., Baetz, B.W. and Kenney, W.A. Estimating the stormwater attenuation benefits derived from planting four monoculture species of deciduous trees on vacant and underutilized urban land parcels. Submitted to Urban Forestry and Urban Greening (June 2012).

Co-Authorship

This thesis has been prepared in accordance with the regulations for a 'Sandwich' thesis format as stipulated by the Faculty of Graduate Studies at McMaster University, and has been co-authored.

Chapter 2: A prototype community-based planning tool for evaluating site suitability for the temporary reuse of vacant lands
by: M.C. Kirnbauer and B.W. Baetz
The methodology, scientific software and application of the decision support tool were completed by M.C. Kirnbauer in consultation with Dr. B.W. Baetz. The paper (Chapter 2) was written by M.C. Kirnbauer and edited by Dr. B.W. Baetz.

Chapter 3: Allocating urban agricultural reuse strategies to inventoried vacant and underutilized land
by: M.C. Kirnbauer and B.W. Baetz
The methodology, scientific software and application of the decision support tool were completed by M.C. Kirnbauer in consultation with Dr. B.W. Baetz. The paper (Chapter 3) was written by M.C. Kirnbauer and edited by Dr. B.W. Baetz.

Chapter 4: A prototype decision support system for the designing and costing of municipal green infrastructure
by: M.C. Kirnbauer and B.W. Baetz
The methodology, scientific software and application of the decision support tool were completed by M.C. Kirnbauer in consultation with Dr. B.W. Baetz. The paper (Chapter 4) was written by M.C. Kirnbauer and edited by Dr. B.W. Baetz.

Chapter 5: Estimating the stormwater attenuation benefits derived from planting four monoculture species of deciduous trees on vacant and underutilized urban land parcels
by: M.C. Kirnbauer, B.W. Baetz, and W.A. Kenney
The modeling and analysis carried out for this paper was completed by M.C. Kirnbauer in consultation with Dr. B.W. Baetz and Dr. W.A. Kenney. The paper (Chapter 5) was written by M.C. Kirnbauer and edited by Dr. B.W. Baetz and Dr. W.A. Kenney.

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Chapter 1. Introduction

1.1 Motivation for Research

The objective of this thesis was to develop a neighbourhood-based vacant and underutilized land inventory that could be carried out by lay persons, and to subsequently allocate and design contextually-appropriate municipal green infrastructure reuse strategies for public and privately owned vacant and underutilized urban lands. Section 1.1 of this thesis describes the impetus for this research by providing a summary of literature that introduces the context of the vacant and underutilized land dilemma, and the need for community-driven solutions. The scope of this research is defined in Section 1.2. As described in Sections 1.2 and 1.3, this thesis focuses on short, medium and long-term, temporary holding strategies for vacant and underutilized urban land, recognizing that some parcels may continue in this use permanently, while others will be developed for a higher-order land use at some point in the future (and as such, will be temporary reuse strategies). The suite of strategies that were studied as part of this thesis can be organized into three municipal green infrastructure categories: parks and open space, urban food production, and stormwater management; these will be described in further detail in Section 1.2.

Many cities around the globe, regardless of size or geographic location struggle with the presence of vacant and underutilized land in the urban environment. Historically, long-term solutions that contribute to the recovery of declining areas have not been implemented on a consistent basis, and this is largely influenced by the fact that many cities in North America have not kept an inventory of privately held vacant or underutilized land (Pagano and Bowman, 2000). Exceptions to this include brownfield (contaminated land) and greenfield (agricultural lands to be developed) inventories.

The term vacant land can hold many meanings for different stakeholders. It has been used in an urban context to describe publicly or privately held residential, industrial, commercial, institutional, agricultural, and open space lands (preserved/not-preserved) that are not being utilized, under-utilized, or abandoned (including derelict buildings or remnants of buildings). Vacant land may be contaminated (i.e. land that cannot be used productively without remediation), whether the contamination is perceived or actual (Bowman and Pagano, 2004). In an attempt to understand the complexity of the vacant land issue in American cities, Bowman and Pagano (2004) conducted a survey of planning directors in U.S. cities with populations of 50,000 or greater and found that on average approximately 15% of a city's land area can be classified as vacant. Of the cities surveyed, some inventories were not tracked consistently, if at all, and some estimates were in fact approximations or best-guesses, as many cities lack a true understanding of the extent of vacant and underutilized land in their cities. This untapped resource presents enormous opportunities socially, environmentally and economically for cities with stable, growing, or shrinking populations (a phenomenon in many de-industrializing cities in North America). The transformation of these spaces has a multitude of benefits: they can stabilize lots and neighbourhoods thereby mitigating the often precipitous economic and social decline in these areas, improve the public realm, create productive landscapes, support sustainable transportation initiatives, introduce new pedestrian connections, attenuate stormwater, clean the air and soil, create networks for locally grown food, increase social capital (relationships among citizens that generate social, returns for a community), and provide places for recreation and quiet retreat (passive uses).

It is becoming increasingly evident that vacant land has many implications for a host of stakeholders. Vacant land can create a declining community image, decreased investment and willingness of banks to provide mortgages in high-risk areas, decreased property values and subsequently a decreased tax base for cities, increased crime, the potential to further marginalize already marginalized peoples, environmental degradation, and inequity with respect to the allocation of services and public amenities (Bowman and Pagano, 2004). A growing body of literature is emerging on vacant land reuse, and particularly, on the quantification of the value of vacant land and its wasted potential. Vacant land, if brought into productive reuse as parks, open space, stormwater management facilities and urban agriculture, for example, has the potential to improve air and water quality, improve urban soils, enhance local biodiversity, and support wildlife habitat (Kent State University [KSU], 2008). The reuse of vacant land can inspire civic pride and provide social utility (Banerjee, 2001). Schilling and Logan (2008) note that each vacant lot is unique, and as such each space will support specific opportunities. For many years New York City, which in the 1990's contained approximately 14,000 to 20,000 vacant lots, permitted neighbourhood groups to utilize and maintain city-owned vacant lots for parkland purposes and garden plots (Bowman and Pagano, 2004). When the City attempted to sell these lots for the development of affordable housing projects, they faced strong community opposition, which later resulted in the implementation of a review process prior to redeveloping urban agricultural land for higher-order land purposes (Bowman and Pagano, 2004). The case study of New York City demonstrates that vacant land is a productive social asset. It further revealed to planners and policy-makers that there is inherent value in vacant parcels that often sit idle across many cities around the globe.

The Pennsylvania Horticultural Society, based out of Philadelphia, a city with abandoned buildings and vacant land in the order of 30,000 parcels, is a leader in a growing movement that seeks to find new ways to reuse vacant land (Bowman and Pagano, 2004). A report prepared by Fairmount Ventures Inc. (as cited in Taylor, 2000), demonstrated that Philadelphia could generate USD$ 1.54 for every USD$ 1 invested in the application of three simple restorative treatments for vacant lots: grading, grass seeding, and planting trees along the lot perimeter (to be used as natural bollards to prevent illegal dumping). The revenue gained from these treatments is attributed to increased tax revenue generated from increases in the assessed property value of the lot (e.g. split-lotting – transferring title of half of the vacant property to each of the abutting two properties, thereby increasing their respective assessed values), increased tax revenue generated from increased assessment values for properties in the immediate vicinity of the restored property, and decreased city expenditures to clean-up illegal dumping on the site (Taylor, 2000).

Gold (1972) provides insight into historical practices for the development of public spaces/green infrastructure, which have largely focused on accommodating users rather than non-users, measuring quantity instead of quality, and seeks support of users (the minority of the population) instead of non-users (the majority of the population). Community input into the design and use of public amenity/green infrastructure spaces is vital to their success. Banerjee (2001) relates the current inequity and lack of public spaces in older and inner-city neighbourhoods to three recent trends: a steady decline of the public realm (related to a decline in municipal service provision), the impact of globalization on local economies, and advances in technology, which has redefined patterns of social interaction.

Poudyal, Hodges and Merrett (2009) anticipate that there will be an increased demand for urban park acreage as urban populations continue to grow. To adequately deliver this service, decision-makers will need to better understand the value of parks and open space. As such, Poudyal et al. (2009) studied urban park benefits and found that both the size of parks and proximity to residential dwellings had a small but positive correlation to property values. Of the 40,984 residential units in the study area, it was estimated that an increase in parkland acreage of 20% would result in an increase in property values in the range of USD$ 6.5 million dollars, or USD$ 160/household (Poudyal et al., 2009). Research conducted by the Wharton School of the University of Pennsylvania found that a variety of greening strategies can have positive impacts on neighbouring property values. The New Kensington Study concluded that (Wachter, 2004):

- Vacant land improvements (basic clean-up and landscaping treatments) can result in increases in surrounding housing values by as much as 30%, or approximately USD$ 12 million dollars;
- New tree plantings within 50 feet of a house can increase surrounding housing values by approximately 10%, or approximately USD$ 4 million dollars;
- Locating a house a $\frac{1}{4}$ mile from a park increases its value by approximately 10%;
- Neighbourhood blocks with multiple vacancies and no applied treatment(s) can reduce residential property values in the vicinity by up to 18%.

Voicu and Been (2008) studied the effects of community gardens on nearby property values in New York City and found that the greatest positive benefit was in the poorest of host neighbourhoods, where property values within a 1000-foot radius of a garden increased by as much as 9% within 5 years after the garden was opened. The authors estimate the net tax benefit for New York City over a 20-year period at approximately USD$ 512,000 per garden (Voicu and Been, 2008). The value of food produced in Cleveland's community gardens (50 acres in total) has been estimated by the Ohio State University Extension to be USD$ 1.2 to USD$ 1.8 million dollars annually (Masi, 2008).

Northam (1971) stresses that a significant challenge with respect to converting vacant land to a valuable, productive use rests with a city's ability to first identify an appropriate array of possibilities for land reuse and secondly to develop a realistic implementation strategy. Banerjee (2001) posits that future solutions will require ingenuity, resourcefulness and creativity. Pioneering researchers in the area of vacant and underutilized land, Pagano and Bowman (2000), state that to take full advantage of vacant land, it is critical that its location and characteristics are identified. Bowman and Pagano (2004) state that while all cities contain vacant land, the land use classification, supply, location, and condition of this land can vary greatly, and that cities continue to search for ways to best transform vacant spaces.

When struggling with the complexity of vacant land issues, municipalities typically respond by formulating strategic plans and policies that attempt to balance a number of objectives, including the maximization of revenues and minimization of costs, protection of property values, and enhancement of economic vitality and prosperity; to this end, using vacant land for its highest use is often the utmost priority (Bowman and Pagano, 2004). There is not a one-size-fits-all solution for the redevelopment of vacant parcels; rather, city officials must develop strategies that fit the spatial context, opportunities, and availability of resources in a city (Bowman and Pagano, 2004).

A variety of planning ideologies such as Smart Growth, New Urbanism, Transit-Oriented Development, Neo-Traditional Development, Traditional Neighbourhood Design, and New Pedestrianism have emerged over the past several decades, demonstrating that there is a growing consensus between experts that there is a need to develop more holistic design approaches to guide urban growth. A common thread among these approaches to development is a series of overarching, guiding principles that aim to reduce sprawl and auto-reliance by intensifying the mix and density of land uses within existing urban areas and developing new mixed-use communities in strategic locations, at transit-supportive densities, and with a high degree of connectivity.

The Growth Plan for the Greater Golden Horseshoe area, which is a Provincial Policy document, projects that 80% of Ontario's population growth over the next 25-year planning horizon (until 2035) will occur within this region, 40% of which will be integrated within the existing, built-up areas in upper- and single-tier municipalities, or in other words, through urban intensification projects (OMPIR, 2006). This translates to the redevelopment of previously used, currently underutilized, and/or vacant sites. With a focus on allocating population growth to inner- and central-city areas, this policy brings into question the quality, quantity, and equity of amenity spaces for highly urbanized populations, such as parkland and open space as well as productive spaces for urban agriculture and urban forestry. In light of these pressures, there will be a mounting need for strategic visioning and cross-disciplinary and cross-jurisdictional governmental and agency coordination to ensure the provision for and quantity of adequate, accessible, and equitable public amenity spaces – elements that are fundamental to the sustainable growth of communities. The growth policies contained in the Growth Plan for the Greater Golden Horseshoe Area seek to relieve outward, greenfield growth pressures by concentrating a significant proportion of new growth to existing built-up areas through infill intensification projects. Many U.S. cities are recognizing this potential and are responding by developing public and private partnerships to facilitate neighbourhood-based revitalization projects (Bowman and Pagano, 2004). Banerjee (2001) states that there is an increasing number of local non-profit community groups that are leading neighbourhood improvement projects, and opines that there could be a potential 21st century community-based movement underway to reclaim the public realm. A fundamental challenge for neighbourhood groups, however, is to develop a strategy that clarifies the needs, goals and objectives of the neighbourhood, defines a range of appropriate treatments, and a restoration time-frame (Taylor, 2000). Bowman and Pagano (2004) emphasize that reviewing land on an individual parcel-level is important. While a small piece of remnant land may not hold city-wide significance if redeveloped as an urban garden, for example, many local implications exist at a neighbourhood-level, the significance of which may be immeasurable. In reviewing the vacant land situation in Philadelphia, the authors state that of the approximately 30,000 vacant parcels, most of them have low market or redevelopment value; however, many of them hold significant social value (Bowman and Pagano, 2004).

A growing body of literature is addressing the importance of grassroots enterprises and public involvement in revitalizing the public realm. Schilling and Logan (2008) believe that communities should begin with small-scale, place-based projects and move to community or city-wide greening plans. Wright and Davlin (1998) state that community-based organizations have the potential to contribute significantly in identifying vacant sites and devising appropriate treatment plans that enhance the urban environment. Bowman and Pagano (2004) stress that community efforts should be directed at a neighbourhood planning level. Through a review of case studies, Taylor (2000) reveals that community involvement plays a leading role in vacant land reuse, and can instill a sense of pride and ownership in communities. The development of a community-based decision support system for the efficient reuse of vacant and underutilized urban land is the focus of this doctoral research; the scope of this research is described in the following section.

1.2 Scope of Thesis

The goal of this research is to provide short-term, medium-term, long-term, and/or permanent restorative strategies for vacant and underutilized urban land within a decision support framework. Kellet, Cavens, Miller, Campbell and Mayhew (2007) define decision support systems as "...techniques and devices (some computer-based, some not) for helping people...understand, compare and evaluate the relative value or benefit embedded in, or enabled by, design alternatives." Drummond and French (2008) note that models and decision support tools created by researchers are rarely implemented outside of the research arena, largely due to their complexity and requirements for data input which often require a sophisticated user or costly software platforms. As such, the authors recommend that planning practitioners and researchers form strategic partnerships to develop meaningful, user-friendly, adaptable urban modeling and planning support software (Drummond and French, 2008). Synthesizing the framework and principles from these sources, this thesis describes the development and application of a Microsoft Excel®-based prototype decision support system (PDSS) for community-based self-assessment planning for vacant and underutilized land, known as C-SAP. This scientific software tool is comprised of four modules, which were developed in collaboration with community champions and design experts. The PDSS was subjected to two (iterative) cycles of acceptance testing by four colleagues specializing in decision support at McMaster University. A summary of each module is provided as follows:

- Vacant and Underutilized Land Inventory (VULI): VULI is a vacant and underutilized land inventory that prompts the user to enter spatial and physical site and neighbourhood characteristics for each vacant and underutilized parcel identified (a binary scoring methodology is employed);

- Site Suitability Indices (SSI): SSI calculates a normalized, relative score for each reuse strategy at each site, based on the suitability of the same treatment at all other inventoried sites (a weighted matrix method is employed, using relative scores and the Analytic Hierarchy Process);

- Location-Allocation Modeling (LOCAL): LOCAL uses a multi-objective binary integer programming formulation for selecting *n from p* locations for each reuse strategy under analysis (user-specified constraints required; coefficients for the model are represented by the Site Suitability Indices);

- Design and Costing Tool (DECO): DECO provides the user with a hands-on design interface for the design of reuse strategies for individual sites. An approximate life cycle cost analysis (LCCA) is then performed by DECO, based on layers in the design drawing and inputs from the user.

The City of Cleveland Planning Commission undertook a one-year planning process to explore strategies for vacant land reuse, citing economics, health and image as the driving forces behind the initiative (KSU, 2008). To combat the ill-effects of vacant and underutilized land, a vacant land reuse framework was adopted by the Cleveland Planning Commission (KSU, 2009). This framework was adapted and used in C-SAP; however, the strategies included in C-SAP were limited to municipal green infrastructure projects that could be designed and constructed by community-led groups (i.e. potentially lay persons), with some anticipated collaboration with city staff and industry partners. The list of reuse strategies included in C-SAP, including a brief definition, is provided below:

- **Community Gardens** - typically individual plots for personal consumption
- **Neighbourhood Farm/Co-op** - a larger plot containing communal growing space; for consumption by the co-op members
- **Commercial Farm** - a larger plot containing commercial growing space; typically produced by fewer individuals; privately held; food sold at market or via a community-shared-agriculture (CSA) model
- **Orchards** - a plot of land consisting of fruit trees
- **Farmers' Markets** - a location where multiple vendors sell produce and other value-added products
- **Tot-lot** - a small park that typically contains a play structure for small children
- **Parkette** - a small park that is typically passive in nature
- **Urban Park/Plaza** - a centrally located urban park; typically located in a central business district (CBD) area; typically passive in nature (with the potential for some vendor space)
- **Neighbourhood Park** - a medium-size park that typically contains opportunities for organized sports, passive recreation, and children's play
- **Community Park** - a large-size park that contains more of the uses described under 'Neighbourhood Park'; a community park may also contain areas for picnicking and/or outdoor baking ovens
- **Individual Sports Fields/Courts** - this category was included to address downtown, highly urbanized lands that may contain remnant parcels that are limited in size, but may accommodate a tennis court, or basketball court, for example
- **Tree Nurseries** - a lot used to grow trees to sell or later transplant to an alternate location

- **Renaturalization** - the naturalizing of a parcel through the use of native plantings in a manner that has regard for any abutting, environmentally sensitive areas

- **Bioretention** - this category includes rain gardens and bio-swales to facilitate stormwater interception, storage, infiltration and evaporation

- **Circulation Enhancement** - a lot that, if developed, provides opportunities for enhanced pedestrian and cyclist circulation - e.g. through-lots that can be used for pathways or trail connections

While C-SAP was developed for community leaders, to support decision-making with respect to the reuse of vacant and underutilized land in productive ways, it is anticipated that multiple stakeholders would benefit from this work including, but not limited to, local governments, government agencies, as well as public and private land owners.

1.3 Summary of Papers

Four technical manuscripts comprise the body of this thesis (Chapters 2-5). Chapters 2-4 present the development of the prototype decision support system, known as C-SAP, as well as a series of locally-based applications and discussions. A summary of each paper can be found in the abstract, presented on the first page of each chapter. Chapter 2, titled *A prototype community-based planning tool for evaluating site suitability for the temporary reuse of vacant lands*, presents the development and subsequent application of VULI and SSI. Chapter 3, titled *Allocating urban agricultural reuse strategies to inventoried vacant and underutilized land,* presents the development and subsequent application of LOCAL. While the application of LOCAL was scoped to urban agricultural applications, it is applicable to the entire suite of green infrastructure reuse strategies included in C-SAP (as described above). Chapter 4, titled *A prototype decision support system for the designing and costing of municipal green infrastructure,* presents the development and application of DECO. Lastly, Chapter 5, titled *Estimating the stormwater attenuation benefits derived from planting four monoculture species of deciduous trees on vacant and underutilized urban land parcels,* presents the results of a stormwater modeling and analysis exercise. This paper presents a modeling methodology that a technically-minded individual could manually set-up in Excel to analyze the stormwater attenuating benefits of the tree canopy on a given site, as a result of a DECO-generated design. This process can assist decision-makers in evaluating the benefits of developing a temporary tree plantation on a vacant or underutilized parcel.

1.4 Structure of Thesis

The main body of this thesis consists of 6 chapters: an introduction, four technical manuscripts, and a conclusion, as well as a series of appendices (hardcopy and electronic). The introduction covers the impetus for the research presented herein, the scope of the research, and a summary of Chapters 2-5. Chapter 6 provides concluding remarks, a highlight of the contributions of the research, notable research/design challenges, and suggestions for future work. The appendices included in this thesis are summarized as follows:

APPENDIX A. REQUIREMENTS DOCUMENT

- This document was prepared prior to the development of the C-SAP scientific software tool, to determine the system, operating, and maintenance requirements for the users of this prototype system.

APPENDIX B. VACANT AND UNDERUTILIZED LAND INVENTORY (VULI) DEVELOPMENT

- Part A of Appendix B presents the draft methodology developed for VULI. This document was the culmination of a comprehensive literature review, and was derived from a series of existing walkability and public amenity audit tools. The document in Part A was circulated to a review team for review/comments (a 4-month process). As a result of this circulation and review process, a final methodology was developed, and is presented in Part B of Appendix B.

APPENDIX C. DECISION SUPPORT TOOL HELP FILES

- Appendix C provides a summary of the help files that were developed to support C-SAP. While these files have not been included in hardcopy format, they are available on the CD, located in Appendix D on the inside back cover of this document. They can also be accessed for no-cost downloading off of the McMaster University Sustainable Communities Research Group website, located at: www.eng.mcmaster.ca/civil/sustain/downloads.html.

APPENDIX D. DECISION SUPPORT TOOL (CD)

- Appendix D is located on the CD provided or, alternatively, on the Sustainable Communities Research Group website. The tool is located in one Excel file, titled C-SAP.xlsm, which is located in the Folder titled C-SAP. All supporting files are also included in the C-SAP folder. It is important to note that once downloaded to a personal computer, the C-SAP folder can be moved to any location on the user's hard drive; however, files cannot be removed from the C-SAP folder. Failure to follow these instructions will result in system errors, and potentially inaccurate applications/output of VULI, SSI, LOCAL and DECO.

APPENDIX E. SUPPLEMENTARY MATERIAL RELATED TO CHAPTER 2

APPENDIX F. SUPPLEMENTARY MATERIAL RELATED TO CHAPTER 3

APPENDIX G. SUPPLEMENTARY MATERIAL RELATED TO CHAPTER 4

APPENDIX H. SUPPLEMENTARY MATERIAL RELATED TO CHAPTER 5

1.5 References

Banerjee, T. (2001). The future of public space. Beyond invented Streets and reinvented places. Journal of the American Planning Association. Vol. 67(2): 9-24.

Bowman, A. O'M. and Pagano, M. A.. (2004). Terra Incognita: Vacant Land and Urban Strategies. Washington, D.C.: Georgetown University Press.

Gold, S. (1972). Nonuse of Neighbourhood Parks. Journal of the American Planning Association. Vol. 38(1): 369-378.

Kellet, R., Cavens, D., Miller, N., Campbell, E., Mayhew, W. (2007). Decision support tools in a Sustainable Urban Neighbourhood (SUN) pilot project. Prepared by the Design Centre for Sustainability, School of Architecture and Landscape Architecture, University of British Columbia for the Federation of Canadian Municipalities Green Municipal Fund. Vancouver, B.C.: University of British Columbia.

Kent State University (KSU). (2008). Re-imagining a more sustainable Cleveland. Citywide strategies for reuse of vacant land. Cleveland: Cleveland Land Lab at the Cleveland Urban Design Collaborative.

Kent State University. (2009). Re-imagining Cleveland. Vacant land re-use pattern book. Cleveland: Cleveland Land Lab at the Cleveland Urban Design Collaborative.

Masi, B. (2008). Defining the urban-agrarian space *in* Cities growing smaller (Urban infill, Volume 1). The Cleveland Land Lab. Experiments for a City in Transition (pp. 87-101). Cleveland: Kent State University.

Northam, R. M. (1971). Vacant urban land in the American City. Land Economics. Vol. 47: 345-355.

Ontario, Ministry of Public Infrastructure Renewal [OMPIR] (2006). Places to Grow Act: Growth plan for the Greater Golden Horseshoe.

Pagano, M. A. and Bowman, A. O'M. (2000). Vacant land in cities: An urban resource. Brookings Institution Survey Series, Centre on Urban and Metropolitan Policy.

Poudyal, N. C., Hodges, D. G., and Merrett, C. D. (2009). A hedonic analysis of the demand for and benefits of urban recreation parks. Land Use Policy. Vol. 26(1): 975-983.

Schilling, J. and Logan, J. (2008). Greening the rust belt. A Green infrastructure model for right sizing America's shrinking cities. Journal of the American Planning Association. Vol. 74(4): 451-466.

Taylor, R. (2000). Strategies for restoring vacant land. An analysis of Northeast cities with recommendations for New Haven. Urban Resources Initiative: New Haven. Accessed from http://www.yale.edu/uri/pubs/WP/WP_46.html on August 17, 2009.

Voicu, I. and Been, V. (2008). The effect of community gardens on neighboring property values. Real Estate Economics. Vol. 36(2): 241-283.

Wachter, S. (2004). The determinants of neighborhood transformation in Philadelphia: Identification and analysis – the New Kensington Plot Study. The Wharton School. University of Pennsylvania.

Wright, T. K. and Davlin, A. (September, 1998). Overcoming obstacles to brownfields and vacant land redevelopment. Land Lines. Vol. 10(5): 1-3. Lincoln Institute of Land Policy.

Chapter 2. A prototype community-based planning tool for evaluating site suitability for the temporary reuse of vacant lands

2.1 Abstract

2.1.1 Problem

Many cities across the globe struggle with the presence of vacant and underutilized land in the urban environment. This is a wasted resource that has significant potential to contribute to a city's green infrastructure/amenities, if the suitability of reuse strategies can be better understood.

2.1.2 Purpose of Research

This paper presents a prototype community-based decision support tool to assist neighbourhood groups in completing a user-customizable vacant and underutilized land inventory at a neighbourhood, community, or city-wide planning scale. The purpose of this research is to create an inventory that captures the relevant neighourhood and site attributes in a way that can be conveyed to the user as a 'site suitability index' (or score). This information can then be used to make more informed decisions with respect to which parcels of vacant land are most suitable for temporary reuse.

2.1.3 Methods

Developed in Microsoft Excel®, the prototype tool allows the user to evaluate up to fifteen community-based reuse strategies across three broad categories: parks, urban food production, and stormwater/ecosystems management, using a hybrid binary scoring methodology.

2.1.4 Results and Conclusions

The prototype tool was applied to 25 sites across the City of Hamilton, Ontario, Canada. The inventoried attributes of (i) neighbourhood quality, (ii) developability potential, (iii) visual quality, (iv) compatibility, (v) transportation, and (vi) vulnerable populations were used to calculate a set of site suitability indices. The indices appeared appropriate for most uses, which validated the hypothesis that the majority of the inventoried

sites would have strong indices based on the fact that they currently function as public amenity spaces.

2.1.5 Takeaway for practice

The development of a holistic approach for the implementation of reuse strategies on vacant urban lands is essential if cities are to optimize the potential utility of these untapped resources as public amenity spaces, at a neighbourhood, community, or city-wide planning scale.

Keywords. decision support, land inventory, urban agriculture, amenity spaces

Sources of Research Support

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2.2 Introduction

There is a renewed focus in many jurisdictions with respect to intensifying existing built-up urbanized areas through the use of vacant and infill lands (OMPIR, 2006). Not only is it critical to determine where population and employment growth should occur, the provision for adequate, accessible, and equitable complementary public spaces, such as active and passive parks and open space, urban food production and stormwater/ecosystems management features, will be of fundamental importance to sustaining this growth. The growing pressures of peak oil, the urban heat island effect, poor air quality, reduced biodiversity, an aging population (Miller, 2008), reduced access to food for vulnerable populations (HFS, 2009), the rise in urban food deserts (Grimm, 2009), and an anticipated growing demand for urban parks and open space (Poudyal, Hodges & Merrett, 2009) will require comprehensive strategies to effectively plan for and sustain productive landscapes for a growing population.

Vacant and underutilized land will be used broadly in this paper to describe any publicly or privately held residential, industrial, commercial, institutional, agricultural, utility, parks and open space, or remnant lands that are not currently being used to their full potential, including lands that are not fulfilling their intended purpose (e.g. underutilized parks). Many cities across the globe, regardless of size or geographic location, struggle with the presence of vacant and underutilized land in the urban environment; currently long-term solutions that contribute to the recovery of declining areas have not been implemented on a consistent basis, if at all (Pagano & Bowman, 2000). While all cities contain vacant and underutilized land, the type, supply, and condition of this land can vary greatly. To take full advantage of these spaces, it is critical that its location and characteristics be identified (Pagano & Bowman, 2000). While some vacant and underutilized lands may pose a human and environmental health risk in urbanized areas due to contaminated soil from past and/or present uses, Heinegg, Maragos, Mason, Rabinowicz, Straccini, and Walsh (2002) attempt to address this issue by providing a set of guidelines for physical and bio-remediation techniques for small-scale, community-based reuse projects, while Rideout (2010) provides insight into best practices for urban agriculture on contaminated lands. Rosenberg and Esnard (2008) state that it is important to not lose sight of the need for transparent site selection models that can be presented to, and understood by, individuals in a public forum. There is a growing momentum, desire and basic need for productive spaces and tools to assist in identifying the most appropriate location for these strategies. Despite these efforts and strides forward, there remains a fundamental challenge for neighbourhood groups to develop rehabilitation strategies that clarify the needs, goals and objectives of the community, define a range of appropriate strategies, and a restoration time-frame (Taylor, 2000). Schilling and Logan (2008) note that each vacant lot is unique, and as such each space will support specific opportunities. Central to the goal of reusing vacant and underutilized land, is an understanding of the spatial distribution of these lands and the site suitability for potential strategies. It is believed that the prototype decision support tool discussed in this paper will assist in clarifying the value and potential utility that certain lands hold for neighbourhood amenity spaces.

Voicu and Been (2008) studied the effects of community gardens on nearby property values in New York and found that the greatest positive benefit was in the poorest of host neighbourhoods, where property values within 1000 feet of a garden increased by as much as 9% within 5 years after the garden was opened. Poudyal, Hodges and Merrett (2009) anticipate that there will be an increased demand for urban park acreage as urban populations continue to grow in cities across North America. Poudyal et al. (2009) studied urban park benefits and found that an increase in parkland acreage of 20% would result in an increase in property values in the range of USD$ 6.5 million dollars, or USD$ 160/household in the study area. Masi (2008) cites work completed by Ohio State University Extension, which estimates Cleveland's community gardens, which cover 50 acres in total, generate between USD$ 1.2 to USD$ 1.8 million dollars worth of food annually.

Continuous Productive Urban Landscapes (known as CPULs) is an ideology of what the urban form could look like if parks and open space elements (including underutilized lands) are connected with linear park, trail, open space, stormwater and food production elements (Viljoen, Bohn, & Howe, 2005). Vacant and underutilized lands hold the potential to progressively build on the CPUL ideology and create, as Viljoen, Bohn, and Howe (2005) describe, loose-fit landscapes that are dynamic in use, aesthetic, and ecological status. These spaces can also provide important cultural links, engaging certain populations that would not otherwise use a traditional park. Food Urbanism, which is centered on continuous productive landscapes, is an emerging concept that focuses on the relationship between food as infrastructure and the organization of a city and how, through redesigning existing spaces, food can transform the urban experience (Grimm, 2009).

2.3 Development of a prototype community-based planning tool

Building on the work undertaken by the Cleveland Land Lab at the Cleveland Urban Design Collaborative, Kent State University, and later adopted by the Cleveland City Planning Commission in 2008 (Cleveland Land Lab, 2008), this paper introduces a prototype decision support tool for identifying the location and condition of vacant and underutilized land in the urban environment, and subsequently quantifying a site suitability index for a suite of fifteen reuse strategies that contribute to a city's green infrastructure capacity. The strategies cover three small-scale, neighbourhood-oriented categories: parks, food production and stormwater management/ecosystems management. Within these categories, the strategies have been divided into short-, medium- and long-term uses, to reflect different classifications of market strength, with long term uses indicating weak market potential and the likelihood that the land will continue to remain underutilized and undeveloped. It is believed that in using these spaces on an interim basis, municipal decision-makers will have the opportunity to test drive various uses across the urban environment and evaluate their social, economic and environmental utility, with the potential to later acquire these lands, making them permanent elements of the city's green infrastructure inventory.

Prior to creating the prototype tool, a requirements document was compiled to address system capabilities, conditions and constraints, system operations, and life cycle sustainment of the software product, with a primary focus on functional, technical, usability and maintainability requirements. The community-based self-assessment planning tool (C-

SAP), as the prototype tool will be known henceforth, is a scientific software product, created using the Microsoft Excel ® 2007 software platform. All macros were written in the built-in Visual Basic Editor (VBE), using the Visual Basic for Applications (VBA) programming language, and are executed via command buttons on the graphical user interface (GUI). The tool consists of a GUI (see Figure 2.1, below) that guides the user through completing a vacant and underutilized land inventory and computing a set of site suitability indices for a suite of reuse strategies (see Figure 2.2, below). Consideration was given to the maintainability of the tool; as such, effort was made to ensure that the majority of the variables were not hardcoded, but rather stored in spreadsheets, and made available to the user for alteration to suit their specific needs.

C-SAP utilizes neighbourhood, street, parcel, bus, and statistics data. With reasonable effort and data substitution, this tool could be readily adapted to many jurisdictions throughout the world. To assist in this endeavour, the GUI guides the user through the process of copying new data into the built-in databases, providing color-coded cells to differentiate between the changeable and non-changeable cells. Subject-specific, graphical help files have been included with the tool to assist the user in completing the inventory, while a user-guide has been provided to convey higher-level information to the user.

2.4 Potential applications of the developed tool

The decision support tool is useful for evaluating the addition or removal of green infrastructure/amenity elements at a neighbourhood, community, or city-wide urban planning scale. It is the intent that this tool would also be useful in expediting application requests from community groups to lease city-owned lands for green infrastructure purposes, as the output from the tool could potentially be included when making the initial request/contact with a city. Expediting the leasing process is critical when lands are being used on a temporary basis to maximize the usefulness and utility of the parcel and achieve the greatest benefits from a longer term use (E. Cubitt, personal communication, July 15, 2010). The output from C-SAP may assist in making the request process consistent, and the review process potentially more efficient, as the city staff member assigned to review the material would be familiar with the format and methodology employed for deriving the suitability indices, providing a certain level of confidence in the appropriateness of the request.

The following sections describe the development of the prototype vacant and underutilized land inventory and provide rationale and support for the organization of the inventoried sub-criteria into a structure consisting of 6 overarching umbrella criteria.

2.5 Vacant and underutilized land inventory (VULI)

Rosenberg and Esnard (2008) present an inventory and scoring methodology to determine suitable locations for transit stop site selection. Their work involved inventorying 3 umbrella criteria: proximity, developability and visual quality, and a series of sub-criteria to identify the most suitable site for 6 potential transit locations (Rosenberg & Esnard, 2008). This method was derived from Cutter, Mitchell and Scott's (1997) method for calculating social vulnerability scores related to GIS-based hazard assessments. Mohajeri and Amin (2010) use an Analytic Hierarchy (AHP) model with four umbrella criteria and twenty six sub-criteria to evaluate five potential candidate sites for transit site selection. C-SAP employs a hybrid approach of these three decision support methods. An overview of the steps required to complete VULI is depicted in Figure 2.3, below.

A three-stage research approach was undertaken during the development of VULI. Step one involved the completion of a literature review of existing inventories, neighbourhood qualities related to walkability, and relevant site selection characteristics for the suite of strategies included. During the process of this literature review, no software packages were discovered, community-based or otherwise, that attempt to quantify the site suitability for the strategies proposed herein. Step two of the research process involved the formulation of the umbrella criteria into six categories: Neighbourhood Quality, Developability Potential, Visual Quality of the Site, Compatibility with the Urban Environment, Transportation Options, and Vulnerable Populations, and the development of a set of forty four sub-criteria (summarized in Figure 2.4, below).

Step 3 of the research process involved a review of the developed inventory framework by an expert panel that included engineering faculty members and professional practitioners from the fields of engineering, parks planning, urban agriculture, and urban planning. It is important to clarify at this point that while the size and shading characteristics for each potential area for reuse are inventoried, these characteristics are not included in the umbrella criteria or sub-criteria. Rather, the user is required to screen the appropriateness of including each strategy prior to initiating the inventory, based on observations of sunlight characteristics and minimum desired size. In the following four sections, each of the umbrella criteria depicted in Figure 2.4 are highlighted, with a discussion of relevant supporting literature.

2.6 Umbrella Criteria 1 and 3: Neighbourhood Quality and Visual Quality of Site

Many municipal Official Plans place a strong emphasis on the urban design goals of creating quality spaces on public and private lands that are pedestrian-oriented, safe, accessible, connected, transit-supported, compatible with and enhancing to surrounding uses, and adaptable and flexible to accommodate future demographics and changing environments. Ewing and Handy (2009) present a methodology for measuring physical qualities of the urban street environment, including imageability, enclosure, human scale, transparency and complexity. Clifton and Levi (2004) wrote an audit protocol for a tool known as the Pedestrian Environment Data Scan (PEDS), which measures environment, pedestrian facility, road attributes, and walking and cycling environment. Alfonzo, Day, and Boarnet (2005) propose a method for inventorying physical environment features linked to physical activity, including attractiveness, land uses, roadways, buildings, and lighting. The San Francisco Department of Public Health (2008) developed a Pedestrian Environment Quality Index Survey that involves inventorying intersections, streets, sidewalks, land uses and safety. Saelens, Sallis, Black, and Chen (2003) present a scoring procedure known as Neighbourhood Environment Walkability Scale (NEWS) whereby they linked walkability to residential density, land use mix, street connectivity, walking and cycling facilities, aesthetics, safety, and general neighbourhood satisfaction. The predominant themes in each of these tools were extracted and used in the development of the sub-criteria for both neighourhood and visual quality criteria of the site.

2.7 Umbrella Criterion 2: Developability Potential

The potential that a site holds for development on a temporary basis is a significant criterion when deciding how to spatially allocate reuse strategies across the urban landscape. To complete this section of VULI, the user is required to inventory a series of high-level characteristics with respect to the site conditions, loosely defining the likelihood of development based on larger material, time, and labour requirements for a specific use. Several key documents were used to develop the scope of the sub-criteria. These include the work completed by the Cleveland Land Lab (2008; 2009) for vacant land reuse, which provides detailed recommendations for site selection for a variety of strategies including parks and urban food production uses, the work presented by Dow (2006) and Heinegg et al. (2002), which addresses barriers to implementing community gardens, a municipal community garden policy (Hamilton, 2010), which addresses capital costs and considerations when building city-supported community gardens, the work of Burkholder, Ng, Niu, and Solanki (2007), which addresses urban agriculture site development, the City of Hamilton Official Plan (2009a), which provides a broad set of principles for parkland design, and the work of Mendes, Balmer, Kaethler and Rhoads (2008), which evaluated the use of land inventories for the identification of suitable locations for urban food production.

2.8 Umbrella Criteria 4 and 5: Compatibility with Urban Environment and Transportation Options

Compatibility with the surrounding urban environment is identified in municipal policy documents as a fundamental design goal for the development of all new public and private spaces (Hamilton, 2009a). Drawing on the work of Brown and Carter (2003), Hohenschau (2005), and municipal planning policy (Hamilton, 2009a), a selection of eleven synergistic, complementary land uses were identified and included in VULI (see Figure 2.4, above). Built-in databases of geocoded, compatible land parcels are required for the decision support tool.

Transportation options are also important in determining appropriate reuse strategies for vacant and underutilized land. Site accessibility via sidewalks, recreational trails, transit, and on-street bike routes are important to the successful and on-going use and stewardship of the green infrastructure strategies included in the C-SAP tool. The City of Hamilton Official Plan Policy (2009a) states that transit stops should be in close proximity and adjacent to, where possible, community facilities including parkland. Hohenschau (2005) echoes the need for transit access for urban food production systems, further noting that high visibility is particularly important for community farms and co-ops.

2.9 Umbrella Criterion 6: Vulnerable populations

For the purposes of this research, vulnerable populations include persons that live in rental units and/or apartment building units (less access to private amenity spaces), aging populations (65+ years of age), low income persons, and at-risk youth. The World Health Organization has been promoting the creation and retrofit of cities to ensure they are age-friendly, a need well understood in Canada, as one in four Canadians will be considered a senior citizen in 25 years (Miller, 2008). From a parks planning perspective, municipalities are also recognizing the need to design parks for a diverse and changing demographic (Hamilton, 2009a). In the United States, it is reported that there are twice as many urban food gardeners over the age of 65 when compared to those under the age of 35 and they recognize a demand for low income families to acquire garden space to grow their own vegetables (Brown & Carter, 2003). The movement to convert lands on, and in close proximity to, non-profit housing is also taking hold (Hamilton, 2010). Hohenschau (2005) states the importance of targeting multi-family housing, where there is little or no growing or amenity space, as well as youth as a key consideration when locating garden plots and amenity spaces. Statistical (census) data are required in the C-SAP tool for the vulnerable populations noted in Figure 2.4, to determine the relative vulnerability of the user-specified vulnerable population immediately surrounding the subject site.

The user has the flexibility to choose which of the forty four sub-criteria are included in the inventory process for each strategy; however, at least one sub-criterion must be chosen for each umbrella criterion. This is required, as the user cannot enter a weight of zero for any of the umbrella criteria weights when using the analytic hierarchy process, as this method uses a reciprocal matrix method, requiring non-zero entries. The following section describes the methodology for generating a matrix of site suitability indices for the evaluated reuse strategies across all, or a subset of, the inventoried sites.

2.10 Site Suitability Indices (SSI)

The steps required for completing the matrix of site suitability indices are depicted in Figure 2.5, below. To calculate the site suitability indices, the binary scores for each sub-criterion are identified and summed from the inventory process (VULI). Typically, if a sub-criterion is present a score of 1 is assigned; otherwise, a score of 0 is applied. These values are then normalized, based on the best performing site for each criterion, for each strategy, which produces a matrix of relative scores that is presented out of 100. Criterion weights are determined using the Analytic Hierarchy Process (AHP). Developed by Thomas Saaty, the Analytic Hierarchy Process is described in detail in many other written works (Saaty, 1977; Saaty, 1990; Palcic & Lalic, 2009), with applications in a broad range of disciplines that span several decades. AHP assists in providing decision support by clarifying the importance of each criterion using a set of pair-wise comparisons (or judgment statements) of the umbrella criteria (see Table 2.1). In C-SAP, a unique set of judgment statements can be entered for each reuse strategy, or statements can be completed on a sub-set of strategies. The user repeats this process until judgment statements have been made for all strategies under analysis. In all evaluated scenarios discussed within this manuscript, a single set of judgment statements is applied to the entire set of evaluated reuse strategies. The consistency ratios (CR's) for each set of judgment statement have been included in Table 2.1, all of which are within acceptable limits of 0.0-0.1 (Saaty, 1990), indicating that the judgment statements made are deemed to be consistent (zero being perfectly consistent). Four sets of judgment statements were completed, generating four unique sets of umbrella criteria weights for each of the two applications discussed below (see Table 2.2). These sets of weights were subsequently used to assess the sensitivity to changes in the umbrella criteria weights and the resulting site suitability indices for the inventoried sites. The methodology used for completing the judgment statements and calculating the umbrella criteria weights is described in detail in Saaty (1977). From the calculated criteria weights, the normalized, relative scores are aggregated, resulting in a set of relative site suitability indices for each reuse strategy, across all inventoried sites. It is important to note that while site suitability indices inherently hold no meaning when evaluated in isolation from the entire set of indices, they provide valuable information when compared and discussed relative to the indices across all inventoried sites for the corresponding strategy of interest.

2.11 Two applications of the prototype decision support tool

As part of verifying the appropriateness of the scoring, weighting and aggregation methodology employed in C-SAP, two applications of the developed tool were analyzed. A discussion of the two applications of C-SAP follows; the first application involved applying C-SAP to 13 existing community garden and neighbourhood farm locations in the City of Hamilton, Ontario, while the second application of the tool involved applying C-SAP more broadly to include two existing sites for each remaining strategy (with the exception of orchards, renaturalization, bioretention, and nurseries, as there are currently no examples of vacant or underutilized land having been converted to these uses within urban Hamilton). The vulnerable population evaluated in all applications of the tool was the percentage of persons living in apartment buildings, due to their lack of backyard amenity space. All sites were pre-screened for sunlight characteristics and size – a value of 'n/a' in the following tables indicates that the site was deemed to be inappropriate for the corresponding use during the pre-screening assessment. Sites that were not located on a corner or through-lot, providing increased circulation options for pedestrians and cyclists, were not considered for circulation enhancement. Google Maps (using satellite imagery and 'Street View') was used in both applications to verify many of the site and neighbourhood characteristics for the locations assessed. This process was later augmented with site visits in situations where these characteristics were poorly understood or unfamiliar.

For all sites analyzed in both applications, it was observed that a site suitability index in the range of 60-100 was achieved for virtually all existing uses (with the majority of these being between 70 and 100). The sites where the site suitability appeared to be less favourable could be linked to specific neighbourhood or site characteristics. Prior to completing this analysis, it was predicted that sites would score reasonably well, as they are currently being used as green infrastructure/amenity spaces across the city, a prediction that appeared to be validated during the evaluation of the output. It is apparent from this analysis that there are several alternatives that are reasonably close to the highest site suitability score for any given strategy in both applications. The tool is useful in articulating the strengths and weaknesses of sites by allowing the user to view two output tables: (i) the six umbrella criteria scores for each strategy, or (ii) the aggregated site suitability indices for each strategy. It is important to recognize that the suitability indices are not intended to provide the user with a definitive answer with respect to the application of a strategy, but rather a means of assisting a user in clarifying the relative suitability of a site for a particular strategy so that they can make better informed decisions. Site suitability indices were calculated for all sites based on the four judgment statement scenarios located in Table 2.1. To conserve space, the output from Scenario 4, which placed a strong importance on the developability potential and visual quality of the site (a total weight of 55%), is discussed in detail below. The output from Scenarios 1, 2, and 3 produced similar results for the best performing sites when compared to Scenario 4, which is indicative of the robustness of the umbrella criteria scores for the best performing sites.

2.12 Application 1: Existing community garden and neighbourhood farm locations

Thirteen community garden and neighbourhood farm locations were inventoried across eleven neighbourhoods in the City of Hamilton, based on the most current community garden directory provided by the City of Hamilton (2009b). The site suitability indices for Scenario 4 were subsequently calculated by C-SAP and are presented in Table 2.3. The index for the current use on each site has been shaded in grey, while the largest site suitability index for each strategy has been outlined in black. As the majority of the inventoried sites currently function at full capacity as community gardens, it was anticipated that these sites would score reasonably well in terms of site suitability. Sites 1, 2, 5, 7, 8, 11, 12 and 13 have relatively high site suitability scores for all urban food production uses (Strategies 1 through 5), with judgment statement Scenario 4 having slightly higher values when compared to Scenario 1 (due to the weights applied to the umbrella criteria). Sites 3, 4, 6, 9, and 10, however, have relatively low site suitability scores for all potential reuse strategies, which may be indicative of their overall lack of suitability for all uses. A review of the umbrella criteria scores provided clarification with respect to the lower suitability indices for these five sites.

Sites 9 and 10 (located directly beside each other in a low-density neighbourhood) did not function at full capacity in 2010; there was space for 100 garden plots at Site 10, however, only 50 were used (B. Wilcox, personal communication, July, 9, 2010). The neighbourhood farm (Site 9) also produced less produce for the food bank in 2010 when compared to previous years due to a reduction in volunteer participation (B. Wilcox, personal communication, July, 9, 2010). The sites scored low in the following criteria for both urban farms and community gardens: Neighbourhood Quality (33), Visual Quality of the site (50), Compatibility with the Urban Environment (43), Transportation Options (50), and Vulnerable Population (8). Centre Paradise Gardens (Site 4) is located in Hamilton's industrial north end, directly across the street from a brewery. While this is a generally successful site for gardening in terms of participation rates, the site had low relative scores for Visual Quality of the site (0), Compatibility with the Urban Environment (29), Transportation Options (25), and Vulnerable Population (33). Keith Neighbourhood Gardens (Site 6) is located approximately 650 metres south-east of Site 4. The site scored low for community gardens in relative Neighbourhood Quality (50), Compatibility with Urban Environment (43), Transportation Options (25), and proximity for Vulnerable Populations (33). While Sites 4 and 6 scored relatively low, these gardens maintain high participation rates, revealing that these spaces provide utility to citizens. However, the developed decision support tool may be useful in locating sites that provide even greater utility for a community. Today's family shared garden (Site 3) has the potential to expand to twice the current productive space. This site scored low in Neighbourhood Quality (33), Visual Quality (25), Compatibility with Urban Environment (43), Transportation Options (25), and Vulnerable Population (3), and it is believed that this is indicative of the less-than-optimal participation rates.

Regardless of the judgment statement scenarios, and the resulting priority matrices, Site 11 was identified as being the most suitable site for virtually all uses. Site 11 is a large, multi-purpose community park, located in a mixed-use, high-density area, and scored extremely high in all 6 umbrella criteria. As such, it was anticipated that it would have high site suitability indices for virtually all reuse strategies. This was confirmed upon review of the C-SAP output.

Due to the fact that identical judgment statements were made for all strategies in each of the four evaluated scenarios, the indices for each strategy typically followed a similar pattern in terms of the ranking of site suitability scores for each strategy. It is not anticipated that this would occur if individual judgment statements had been made for each strategy.

2.13 Application 2: Existing urban plaza, parkette, community park, neighbourhood park, circulation enhancement, tot-lot, and farmers' market locations

In the second application, C-SAP was applied to twelve existing sites to validate the output for a broader range of reuse strategies: two urban plazas, two parkettes, two community parks, two neighbourhood parks, two circulation enhancement features/tot-lots, and two farmers' markets. Sites 7 and 11 each serve a dual function as both a tot-lot and a circulation enhancement feature. Sites 4 and 8 are hardscaped, actively used parking lots that were deemed to be suitable only for farmers' markets. To conserve space, the output for Scenario 4 is shown in Table 2.4 below. The grey shaded areas correspond to the site suitability scores for the existing use on the site, while the outlined scores correspond to the largest site suitability score for each strategy.

While there are no existing orchards or commercial farming operations in the City of Hamilton, Sites 1, 2, 9 and 10 appear to be suitable locations, scoring close to 80 for both uses. There are no existing uses of vacant land in the city for nurseries, bioretention, or renaturalization; however, Site 1 appears to be most suitable for nurseries and bioretention strategies, while Sites 9 and 10 appear to be most suitable for renaturalization. Site 8, an existing farmer's market, scored high in all umbrella criteria resulting in the largest site suitability score (93) for this reuse strategy. Site 4 had lower vulnerable population, transportation, visual quality of the site, and compatibility with the urban environment scores, resulting in a site suitability score of 71. Site 8 is located on a collector road in the heart of a mixed-use, highly visible, highly travelled area, while Site 4 is located in a rear parking lot, set back from an arterial roadway, with less visual quality, fewer pedestrians passing by, and fewer overall surrounding compatible uses. It should be noted that both farmers' market locations are successful sites with respect to patronage, which may be indicative that suitability indices in the order of 70 or greater may be generally well suited to a given strategy. This validates the results obtained from Application 1. Site 7 and 11, both functioning as circulation enhancement features and tot-lots, had lower site suitability indices (59-73). The output from C-SAP reveals that Site 7 may be more suitable for renaturalization, while Site 11 appears to be equally suitable for all reuse strategies, with the exception of plant nurseries and bioretention features. Sites 2 and 10, both community parks, had generally strong suitability indices (73 and 78, respectively) indicating that the existing uses are generally well suited at both of these locations. This is validated by the observed patronage at both of these locations. While scoring well for their existing uses, it should be noted that Sites 2 and 10 have a variety of other reuse strategies that appear to be suitable alternatives. Site 3, an existing parkette, scored lower than seven of the site suitability indices for this use on alternative sites, while Site 12 had the 3rd highest suitability index for a parkette across all evaluated sites. Located on a multi-lane collector road, close to a busy downtown intersection, Site 3 scored lower in neighbourhood quality and visual quality of the site. Sites 1 and 5, both urban plazas, scored notably different. Site 1, a 1.7-acre downtown urban plaza, scored very strongly in terms of site suitability, while Site 5 scored distinctly lower due to its compatibility with the urban environment (57), transportation options (50) and proximity to vulnerable populations (25). The largest site suitability index for neighbourhood parks (79) corresponds to Site 9, which is an existing neighbourhood park. Site 6, also an existing neighbourhood park, had a slightly lower suitability index (73), scoring particularly low in neighbourhood quality and transportation criteria scores.

Overall, Application 2 results validate the results from Application 1, echoing that suitability indices between 70 and 100 appear to be strong indicators of the general suitability of a particular reuse strategy. With the exception of Site 7, discussed above, all existing sites evaluated in Application 2 resulted in suitability indices greater than 70. It was anticipated that the indices would be generally high due to the fact that the inventoried sites are all existing sites within the city's green infrastructure inventory, and as such lend themselves to alternative green infrastructure reuse strategies. It is apparent from the review of the four criteria weight scenarios, described in Table 2.1 and Table 2.2, that different weights can have a significant impact on the site suitability indices, and as such, users should be prudent in making judgment statements that reflect their values and preferences. While the tool is useful in clarifying the relative suitability of reuse strategies across vacant lands, there are several limitations of this methodology that are identified and addressed below.

2.14 Limitations of methodology

Rosenberg and Esnard (2008) discuss several limitations related to their site inventory process that are relevant to the vacant and underutilized land inventory (VULI) described herein. First, the user is required to make inherently subjective yes/no statements in VULI with respect to neighbourhood and site characteristics, and as such the output could vary between users of the tool. Efforts have been made to reduce this subjectivity by providing visual help files to guide the user inputs. Further, efforts were made to formulate the questions in a way that focused on inventorying the physical characteristics, with fewer open-ended questions about user perceptions (such as the 'quality of the space'). It is strongly recommended, for consistency, that the same user or community group complete the entire inventory for a particular neighbourhood. Second, to reveal a more accurate picture of site suitability, it is strongly recommended that the user include a site in the inventory that has strong characteristics across all six criteria, and that they complete a comprehensive inventory at the minimum scale of the neighbourhood-level, to minimize the chance that the indices are over-inflated. Third, correlations between the 6 umbrella criteria (and sub-criteria) were not addressed, as this was considered beyond the scope of this research. It should be noted, however, that studying the relationship between the criteria as part of a future research project could provide valuable insight into further refining the vacant and underutilized land inventory. Lastly, due to the fact that the site suitability indices are relative to the best performing site for a particular use, conclusions cannot be drawn with respect to the best use for a single site (e.g. "community gardens are most suitable for site 1 when compared with all other uses evaluated"); rather, statements can be made with respect to evaluating all sites for their potential appropriateness for a particular strategy (e.g. "community gardens had the highest site suitability index at site 1 when compared to community gardens at all other sites"). Future work, currently being drafted for publication, will address this issue and assist users in carrying out location-allocation analyses based on user-specified, adjustable constraints such as the maximum number of each reuse strategies desired, minimum distance between strategies, minimum residential density required to support each use, minimum and maximum size requirements, and sunlight conditions.

2.15 Conclusions

This paper introduces a prototype decision support tool (C-SAP) for identifying and inventorying the location and condition of vacant and underutilized land across the urban environment. The tool subsequently evaluates the site suitability of fifteen reuse strategies across three small-scale, neighbourhood-oriented categories: parks, food production and stormwater management/ecosystems management. Using C-SAP, forty four sub-criteria are inventoried and organized into six umbrella criteria. The umbrella criteria are assigned weights and the relative sub-criteria scores are aggregated and presented as a set of site suitability indices for each strategy across the inventoried sites. This information can then be used by community groups or municipal decision-makers in determining which sites are most suitable for reuse based on their developability potential, neighourhood and site quality, compatibility with the surrounding urban environment, accessibility potential, and proximity to vulnerable populations. The decision support tool was applied to twenty five existing sites in the City of Hamilton to evaluate the appropriateness of the methodology employed. The majority of the sites evaluated had relatively strong site suitability scores for their intended use. This result was generally anticipated prior to completing the analyses, as these sites are currently being used as public amenity spaces, and therefore these analyses were in essence a validation exercise. The process described within this manuscript for determining site suitability is believed to be a useful and informative process in the analysis of vacant and underutilized land, helping to articulate and quantify the inherent potential of these spaces for future reuse.

2.16 Acknowledgements

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2.17 References

Alfonzo, M., Day, K., & Boarnet, M. (2005). *Irvine Minnesota inventory for observation of physical environment features linked to physical activity (training protocol)*, Retrieved from https://webfiles.uci.edu/kday/public/index.html

Brown, K. H. & Carter, A. (2003). *Urban agriculture and community food security in the United States: Farming from the city centre to the urban fringe*. Retrieved from http://www.foodsecurity.org/PrimerCFSCUAC.pdf

Burkholder, G., Ng, P., Niu, J. & Solanki, A. (2007). *Growing gardens: A resource package on how to start your own garden*. Retrieved from http://www.spec.bc.ca/Resources/Documents/Food/Growing-Gardens-Manual.pdf

Hamilton, City of (2009a). *Urban Hamilton Official Plan: Vibrant, healthy, sustainable Hamilton*. Retrieved from http://www.hamilton.ca/NR/rdonlyres/AAE4F707-14B1-47AD-B69E-6948A56F3C9/0/SSSPUHOPVol1.pdf

Hamilton, City of (2009b). *Hamilton community garden directory.* Retrieved from http://www.naturallyhamilton.ca/community-gardening-hamilton

Hamilton, City of (2010). *Community garden Policy (PW10044). Retrieved from* http://www.hamilton.ca/NR/rdonlyres/F8B4672C-6E0D-4A5B-8A52-C2556C7914B7/0/Apr19EDRMS_n86758_v1_7_1__PW10044.pdf

Cleveland Land Lab (2008). *Re-imagining a more sustainable Cleveland: Citywide strategies for reuse of vacant land.* Retrieved from http://www.neighborhoodprogress.org/uploaded_pics/reimagining_final_screen-res_file_1236290773_file_1241529460.pdf

Cleveland Land Lab (2009). *Re-imagining Cleveland: Vacant land reuse pattern book.* Retrieved from http://neighborhoodprogress.org/uploaded_pics/patternbookFINAL_lo-res_file_1241529170.pdf

Clifton, K. J. & Livi, A. D. (2004). *Pedestrian Environment Data Scan (PEDS) audit protocol*. Retrieved from http://kellyjclifton.com/?page_id=38

Cutter, S. L., Mitchee, J. T. & Scott, M. S. (1997). *Handbook for conducting a GIS-based hazards assessment at the county level*. Retrieved from http://training.fema.gov/EMIWeb/edu/docs/hrm/Session%206%20-%20Handbook%20GIS-Based%20Hazards%20Assessment.pdf

Dow, C. L. (2006). *Benefits and barriers to implementing and managing well rooted community gardens in Waterloo Region, Ontario* (Master's thesis). Retrieved from http://www.cityfarmer.org/WaterlooDowCG.html

Ewing, R. & Handy, S. (2009). Measuring the unmeasurable: Urban design qualities related to walkability. *Journal of Urban Design, 14*(1), 65-84.

Grimm, J. (2009). *Food urbanism: A sustainable design option for urban communities.* Retrieved from http://johnsonlinn-localfood.webs.com/Planning%20Resources/Food%20Urbanism_Grimm.pdf

Heinegg, A., Maragos, P., Mason, E., Rabinowicz, J., Straccini, G., & Walsh, H. (2002). *Soil contamination and urban agriculture: A practical guide to soil contamination issues for individuals and groups*. Retrieved from http://mse-research.mcgill.ca/envr401_2002/brownfields/guide.pdf

HFS (2009). *Hamilton hunger count 2009.* Retrieved from http://www.hamiltonfoodshare.org/downloads/Hunger_count_Report_2009__final.pdf

Hohenschau, D. (2005). *Community food security and the landscape of cities* (Master's Thesis). Retrieved from https://circle.ubc.ca/handle/2429/16818

Masi, B. (2008). Defining the urban-agrarian space in S. Rugare & T. Shwarz (Eds), *Cities growing smaller(Urban Infill Volume 1)* (pp. 87-101). Cleveland, OH: Kent State University.

Mendes, W., Balmer, K., Kaethler, T., & Rhoads, A. (2008). Using land inventories to plan for urban agriculture: Experiences from Portland and Vancouver. *Journal of the American Planning Association, 74*(4), 435-449.

Miller, G. (2008). Inclusive Design Must be Integrated with Drive for Sustainability. *Ontario Planning Journal, 23,* 6 – 7.

Mohajeri, N. & Amin, G.R. (2010). Railway station site selection using analytical hierarchy process and data envelopment analysis. *Computers and Industrial Engineering, 59*, 107-114.

Ontario Ministry of Public Infrastructure Renewal [OMPIR] (2006). *Places to grow: Growth plan for the Greater Golden Horseshoe.* Ministry of Public Infrastructure Renewal, Retrieved from https://www.placestogrow.ca/images/pdfs/FPLAN-ENG-WEB-ALL.pdf

Pagano, M. A. & Bowman, A. O'M. (2000). *Vacant land in cities: An urban resource*. Retrieved from http://www.mrsc.org/artdocmisc/paganofinal.pdf

Palcic, I. & Lalic, B. (2009). Analytic Hierarchy Process as a tool for selecting and evaluating projects. *International Journal of Simulation Modelling, 8*(1), 16-26.

Poudyal, N. C., Hodges, D. G. & Merrett, C. D. (2009). A hedonic analysis of the demand for and benefits of urban recreation parks. *Land Use Policy, 26*(1), 975-983.

Rideout, K. (2010). *Urban agriculture: Issues for public and environmental health* [PowerPoint Slides]. Retrieved from http://www.ncceh.ca/sites/default/files/UBC_SOEH_2010_Urban_Ag.pdf

Rosenberg, J. L. & Esnard, A-M. (2008). Applying a hybrid scoring methodology to transit site selection. *Journal of Urban Planning and Development, 134*(4), 180-186.

Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology, 15*, 234-281.

Saaty, T. L. (1990). How to make a decision: The Analytic Hierarchy Process. *European Journal of Operational Research, 48,* 9-26.

Saelens, B. E., Sallis, J. F., Black, J. & Chen, D. (2003). Neighborhood-based differences in physical activity: An environment scale evaluation. *American Journal of Public Health, 93*, 1552-1558.

San Francisco Department of Public Health (2008). *The Pedestrian Environmental Quality Index (PEQI): An assessment of the physical condition of streets and intersections (Draft Report).* Retrieved from http://www.sfphes.org/HIA_Tools/PEQI_Methods_2008.pdf

Schilling, J. & Logan, J. (2008). Greening the rust belt. A Green infrastructure model for right sizing America's shrinking cities. *Journal of the American Planning Association, 74*(4), 451-466.

Taylor, R. (2000). *Strategies for restoring vacant land: an analysis of northeast cities with recommendations for New Haven.* Retrieved from http://www.yale.edu/uri/pubs/WP/WP_46.html

Viljoen, A., Bohn, K. & Howe, J. (2005). *CPULs: Continuous productive urban landscapes.* New York, NY: Elsevier.

Voicu, I. & Been, V. (2008). The effect of community gardens on neighboring property values. *Real Estate Economics, 36*(2), 241-283.

Table 2.1 Judgment Statements for Scenarios 1- 4

<table>
<tr><th>Left-hand side of statement</th><th>Scenario 1 Middle of statement (CR=0.00)[1]</th><th>Scenario 2 Middle of statement (CR=0.10)[1]</th><th>Scenario 3 Middle of statement (CR=0.10)[1]</th><th>Scenario 4 Middle of Statement (CR=0.05)[1]</th><th>Right-hand side of statement</th></tr>
<tr><td rowspan="5">Neighbourhood Quality is</td><td rowspan="5">equal (1)</td><td rowspan="5">moderately more important (3)</td><td rowspan="5">moderately less important (1/3)</td><td>slightly less important (1/2)</td><td>when compared to developability potential</td></tr>
<tr><td>slightly less important (1/2)</td><td>when compared to visual quality</td></tr>
<tr><td>moderately more important (3)</td><td>when compared to compatibility with urban environment</td></tr>
<tr><td>equally important (1)</td><td>when compared to transportation options</td></tr>
<tr><td>equally important (1)</td><td>when compared to vulnerable populations</td></tr>
<tr><td rowspan="4">Developability potential is</td><td rowspan="4">equal (1)</td><td rowspan="4">moderately more important (3)</td><td rowspan="4">moderately less important (1/3)</td><td>slightly more important (2)</td><td>when compared to visual quality</td></tr>
<tr><td>strongly more important (5)</td><td>when compared to proximity to compatibility with urban environment</td></tr>
<tr><td>moderately more important (3)</td><td>when compared to transportation options</td></tr>
<tr><td>moderately more important (3)</td><td>when compared to vulnerable populations</td></tr>
<tr><td rowspan="3">Visual Quality of Site is</td><td rowspan="3">equal (1)</td><td rowspan="3">moderately more important (3)</td><td rowspan="3">moderately less important (1/3)</td><td>strongly more important (5)</td><td>when compared to compatibility with urban environment</td></tr>
<tr><td>slightly more important (2)</td><td>when compared to transportation options</td></tr>
<tr><td>very close, but slightly more important (1.5)</td><td>when compared to vulnerable populations</td></tr>
<tr><td rowspan="2">Compatibility with Urban Environment is</td><td rowspan="2">equal (1)</td><td rowspan="2">moderately more important (3)</td><td rowspan="2">moderately less important (1/3)</td><td>moderately less (1/3)</td><td>when compared to transportation options</td></tr>
<tr><td>strongly less important (1/5)</td><td>when compared to vulnerable populations</td></tr>
<tr><td>Transportation Options are</td><td>equal (1)</td><td>moderately more important (3)</td><td>moderately less important (1/3)</td><td>moderately more important (3)</td><td>when compared to vulnerable populations</td></tr>
</table>

Note: To conserve space, only the results for Scenario 4 are shown herein, in Table 2.3 and Table 2.4

[1]CR=Consistency Ratio (Saaty, 1977; 1990). A CR of zero denotes perfect consistency in the judgment statements (acceptable range 0.0-0.1)

Table 2.2 Normalized umbrella criteria weights

Umbrella Criteria	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Neighbourhood Quality	17	34	6	13
Developability Potential	17	24	8	33
Visual Quality of Site	17	17	11	22
Compatibility with Environment	17	11	17	4
Transportation Options	17	8	24	15
Vulnerable Populations	17	6	34	12

Table 2.3 Site Suitability Indices for Application 1, Scenario 4

STRATEGY[1] \ SITE[2]	1	2	3	4	5	6	7	8	9	10	11	12	13
1	87	77	36	39	94	53	77	75	46	46	97	72	64
2	87	77	41	45	94	55	79	77	50	50	97	74	66
3	87	68	38	45	82	55	77	70	46	46	85	69	61
4	88	70	39	44	84	58	79	77	51	51	88	73	65
5	75	66	45	43	84	44	71	69	52	52	99	68	65
6	88	77	39	43	96	56	77	78	57	57	100	77	68
7	86	77	41	43	96	54	78	79	55	55	100	78	67
8	74	64	45	42	80	43	70	67	54	54	100	66	61
9	87	77	41	45	94	55	79	76	50	50	97	74	66
10	78	68	44	48	85	47	71	68	52	52	97	66	67
11	87	77	43	43	97	55	80	79	54	54	100	79	68
12	72	56	43	47	70	35	56	65	46	46	90	55	67
13	82	69	32	36	76	48	66	78	38	38	73	58	52
14	74	64	44	47	66	36	58	69	49	49	91	55	63
15	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Note: cells shaded in grey correspond to the site suitability index for the existing use at each site, while outlined cells correspond to the largest site suitability index for each strategy

[1]Strategy 1 = Community Gardens, Strategy 2= Neighbourhood Farm, Strategy 3 = Commercial Farm, Strategy 4 = Orchards, Strategy 5=Farmers' Market, Strategy 6=Tot lot, Strategy 7=Parkette, Strategy 8=Urban Plaza, Strategy 9=Neighbourhood Park, Strategy 10=Community Park, Strategy 11=Fields/Courts, Strategy 12=Tree/Plant Nurseries, Strategy 13=Renaturalization, Strategy 14=Bioretention, Strategy 15=Circulation Enhancement

[2]Site 1=Jamesville Community Centre, Site 2=Churchill Park Community Gardens, Site 3=Today's Family Community Garden, Site 4=Centre Paradise Community Garden, Site 5=Hill Street Community Gardens, Site 6=Keith Neighbourhood Garden, Site 7=Stuart Street Gardeners, Site 8=Oriole Crescent Gardens, Site 9=West Hamilton Baptist Church, Site 10=West Hamilton Baptist Church, Site 11=Victoria Park Community Gardens, Site 12=Green Venture, Site 13=Athens Street Community Garden

Table 2.4 Site Suitability Indices for Application 2, Scenario 4

STRATEGY[1] \ SITE[2]	1	2	3	4	5	6	7	8	9	10	11	12
1	74	76	71	n/a	68	73	64	n/a	79	79	75	71
2	74	76	71	n/a	68	73	64	n/a	79	79	75	71
3	79	78	76	n/a	67	75	64	n/a	85	79	73	75
4	80	81	77	n/a	66	74	61	n/a	82	79	73	73
5	90	73	80	71	74	75	56	93	78	76	74	78
6	75	78	71	n/a	66	73	61	n/a	80	78	73	74
7	73	76	69	n/a	66	72	61	n/a	79	78	74	74
8	87	73	77	n/a	71	72	58	n/a	78	77	72	74
9	74	76	70	n/a	68	73	64	n/a	79	79	75	71
10	83	73	79	n/a	68	73	61	n/a	78	78	74	71
11	73	77	69	n/a	67	72	62	n/a	80	78	75	75
12	66	51	63	n/a	34	53	53	n/a	51	56	53	39
13	64	69	54	n/a	58	71	72	n/a	81	81	74	62
14	71	55	68	n/a	37	56	56	n/a	56	67	62	41
15	n/a	n/a	n/a	n/a	n/a	n/a	59	n/a	n/a	n/a	73	n/a

General note: cells shaded in grey correspond to the site suitability index for the existing use at each site, while outlined cells correspond to the largest site suitability index for each treatment

[1]Strategy 1 = Community Gardens, Strategy 2= Neighbourhood Farm, Strategy 3 = Commercial Farm, Strategy 4 = Orchards, Strategy 5=Farmers' Market, Strategy 6=Tot lot, Strategy 7=Parkette, Strategy 8=Urban Plaza, Strategy 9=Neighbourhood Park, Strategy 10=Community Park, Strategy 11=Fields/Courts, Strategy 12=Tree/Plant Nurseries, Strategy 13=Renaturalization, Strategy 14=Bioretention, Strategy 15=Circulation Enhancement

[2]Site 1 = Urban Plaza, Site 2 = Community Park, Site 3 = Parkette, Site 4 = Farmers' Market, Site 5 = Urban Plaza, Site 6 = Neighbourhood Park, Site 7 = Circulation Enhancement/Tot-lot, Site 8 = Farmers' Market, Site 9 = Neighbourhood Park, Site 10 = Community Park, Site 11 = Circulation Enhancement/Tot-lot, Site 12 = Parkette

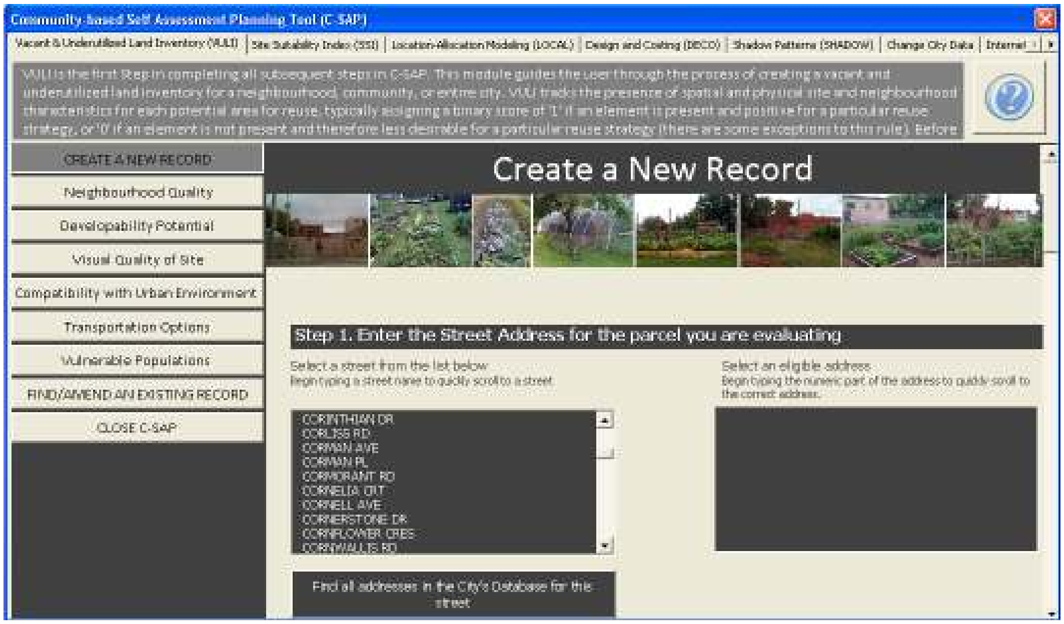

Figure 2.1 Screenshot of Graphical User Interface (GUI)

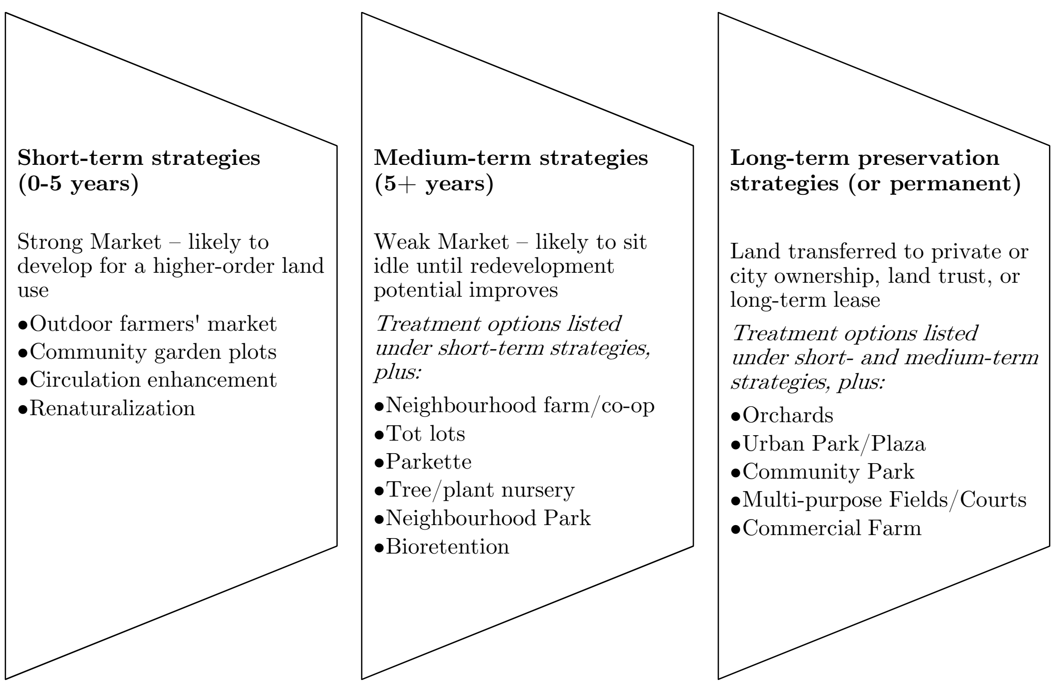

Figure 2.2 Strategies included in prototype decision support tool (Cleveland Land lab, 2008; 2009)

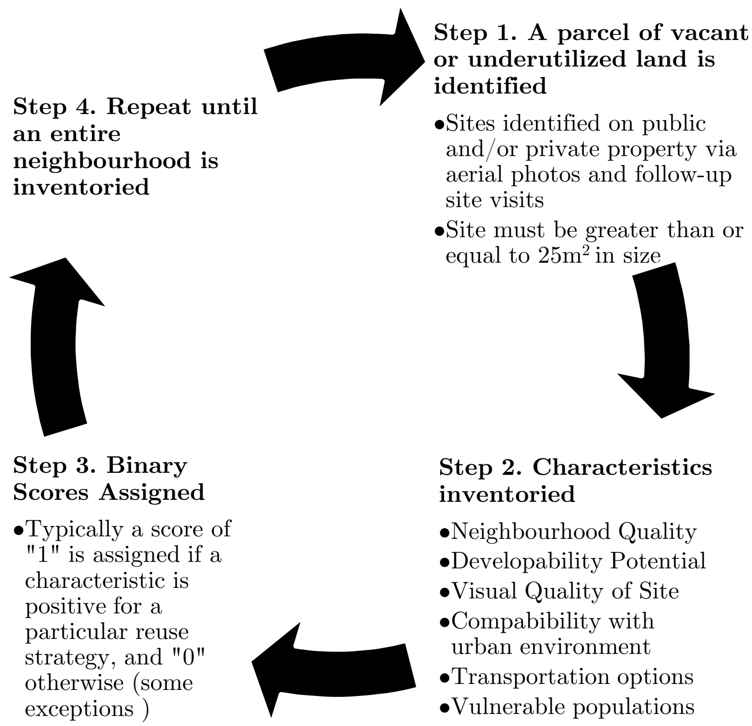

Figure 2.3 Flow diagram for completing the vacant and underutilized land inventory

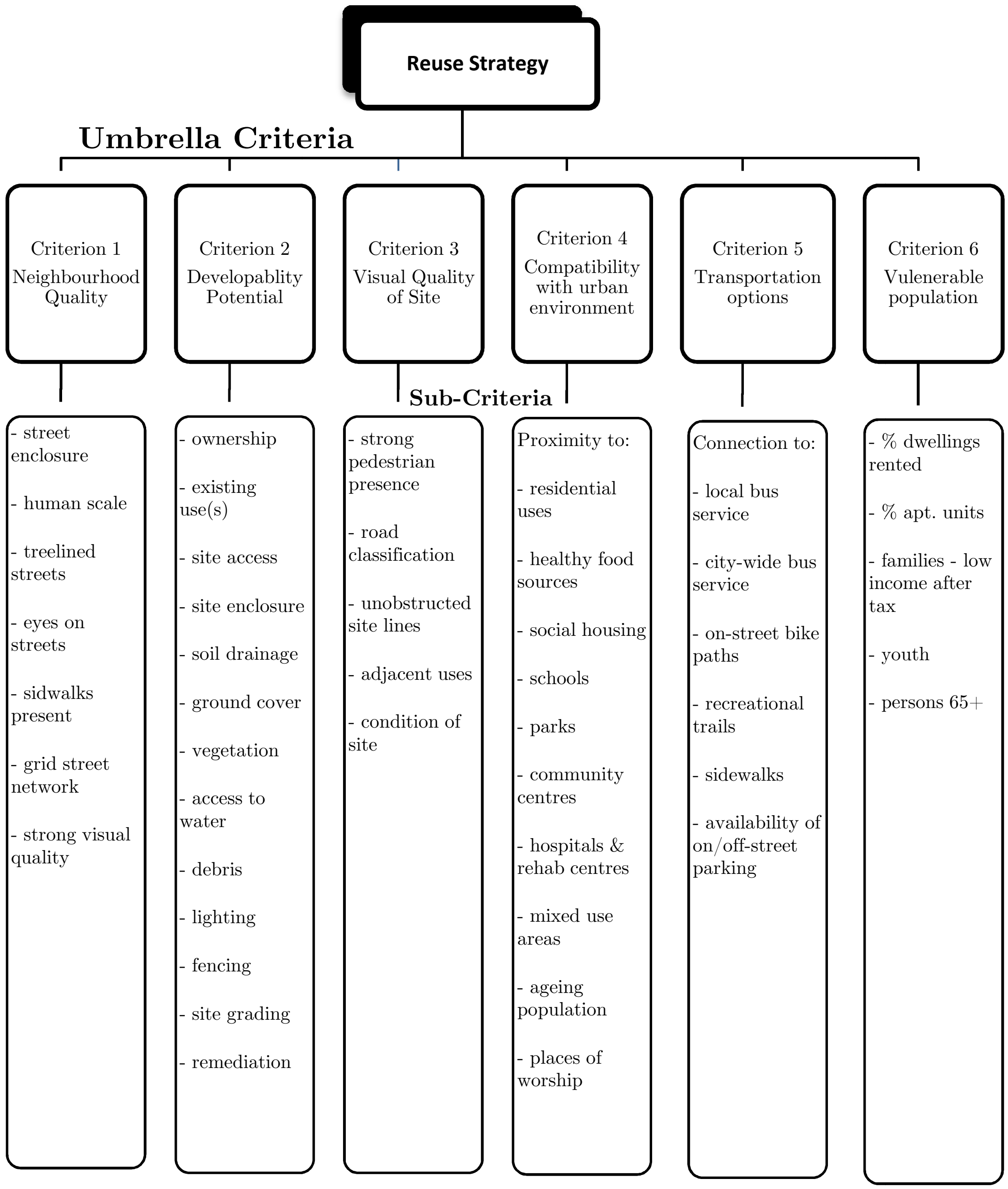

Figure 2.4 Vacant and underutilized land characteristics: umbrella criteria and sub-criteria

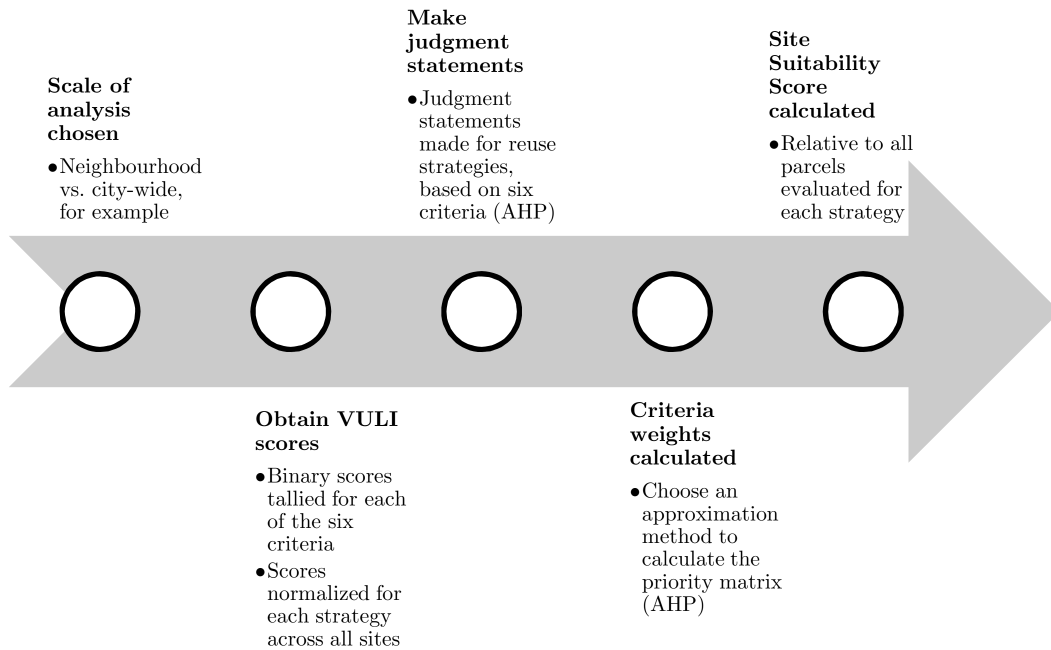

Figure 2.5 Flow diagram for calculating the site suitability index

Chapter 3. Allocating urban agricultural reuse strategies to inventoried vacant and underutilized land

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Kirnbauer, M.K. and Baetz, B.W. "Allocating urban agricultural reuse strategies to inventoried vacant and underutilized land." Journal of Environmental Informatics (in press)

3.1 Abstract

Community groups have a growing desire to use vacant and underutilized land for urban food production purposes; however, there are limited community-based tools available to assess the suitability of sites or location-allocation decisions. The purpose of this research is to provide decision support to community groups via a scientific software product developed in Microsoft Excel® that will aid users in identifying and inventorying the location and condition of vacant and underutilized land, determining the relative site suitability of the inventoried land, and allocating urban agricultural reuse strategies across the urban landscape. This paper describes an augmented capacity to the prototype community-based decision support tool (C-SAP) developed by Kirnbauer and Baetz (2011). C-SAP includes two existing tools that employ a binary scoring methodology for the vacant and underutilized land inventory process (VULI) and the analytic hierarchy process for the calculation of a set of site suitability indices (SSI). The additional capacity introduced herein, known as LOCAL, employs a multi-objective binary integer program formulation for the location-allocation of reuse strategies at a neighborhood, community or potentially city-wide planning level. The application of the prototype decision support tool to twenty one sites identified as potential future sites for urban agriculture is summarized and discussed. This tool has the potential to assist groups in clarifying both community needs and constraints, while producing outputs that provide a scoped, informed direction to users for the allocation of reuse strategies. This paper describes a methodology for engaging community groups in making well-informed decisions related to effectively and efficiently bringing vacant and underutilized land back into productive reuse in a way that complements city-wide land use planning initiatives related to sustainable growth.

Keywords: urban food production, food urbanism, decision support, analytic hierarchy process, land inventory, site suitability

3.2 Introduction

Land-use planning authorities in many jurisdictions across the globe are challenged by a rising need to formulate and implement effective policies that forecast, plan for, and deliver urban growth (or shrinkage) plans that alleviate the social, environmental, and economic pressures created as a result of historical policies that facilitated the ever-present patterns of urban sprawl and urban decline. Coupled with the challenge of urban growth is the provision for adequate, accessible, and equitable, complementary productive public spaces, which will be critical in sustaining residential and employment populations. For example, unprecedented policies in the Province of Ontario, Canada have placed requirements for municipalities to accommodate up to 40% of new residential growth in already built-up areas, through intensification projects directed largely to vacant and underutilized land parcels (OMPIR, 2006). Existing vacant and underutilized land parcels, including publicly or privately held residential, industrial, commercial, institutional, agricultural, utility, parks and open space, or remnant lands that are not currently being used to their full potential or not fulfilling their intended purpose, hold untapped opportunities for productive reuse, which may act to enhance, anchor or stabilize declining neighborhoods.

There is a growing movement at the community-level across many jurisdictions, both in growing and shrinking cities, towards vacant and underutilized land reuse for urban agricultural purposes. An established philosophy that is gaining new momentum among urban planners, architects, community advocates, and city officials is the development and retrofitting efforts of communities to integrate a typology of productive uses into the urban landscape (Cleveland Land Lab 2008, 2009; Friedman, 2007; Grimm, 2009; Hohenschau, 2005; Langdon, 2008; Viljoen, Bohn and Howe, 2005). In recent years, there is mounting interest in movements such as 'the 100-mile-diet' (Smith and McKinnon, 2007), 'zero-mile-diet' (MacDonald, 2010), 'slow food movement' (Patrini and Waters, 2007), and organic farming on the urban fringe (Beauchesne and Bryant, 1999) as a way to transition from our dependence on cheap oil to more resilient, locally-focused communities. These efforts are complemented by a growing body of literature that seeks to answer many of the lingering questions surrounding how to reuse vacant and underutilized land effectively and safely, in ways that are compatible with the urban environment and city planning policies, and at the same time yield high value or utility for a community (de Zeeuw, 2004; Heinegg, Maragos, Mason, Rabinowicz, Straccini, and Walsh, 2002; Kirnbauer and Baetz, 2011; Rideout, 2010). Further driving this movement forward is the issue of community food security (Brown and Carter, 2003), with a particular focus on vulnerable, at-risk populations (HFS, 2010). Defined typologies for urban agricultural, including recommended minimum and maximum area, appropriate location (e.g. intra-urban vs. extra-urban), and service radii have been presented in recent works (Cleveland Land Lab, 2008, 2009; Duany Plater-Zyberk, cited in Langdon, 2008; Grimm 2009; Hohenschau, 2005; Mendes, Balmer, Kaethler, and Rhoads, 2008).

Recent work completed on two Pacific Northwest cities demonstrated that land inventories can be used to integrate urban agriculture into planning and policy-making processes (Mendes et al., 2008). Both Portland, Oregon and Vancouver, British Columbia have developed inventories on city-owned land to determine the overall suitability for community gardens and other urban agriculture uses, using high-resolution aerial photos to assess attributes including tree canopy, the presence of buildings and parking (Mendes et al., 2008). Kirnbauer and Baetz (2011) present a prototype community-based decision support tool, known as C-SAP, to assist community groups in completing a vacant and underutilized land inventory based on six umbrella criteria: neighborhood quality, developability potential, visual quality (of the site), compatibility with the urban environment, modal options, and vulnerable population characteristics. The prototype tool allows the user to evaluate up to fifteen community-based reuse strategies for vacant and underutilized land, five of which are related to urban food production, and provides the user with a set of relative site suitability indices for each strategy across all inventoried sites (Kirnbauer and Baetz, 2011).

The following paper introduces an additional capacity, hereafter referred to as LOCAL, to the community-based prototype decision support tool, known as C-SAP (Kirnbauer and Baetz, 2011), that allows the user to carry out location-allocation modeling using a multi-objective binary integer programming approach and a set of user-specified constraints. While the augmentation has the potential to evaluate all fifteen strategies in the location-allocation model, only the urban agricultural uses are employed in the application discussed herein. The tool was applied to twenty one sites that were identified by the Hamilton Community Garden Network (HCGN) as being currently underutilized and potential urban food production locations across the City of Hamilton, Ontario. A range of allocation scenarios were generated (eight in total) using LOCAL to assess the sensitivity of the model to changes in community requirements and constraints. While applied to a municipality in Ontario, Canada, this tool is not limited to this municipal jurisdiction; with reasonable modifications, including the replacement of built-in parcel and census data, C-SAP could be applied to jurisdictions across the globe.

It is important to note that the integrity of all data inputs, and therefore the integrity of the LOCAL outputs, is dependent on the user adhering to the specific data input (e.g. latitudinal and longitudinal coordinates must be represented in decimal degrees) and spreadsheet formatting requirements (e.g. column position/headings must coincide with the templates provided), as identified in the instructions provided in C-SAP. Furthermore, the accuracy of all geo-coded data inputs should be verified to ensure the integrity of the spatial data utilized in C-SAP. An overview of C-SAP, including the additional capacity, is described below.

3.3 Description of C-SAP's existing and augmented capacity

The location-allocation model discussed within this manuscript is an additional module, developed to augment the existing decision support tool created by Kirnbauer and Baetz (2011). Figure 3.1 depicts a simplified flow diagram for the existing tool with the augmented capacity. Prior to the module development, the tool could be used to inventory the location, condition, and other relevant attributes of vacant and underutilized urban land. The inventoried data are subsequently assigned a binary score and normalized. The user is then required to complete a series of judgment statements relating to the importance of each criterion, using the Analytic Hierarchy Process (AHP). This process can be completed for a suite of fifteen reuse strategies, or a user-specified sub-set of these strategies, that contribute to a city's green infrastructure capacity: community gardens, neighbourhood farms, commercial farms, orchards, farmers' markets, tot-lots, parkettes, urban plazas, neighbourhood parks, community parks, fields/courts, tree/plant nurseries, renaturalization, bioretention, and circulation enhancement.

AHP is used to calculate the weights of each of the six umbrella criteria (i.e. a priority vector) based on the user-specified judgment statements (Saaty, 1990). The product of the weights and matrix of relative scores is calculated and provided to the user in the form of a site suitability matrix. This process produces a suitability index for each reuse strategy at each site, based on the best performing site for each criterion. The matrix of suitability indices can then be reviewed by the user and statements with respect to the suitability of a particular use across the evaluated sites can be made. This process is described in detail in Kirnbauer and Baetz (2011).

The additional capacity to the existing decision support tool involves the application of a multi-objective program that utilizes the site suitability matrix as the decision variable coefficients in a binary integer location-allocation model (LOCAL), for a user-specified set of the inventoried sites and associated constraints. Each constraint in the model can be altered by the user to perform a series of “what-if” scenarios and sensitivity analyses to assist the user in better articulating the potential trade-offs of heavily constraining the binary integer programming model or fully relaxing the model constraints. By performing “what-if” analyses, the user is provided with a series of output files that identify potential alternative location-allocation solutions, which can be useful for initiating well-informed discussions related to suitable locations for vacant and underutilized land reuse. The model is further described below.

3.4 Methodology

3.4.1 Overview of the location-allocation (LOCAL) model

LOCAL is based on a binary integer programming formulation and is solved via customized code modules written in the Visual Basic for Applications (VBA) programming language, provided in the Microsoft Excel® developer’s environment. A screenshot of the customized graphical user interface (GUI), used to complete LOCAL, is shown in Figure 3.2. The program requires the Solver add-in, which is typically included on the Microsoft Excel® installation CD’s. OpenSolver, an Excel VBA add-in, is also required to extend Excel’s built-in Solver with a more powerful Linear Programming solver (Mason, 2011). OpenSolver removes the artificial limits, imposed by the traditional Solver package, on the size of problem that can be solved in Excel (i.e. variable and constraint limitations). OpenSolver can be used to solve large linear and integer programming optimization problems, and is available for public download at opensolver.org. LOCAL uses Excel’s traditional Solver add-in to build the model and subsequently, OpenSolver uses a separate engine to solve the programming model.

The steps required to complete LOCAL are depicted in Figure 3.3. Prior to completing LOCAL, an inventory of vacant and underutilized land needs to be completed for the minimum planning scale of a neighourhood, and the site suitability matrix calculated for the evaluated sites. Following these steps, the user can query the inventoried sites for 3 different scales of analysis: a single neighourhood, a series of neighborhoods, or an entire city. The user is then required to enter a set of mandatory and optional constraints. These constraints include:

- the minimum contiguous area required for each strategy to be viable at a particular location;
- the maximum area desired at one location for each strategy (may be a combination of several fragmented areas that also meet the minimum contiguous area requirement);
- the maximum number of reuse strategies allocated across the area under analysis;
- the service radius for each strategy and the corresponding minimum population density required within this radius;
- the minimum separation distance required between strategies of the same type;
- the minimum width or length requirements for the area for reuse, and
- the sunlight conditions at the site

The user is also required to identify whether the area is deficient in a particular use. Pop-up comments are provided for the user to assist them in completing this input.

Once the binary program builder button is selected on the graphical user interface (GUI), the model is built and executed automatically for the user, so there is no interfacing required between the user and the traditional Solver dialogue box. The model formulation is described below.

3.4.2 Model formulation

Prior to running the model, a series of precursor conditions need to be satisfied. First, a check is carried out to determine if the area under analysis is deficient in terms of the particular reuse strategy (e.g. acres of strategy j per 1000 persons); if the spatial area under analysis is not deemed deficient in a particular reuse strategy, the use is removed from the model. Next a check is completed to determine if the minimum area is met at each site for each strategy. Similar subsequent checks are completed for minimum dimension requirements (if any) and finally minimum population density requirements. Sites that do not meet the minimum specified requirements are removed from the analysis by setting their site suitability scores to 0. Following the validation of the precursor conditions, the model is automatically built and executed as follows:

Objective Function: Maximize the cumulative sum of the site suitability scores across the allocated sites

Max $\{ \sum_{j=1}^{m} \sum_{i=1}^{n} SSI_i^j \cdot X_i^j \}$ (3.1)

Where:
SSI_i^j = Site Suitability Index (coefficient) for strategy j at site i
X_i^j = binary decision variable (equal to 1 if the strategy j is allocated to site *i*; 0 if the strategy j is not allocated to site i)
j = 1, 2,..., m (m_{max}=15), and
i = 1, 2,...,n (n sites for potential reuse)

Subject to the following constraints:

Constraint 1. Decision variables must be binary

$X_i^j \in 0,1$

Constraint 2. The sum of each reuse strategy allocated across the area under analysis must be less than or equal to the user-specified maximum number desired for each strategy

$\sum_{i=1}^{n} X_i^j \leq X^{max\, j}$ for each j, j = 1 to m

Constraint 3. The distance between reuse strategies of the same type (e.g. community gardens) must be greater than or equal to the minimum, user-specified separation distance for each strategy. C-SAP will calculate the distance between all potential areas for reuse and ensure that a maximum of one allocation can be made when the minimum distance separation criterion is violated (this ensures a broader spatial distribution of each reuse strategy).

If $D_{i,k} \leq D_{min.sep.}^j$ for any site i and adjacent site k (i≠k), for *i=1,...n* and *k=1,...n* then:

$\sum_{i=1}^{n-1} \sum_{k=i+1}^{n} (X_i^j + X_k^j) \leq 1$ for each j, j = 1 to m

Where:
$D_{i,k}$= geodesic (i.e. straight line) distance between site i and site k
$D_{min.sep.}^j$= minimum separation distance required for reuse strategy, j

X_i^j *and* X_k^j= binary decision variable for reuse strategy j at sites i and k, respectively

Constraint 4. The number of reuse strategies assigned at each site must be less than or equal to 1 (for each run of the solver model)

$\sum_{j=1}^{m} X_i^j \leq 1, \text{for each i; i} = 1 \text{ to n}$

Post calculation. The maximum, user-specified area is allocated to each site identified by the model. The potential area for reuse at each site is subsequently re-calculated (previous area minus area allocated; the remaining area is used in subsequent strategy allocations, if any).

Precursor checks prior to additional (optional) strategy allocations. The same precursor conditions must be satisfied for each reuse strategy prior to including it in the analysis. Each reuse strategy allocated in the previous step is identified and eliminated from subsequent runs of the model (i.e. to avoid assigning the same use at a site)

Model loops (optional). The solver model will loop, assigning additional uses to each site, where possible, until no viable options to assign additional strategies exist at any site.

Several limitations with respect to the formulation of the model warrant further discussion. Firstly, Solver and OpenSolver do not have the capacity to dynamically adjust the remaining area available at each site once a reuse strategy has been allocated, and subsequently iterate within the OpenSolver engine to allocate additional uses. In other words, only one strategy can be allocated to each site via each run of the model. As such, a hybrid approach was developed whereby a programming routine, outside of the Solver model, is used to perform a series of model adjustments and subsequently iterate and initiate the Solver model, creating a looping sequence, until no additional strategies can be assigned without violating the model constraints. It is important to note that while this tool is useful in assisting a user in solving combinatorial location-allocation optimization problems relating to vacant and underutilized land reuse, it provides a heuristic approach for the generation of 'good', near-optimal solutions, but not necessarily 'the optimal' solution.

3.5 Decision support tool output

This tool is helpful in allocating reuse strategies to vacant and underutilized land, based on a series of user-specified constraints. It provides output to the user in two different formats: a tabular format and a spatial format. The first output option is a Microsoft Excel® spreadsheet, which includes a summary of all inventoried site and neighborhood characteristics, umbrella criteria scores, relative scoring, site suitability indices, model output for strategy allocations, and finally the areas allocated for each strategy across the evaluated landscape. The second output option involves the creation of a keyhole markup language (.kml) file, that ties tabulated allocation data stored in the prototype decision support tool to the geographic coordinates of the inventoried parcel, and is presented in electronic map format for sharing/viewing on the web or in Google Earth. This is carried out by linking key elements of the output to a mapping tool provided on a publicly accessible geo-coding website (BatchGeo, 2011). The model can be reset and the queried data restored for additional analyses of the neighborhood(s), or the user can query a new neighborhood(s), repeating this process as many times as desired.

3.6 A note on the branch and bound method

The binary integer programming approach described herein resolves a binary vector x for each inventoried site that maximizes the objective function described above, subject to a set of linear constraints. This is done using a linear programming-based branch-and-bound method (Frontline Systems Inc., 2010). Integer programs make a model non-convex, where there may be a large number of local minima and maxima. Problems of this nature often require longer computing times and extensive memory requirements; in problems involving just a few hundred variables, it is possible that the solution will never converge on the global maximum (Frontline Systems Inc, 2010). As such, the application of global optimization techniques is required to guarantee convergence in finite time to the optimal solution. With well-formulated models, these problems can sometimes be resolved.

The branch and bound algorithm searches for an optimal solution to the binary integer programming problem by solving a standard linear programming (relaxed) problem, in which the binary integer requirement on the variables is replaced by the relaxed constraint $0 \leq x \leq 1$ (Frontline Systems Inc., 2010). If the solution contains one or more non-integer values, the algorithm branches, creating two new sub-problems at the node representing the first non-integer decision variable. Two constraints are added at each non-integer node to create two new branches: $x_i = 1$ and $x_i=0$. For each new branch, a relaxed linear program (i.e. 'a regular Solver LP') is solved to determine if a better solution exists; this process continues, eliminating sets of sub-problems that are either infeasible or cannot be better than a solution already obtained, until all decision variables have integer values and all constraints are satisfied (Frontline Systems Inc, 2010).

3.7 Application of LOCAL and discussion of key findings

The developed decision support system was applied to a series of sites identified in Hamilton, Ontario as potential/desirable sites for future community gardening projects. A non-profit organization, known as The Hamilton Community Garden Network (HCGN), supports and promotes individuals and communities in developing and maintaining community gardens in Hamilton, Ontario from the perspective of improving food security and increasing community involvement (Personal Communication, C. Wagner, July 19, 2011). Following a public meeting held by the HCGN, a report produced by Mayo (2008) was prepared, providing a summary of key meeting discussion topics, a literature review of best practices and municipal policies in other cities across Canada, and strategic future directions for the HCGN to best ensure the growth of community gardens to combat social alienation and ensure a path towards a food secure city. While Hamilton is an agricultural city, with over 50 agricultural operations in the outer wards and peri-urban locations, finding suitable land in inner wards was identified as a key issue in Hamilton (Mayo, 2008). As one of the key actions put forth in the HCGN report was educating community garden leaders through the development of a toolkit (Mayo, 2008), it is believed that LOCAL could be an integral part of this toolkit and assist leaders in making well-informed decisions related to the primary issue of allocating agricultural uses to suitable urban locations. At the community meeting, a mapping process was carried out whereby attendees were asked to identify parcels of land across the city that were believed to be suitable locations for urban agriculture. Throughout this process, thirty one sites were identified on both private and public lands, of which twenty one were used in the application of LOCAL, spanning seventeen distinct neighborhoods across the city. Ten of the thirty one identified sites have since been developed for gardens, other land uses, or could not be identified, and as such were not included in the application. The remaining twenty one sites were inventoried in C-SAP to evaluate the suitability of each site for urban food production uses and allocate a suite of strategies across the evaluated neighborhoods. As part of the inventory process, the spatial and physical attributes of each site were collected, scored, normalized, and presented as a matrix of site suitability indices for reuse strategy.

The typology of urban agricultural reuse strategies available for application in the decision support tool includes community gardens, neighborhood farms/co-ops, commercial farms, orchards and farmers' markets. Community gardens/allotments provide opportunities for individuals to grow their own food for personal consumption. Neighborhood farms/co-ops provide opportunities to work as part of a group on a communal plot(s) for the benefit of the growers. Commercial farms are commercially run growing operations, typically operated by one person for sale to markets or grocers. Orchards provide opportunities for growing fruiting crops for community consumption and commercial sale. Farmers' markets provide opportunities for selling locally grown produce outdoors. All of these uses were selected as potential uses for each of the inventoried sites. Upon completion of the land inventory for the twenty one sites, fifteen pair-wise comparisons of the umbrella criteria (judgment statements) for each reuse strategy were completed. These statements were used to evaluate the weight of each of the umbrella criteria used in the inventory process, using the Analytic Hierarchy Process (Kirnbauer and Baetz, 2011). Three sets of judgment statements were used in the application described herein: a set for community gardens and neighborhood farms, a set for commercial farms and orchards, and a set for farmers' markets. This was done as the relative importance of the umbrella criteria within each grouping was deemed similar based on the intended use. The resulting weights for each criterion are summarized in Table 3.1, while the calculated site suitability indices are summarized in Table 3.2 (the product of the weights and the inventory scores).

The umbrella criteria weights for each applied set of judgment statements demonstrate shifts in priorities for each use, and assist in articulating the importance of the various neighborhood and on-site characteristics inventoried prior to applying the statements. Developability potential, which reflects the overall material and labour requirements necessary to develop the site for the intended use, is deemed significant for all uses (weight of 1/3 to 1/2 of the aggregated site suitability score). Visual quality of the site, compatibility with the urban environment and proximity to vulnerable populations weigh significantly high for community gardens and neighborhood farm uses. Commercial farms and orchards have lower transportation, neighborhood quality and vulnerable population criteria weights. This reflects the assumption that individuals will not be traveling as frequently to these sites as it is anticipated that they will operate at a predominantly commercial-level, with fewer participants, and potentially fewer direct sales to neighboring residents. Farmers' markets were given higher transportation, neighborhood quality and visual quality criteria weights, as it is important to provide sufficient access to these sites for citizens as well as maintaining a strong visual presence.

Table 3.2 shows the site suitability indices for each reuse strategy across all evaluated sites, with the largest, 2nd largest and 3rd largest site suitability index for each strategy distinctly outlined. Suitability indices have been normalized and are presented out of a maximum score of 100. Community gardens and neighborhood farms are presented together in Table 3.2, as they scored identically due to the application of common criteria weights and common inventoried attributes (note: not all attributes were relevant for the remaining three uses and as such did not need to be inventoried, resulting in different scores).

As described in Kirnbauer and Baetz (2011), the user can customize the inventory questions for each strategy, prior to initiating the neighborhood inventory process. These questions are then held constant for the entire neighborhood(s) analysis. In this instance, the same questions were selected for community gardens and neighborhood farms, reflecting the equal importance of all inventoried attributes for both strategies (resulting in all sites being scored the same for both strategies). Several sites scored consistently high for many of the agricultural uses including Sites A, E, I, O, and R, four of which are active city-operated parks (e.g. fields, diamonds, play structures) and one which is adjacent to a recreational trail, with Site E (Corktown Park) scoring the highest for all urban agricultural uses (>80 for all uses). This is a logical outcome as parks have been allocated across the city in an attempt to service residential neighborhoods at specified levels of service. It stands to reason then that these sites will likely be ideal candidates for agricultural uses based on population density, overall accessibility, and overall compatibility with the urban environment, particularly sensitivity to abutting uses. Several other options that appear quite reasonable other than the highest ranked suitability index are apparent in Table 3.2. Community gardens and neighborhood farms, commercial farms, orchards, and farmers' markets had suitability indices greater than 70 for five, eight, seven, and ten sites, respectively. While the scoring methodology used in the prototype decision support tool does not have a distinct site suitability threshold whereby scores above are accepted and scores below are rejected, it provides the user with a set of options that may facilitate the location-allocation decision-making process. A user may choose to exit the decision support tool after calculating the site suitability indices; however, LOCAL was developed to use the output shown in Table 3.2 along with a set of user-specified constraints to further articulate where to best allocate uses across the urban fabric. An example of the type of analyses that a user could complete is described below.

For the twenty one sites inventoried, eight different constraint scenarios (A1-A8) were evaluated to observe the sensitivity of changes to the user constraints and their effect on allocation patterns and overall objective function values. To conserve space, inputs for the first of eight constraint scenarios are summarized in Table 3.3. LOCAL converged to a feasible solution for all evaluated constraint scenarios. The efficient run time in LOCAL is largely due to the binary integer programming formulation and imposed constraints, which effectively "prune out" infeasible options.

The following constraints were adjusted: the maximum number of each strategy desired across the community, the minimum population density required for each strategy, the minimum contiguous area required, and the minimum dimensions required to ensure a site is useable for a particular strategy. Applications A1 and A5 were constrained by all four parameters; applications A2 and A6 were constrained by the minimum dimension requirements, the maximum number of strategies desired, and the minimum area. Applications A3 and A7 were constrained by the maximum number of strategies desired and the minimum area, while applications A4 and A8 were constrained by the maximum number of strategies desired. Minimum and maximum areas for each strategy were derived from a variety of sources on urban agriculture typologies (Cleveland Land Lab, 2008, 2009; Duany Plater-Zyberk, cited in Langdon, 2008; Grimm 2009; Hohenschau, 2005; Mendes et al., 2008).

A simplified spatial summary of the location-allocation model results is depicted in Figure 3.4 and Figure 3.5 for applications A1 and A4, respectively. Due to the size of the accompanying tabular data output, excerpts have not been included within this manuscript. Across all eight applications, Sites B, E, F, I, K, P and R did not have a large number of strategies allocated to them. This is explained by the fact that they did not meet the minimum contiguous area requirement in the majority of the applications or minimum density requirements. The objective of applications A1 through A4 was to allocate four of each urban agriculture strategy (community garden, neighborhood farm, commercial farm, orchard, farmers' market) across the twenty one inventoried sites. Application A1, the most constrained of applications A1 through A4, was effective in allocating 100% of the desired orchards, but fell short in all other strategy categories, largely due to the density requirement (only Sites E, H, J, R, and S met this requirement for community gardens and Sites H and J for neighborhood farms). This application had a resulting objective function value of 590 (the product of the site suitability indices multiplied by the decision variables). Application A2 was effective in allocating 100% of the desired community gardens, neighborhood farms, orchards and farmers' markets but only found one out of four locations for a commercial farm. This application achieved an objective function value of 1070, sizably larger than the first application, largely explained by the fact that the density requirement was relaxed. Application 3 further relaxed the constraints by removing the minimum dimension requirement. In doing so, 100% of the desired community gardens, neighborhood farms, orchards and farmers' markets and three out of four locations for commercial farms were allocated. The objective function value for this application increased to 1190. Finally, Application 4 was further relaxed by reducing the minimum contiguous area from 300 m^2 to 200 m^2 for all uses with the exception of commercial farms (which were held at 1200m^2). All of the desired uses were allocated and an objective function value of 1270 was achieved.

The objective of applications A5 through A8 was to allocate 8 community gardens, 5 neighourhood farms, 2 commercial farms, 2 orchards and 4 farmers' markets across the twenty one inventoried sites. These applications followed the same sequence with respect to relaxing the constraints and achieved similar success rates in terms of allocations, with objective function values ranging from 460 to 1350.

The output from LOCAL reveals that as the constraints are relaxed, a set of eight viable allocation scenarios are generated, with each relaxation resulting in an increase in the number of reuse strategy allocations and therefore an increase in the objective function value. It is recognized, however, that resolving a completely relaxed problem may not capture the needs and values of the user, thereby limiting the usefulness of the output. It is very likely, on the other hand, that the user may need to impose constraints, such as those applied in the eight applications discussed herein, to achieve the desired goals for delivering equitable access to productive public spaces. It is recommended that the user generate a variety of scenarios similar to the methodology presented in this manuscript, as this process may assist in generating meaningful discussion, potentially leading to improved decision-making.

3.8 Conclusions

This paper describes an augmentation to a prototype decision support tool for identifying and inventorying the location and condition of vacant and underutilized land and determining the relative suitability of each identified site for a suite of parks and open space, urban agriculture, and stormwater management uses (Kirnbauer and Baetz, 2011). The augmented decision support capacity allocates reuse strategies across the urban environment, subject to a set of user-specified constraints. The prototype decision support tool was subsequently applied to a case study of inventoried data for twenty one sites identified by the Hamilton

Community Garden Network as potential future urban agricultural locations (Mayo, 2008). A variety of constraint scenarios were applied to the twenty one sites and the output was summarized and discussed herein. As expected, the highly constrained model was not successful in meeting the user needs, while the least constrained scenario was successful in meeting 100% of the user needs for the total number of allocations desired. The decision support tool is able to generate scenarios quickly, with the binary integer programming model converging to a solution in a matter of seconds in all applied scenarios. This output provides the user with 'good', near-optimal solutions and may assist in making well-informed decisions related to location-allocation problems for the temporary reuse of vacant and underutilized land.

The decision support tool, including LOCAL, and accompanying files are available for download off of the McMaster University Sustainable Communities Research Group website, located at: www.eng.mcmaster.ca/civil/sustain/downloads.html.

3.9 Acknowledgements

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3.10 References

BatchGeo LLC. How to use BatchGeo. http://batchgeo.com (accessed July 12, 2011).

Beauchesne, A., Bryant, C. (1999). Agriculture and innovation in the urban fringe: The case of organic farming in Quebec, Canada. Tijdschrift voor Economische en Sociale Geografie 90(3), 320-328. doi:10.1111/1467-9663.00073

Brown, K. H., Carter, A. (2003). Urban agriculture and community food security in the United States: Farming from the city centre to the urban fringe, A Primer Prepared by the Community Food Security Coalition's North American Urban Agriculture Committee.

Cleveland Land Lab. (2008). Re-imagining a more sustainable Cleveland: Citywide strategies for reuse of vacant land. Adopted by the Cleveland

City Planning Commission on December 19, 2008, Prepared by the Cleveland Land Lab at the Cleveland Urban Design Collaborative, Kent State University.

Cleveland Land Lab. (2009). Re-imagining Cleveland: Vacant land reuse pattern book. Prepared by the Cleveland Land Lab at the Cleveland Urban Design Collaborative, Kent State University.

de Zeeuw, I. H. (2004). The development of urban agriculture; some lessons learnt. Keynote paper presented at the Urban Agriculture, Agro-tourism and City Region Development International Conference, Beijing.

Friedman, A. (2007). Farming in suburbia. Open House International 32(1), 7-15.

Frontline Systems Inc. (2010). Solver tutorial: Size, sparsity and integer variables. (accessed June 10, 2011).

Grimm, J. (2009). Food urbanism: a sustainable design option for urban communities. Landscape Architecture and Environmental Studies, Iowa State University.

Heinegg, A., Maragos, P., Mason, E., Rabinowicz, J., Straccini, G., & Walsh, H. (2002). Soil contamination and urban agriculture: A practical guide to soil contamination issues for individuals and groups. Prepared by McGill School of Environment.

Hamilton Food Share (2010). Hamilton hunger count 2010, Hamilton, Ontario, Canada.

Hohenschau, D. (2005). Community food security and the landscape of cities. Master of Landscape Architecture, University of British Columbia, Vancouver, B.C., Canada.

Kirnbauer, M. C., Baetz, B. W. (2011). A prototype community-based planning tool for evaluating site suitability for the temporary reuse of vacant and underutilized land. Manuscript submitted for publication.

Langdon, P. (2008). Newest eco-development model: 'Agricultural urbanism'. New Urban News 13(4), 1; 8-10.

MacDonald, C. (2010). Blue and white and green all over. U of T Magazine, 36-37.

Mason, A. (2011). OpenSolver Toolbar. (Software). http://opensolver.org/ (accessed October 22, 2010).

Mayo, J. (2008). Report for the Hamilton Community Garden Network (HCGN) on the Growth of community gardens in Hamilton. Funded by the HCGN, the Chronic Disease Prevention-Adult Program, and the Healthy Living Division of the City of Hamilton, Ontario.

Mendes, W., Balmer, K., Kaethler, T., & Rhoads, A. (2008). Using land inventories to plan for urban agriculture: Experiences from Portland and Vancouver. Journal of the American Planning Association 74(4), 435-449. doi:10.1080/01944360802354923.

Ontario Ministry of Public Infrastructure Renewal [OMPIR]. (2006). Places to Grow: Growth Plan for the Greater Golden Horseshoe.

Patrini, C. & Waters, A. (2007). Slow Food Nation: Why our Food Should be Good, Clean and Fair. Rizzoli Ex Libris.

Rideout, K. (2010). Urban agriculture: Issues for public and environmental health. (Powerpoint Slides). National Collaborating Centre for Environmental Health, School of Environmental Health Seminar Series, University of British Columbia, B.C., Canada.

Saaty, T. L. (1990). How to make a decision: The Analytic Hierarchy Process. European Journal of Operational Research 48, 9-26. doi:10.1016/0377-2217(90)90057-I.

Smith, A. D. & McKinnon, J. B. (2007). The 100-Mile Diet: A Year of Local Eating. Vintage Canada.

Viljoen, A., Bohn, K., & Howe, J. (2005). CPULs: Continuous Productive Urban Landscapes Elsevier.

Table 3.1 Normalized weights for umbrella criteria, based on user-specified judgment statements

Umbrella Criteria	Community Gardens & Neighborhood Farm	Commercial Farms & Orchards	Farmers' Markets
Neighborhood Quality	8	7	10
Developability Potential	33	45	31
Visual Quality of Site	18	15	18
Compatibility with Environment	18	15	12
Modal Options	7	5	21
Vulnerable Populations	16	13	8

Table 3.2 Normalized Site Suitability Indices (SSI) for each strategy across twenty one sites

Site ID	Community Gardens & Neighborhood Farms	Commercial Farm	Orchards	Farmers' Markets
A	75	76	72	75
B	62	60	59	71
C	66	65	64	68
D	64	72	65	76
E	83	85	85	90
F	51	56	55	47
G	66	58	59	67
H	41	46	45	43
I	79	76	81	75
J	70	73	71	71
K	57	61	63	53
L	68	73	71	63
M	38	52	47	47
N	40	43	44	52
O	69	72	78	87
P	63	64	60	71
Q	61	55	60	68
R	78	76	73	84
S	49	57	57	49
T	63	67	66	71
U	51	54	54	51

Largest site suitability index for each strategy

2nd Largest site suitability index for each strategy

3rd Largest site suitability index for each strategy

Table 3.3 User-specified constraints (input) for the first of eight applications (A1)

Reuse Strategy	Minimum Area (m^2)[1]	Maximum Area (m^2)[2]	Max. # strategies desired (actual # strategies allocated using LOCAL)[3]	Service radius for each reuse strategy (m)	Minimum population density (upa)[4]	Minimum separation distance (m)[5]	Is the area currently deficient ?(y/n)[6]	Minimum width (m)[7]	Minimum length (m)[7]	Sunlight conditions
Community Gardens	300	2023	4 (3)	400	25	400	Y	10	30	Full Sun
Neighborhood Farm	300	4046	4 (1)	800	50	800	Y	10	30	Full Sun
Commercial Farm	1200	4046	4 (2)	1000	50	1000	Y	10	120	Full Sun
Orchards	300	4046	4 (4)	1000	50	1000	Y	20	15	Full Sun
Farmers' Markets	300	2023	4 (0)	1000	50	1000	Y	5	60	Any

[1] Minimum contiguous area required for each strategy at a given site
[2] Maximum area desired at a given site for each strategy
[3] Maximum number of strategies desired across the entire area under evaluation
[4] Minimum population density required within the service radius for each strategy to be considered viable (units/hectare)
[5] Minimum separation distance between strategies of the same type
[6] Is the area currently deficient in the corresponding strategy? If no, the strategy is not considered in the analysis.
[7] Minimum width and length of the site to make it useable for the corresponding reuse strategy

Figure 3.1 Overview of prototype decision support tool, known as C-SAP

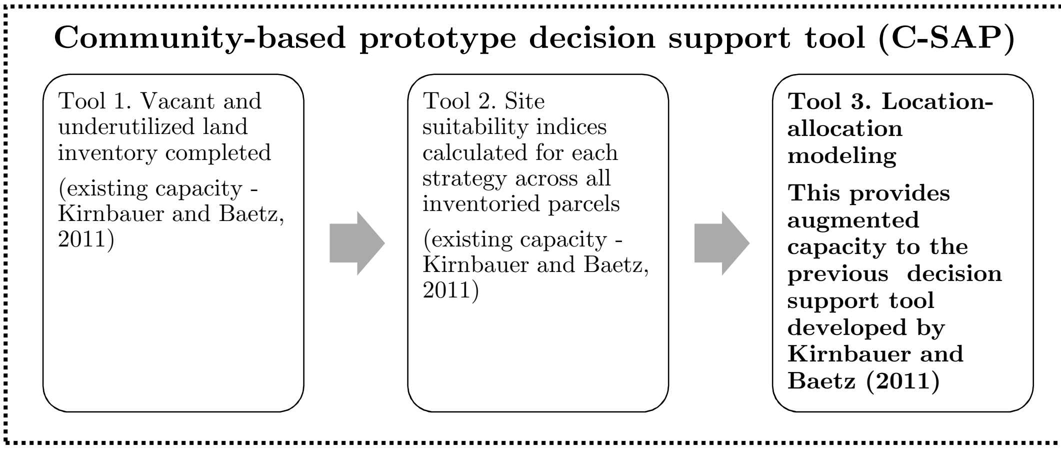

Figure 3.2 Screenshot of the customized GUI used to complete LOCAL

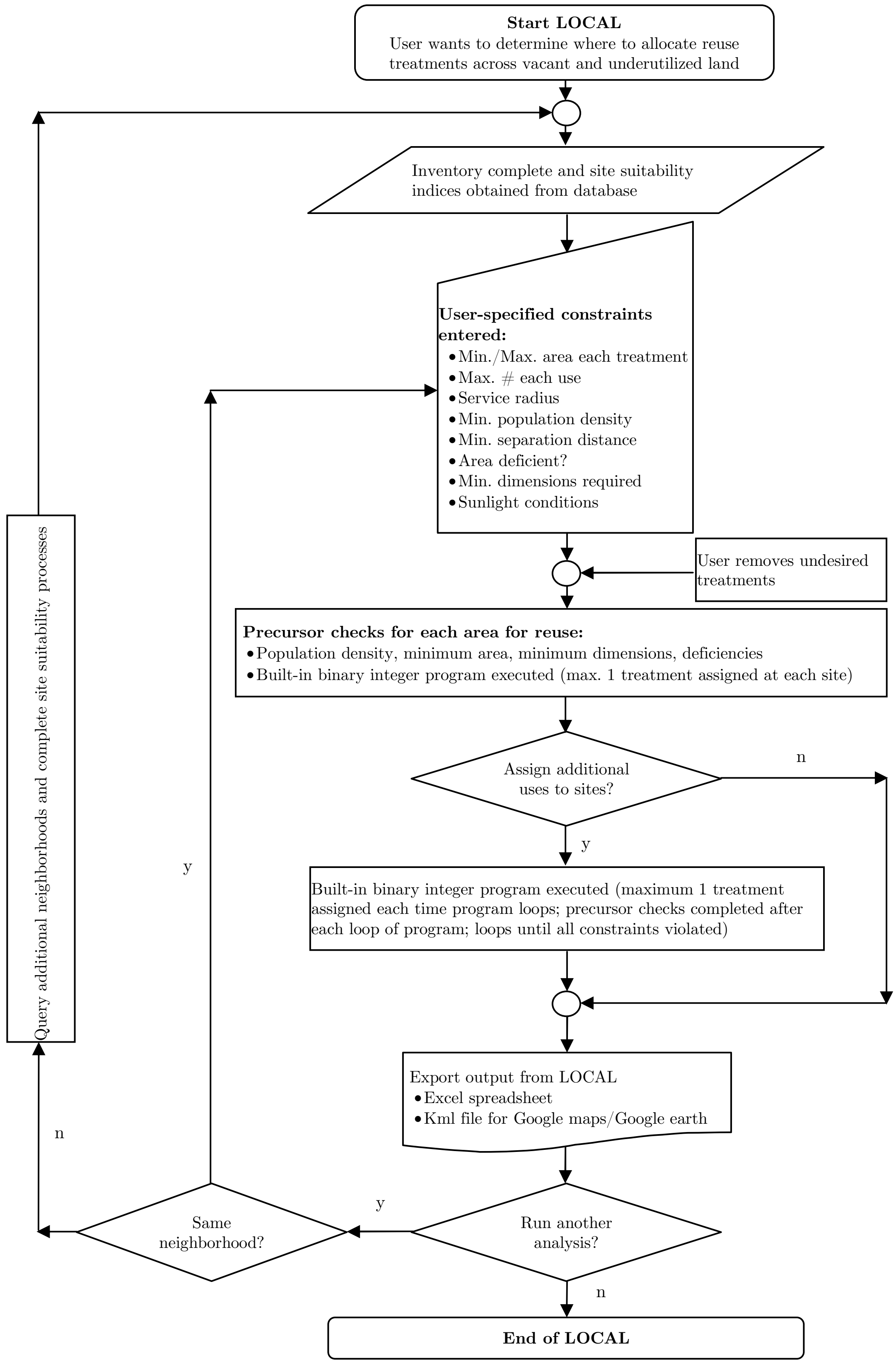

Figure 3.3 Flow diagram for LOCAL

Figure 3.4 Simplified depiction of LOCAL output for Application 1 (most constrained)

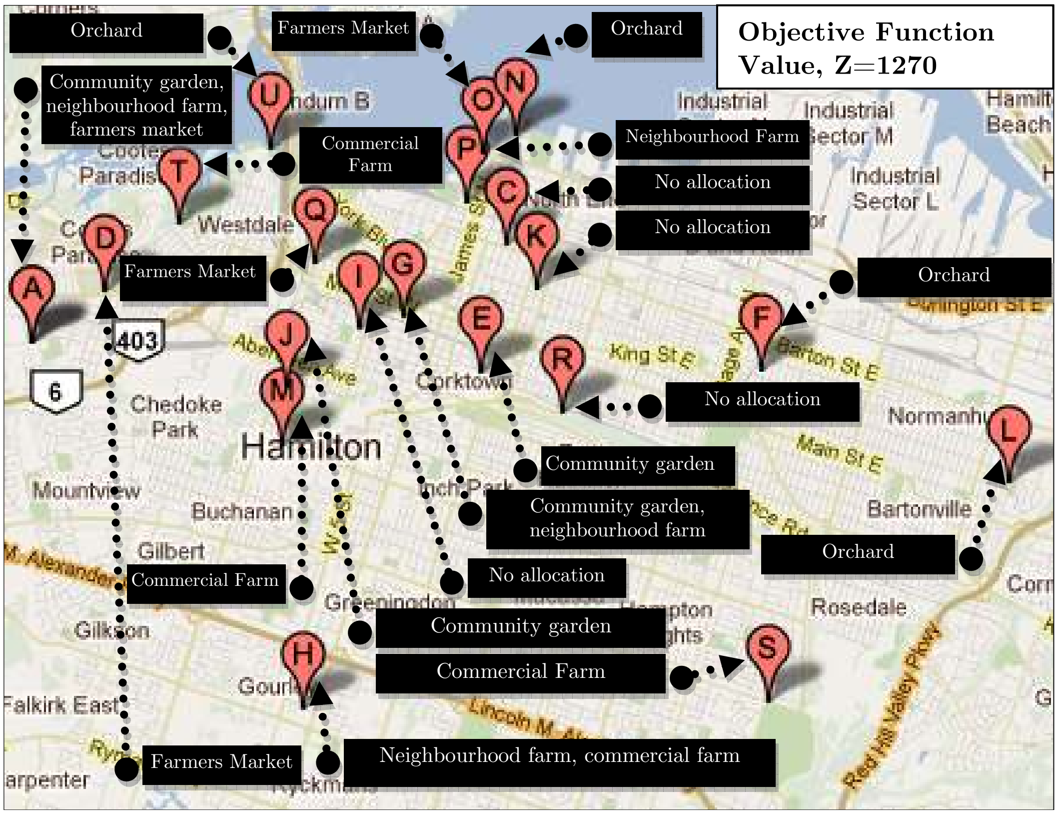

Figure 3.5 Simplified depiction of LOCAL output for Application 4 (least constrained)

Chapter 4. A Prototype Decision Support System for the Designing and Costing of Municipal Green Infrastructure

4.1 Abstract

There is growing momentum across many municipal jurisdictions in North America to reuse public and privately held vacant and underutilized urban land on a temporary to potentially permanent basis for community-based projects. Some uses include urban agriculture, parks and open spaces, and linear connections. Across many jurisdictions, limited resources have been allocated to inventorying and determining the valuation of these urban assets and their potential to contribute to a city's green infrastructure capacity. The purpose of this research is to add an augmented capacity to an existing Microsoft Excel-based decision support tool, developed by Kirnbauer and Baetz (2011a,b). The tool currently captures the condition and location of vacant and underutilized land, calculates the relative suitability of the inventoried land for a suite of reuse strategies, and allows the user to evaluate location-allocation modeling scenarios. The additional capacity introduced herein as 'DECO' provides users with the ability to produce a scaled design drawing for each allocated reuse strategy, and subsequently perform a life cycle cost analysis (LCCA) based on user-defined design scenarios. The application of DECO to an underutilized hydro corridor is presented and discussed herein. DECO has the potential to assist community groups, municipal planning staff and private and public land owners in clarifying the economic trade-offs between various design alternatives, given a specified life cycle length. DECO is designed to allow the user to perform a series of "what-if" scenarios/sensitivity analyses to aid in well-informed green infrastructure investment decisions.

CE Database subject headings: Decision support systems; Life cycles; Urban development; Land management; Infrastructure

Author keywords: Life cycle cost analysis (LCCA); Green infrastructure; Parks and open space; Urban agriculture; Vacant land

4.2 Introduction

A significant challenge for land-use planning authorities is the need to develop and effectively implement policies that deliver urban growth plans, while addressing objectives related to the triple bottom line (environmental, economic, and social impacts). Coupled with this challenge is the need to design urban environments to ensure they provide adequate, accessible and equitable opportunities for recreation, food production, and linear connections, to facilitate continuous productive urban landscapes (Kirnbauer and Baetz, 2011a,b; Viljoen et al., 2005). There is considerable potential in using vacant and underutilized lands, including publicly or privately held residential, industrial, commercial, institutional, agricultural, utility, parks and open space, or remnant lands, to contribute to a city's green infrastructure capacity, on either a temporary or possibly permanent basis (Kirnbauer and Baetz, 2011a). A growing body of literature attempts to address vacant and underutilized land reuse in ways that are productive, cost-effective, safe, and compatible with the urban environment (Cleveland Land Lab, 2008, 2009; de Zeeuw, 2004; Heinegg et al., 2002; Kirnbauer and Baetz, 2011a,b; Rideout, 2010). Urban planners, community advocates, and city officials are recognizing the benefits from recent efforts to integrate a typology of productive uses into the urban landscape (Cleveland Land Lab 2008, 2009; Friedman, 2007; Grimm, 2009; Hohenschau, 2005; Langdon, 2008; Viljoen et al., 2005). The issue of community food security is at the forefront of many policy agendas (Brown and Carter, 2003), with a particular focus on vulnerable, at-risk populations (Hamilton Food Share, 2010). This is further driving a movement across many cities to reuse vacant and underutilized urban lands for food production purposes.

Kirnbauer and Baetz (2011a) present a prototype community-based decision support tool, known as C-SAP, to assist community groups in completing a vacant and underutilized land inventory based on six umbrella criteria: neighborhood quality, developability potential, visual quality, compatibility with the urban environment, transportation options, and vulnerable population characteristics. C-SAP employs a binary scoring methodology for the vacant and underutilized land inventory process and the analytic hierarchy process (AHP) for the calculation of a set of relative, normalized site suitability indices for each treatment across all inventoried sites (Kirnbauer and Baetz, 2011a). The prototype tool allows the user to evaluate up to fifteen community-based reuse strategies at each inventoried site. An additional capacity to C-SAP, described in Kirnbauer and Baetz (2011b), uses a multi-objective binary integer program formulation for the location-allocation of reuse strategies across the inventoried sites.

Allouche and Freure (2002) states that the aim of decision-making processes is to identify the course of action that is most beneficial within predetermined economic, time, and resource constraints. Life cycle cost analysis (LCCA) software is emerging in many industries to provide quick and reliable estimates for the total costs of infrastructure management decisions, thereby allowing users to perform cost comparisons and risk assessments for their investment alternatives (Rahman and Vanier, 2004). The following paper introduces an additional capacity to C-SAP (Kirnbauer and Baetz, 2011a,b), hereafter referred to as DECO, that provides the user with the necessary tools to design a vacant or underutilized land reuse plan and subsequently perform an LCCA on a user-specified set of design alternatives. This can be repeated across varying life cycle lengths, producing categorized estimates of life cycle costs, expressed as present values (or "base year" values). While many decision support applications limit the user's ability to access or understand little about the internal calculations of the system (often deemed to be "black boxes"), DECO was developed to be transparent, understandable, and adaptable by users, to increase the potential usability and application of the tool.

DECO is used to design and cost two urban agricultural design alternatives, both located on an underutilized 10-acre hydro corridor application. Each design was evaluated using 4 different life cycle lengths to assess the impact of alternative land lease agreement lengths on the life cycle costs for each alternative. The sensitivity of the preferred alternative to changes to materials selection and maintenance frequency is also discussed herein. While applied to a municipality in Ontario, Canada, with reasonable modifications, this prototype tool could be used virtually anywhere across the globe.

4.3 Life Cycle Cost Analysis (LCCA) as a Decision Support Tool for Managing Municipal Infrastructure

Life cycle cost analysis is a method for evaluating the total economic costs of competing investment decisions, by analyzing initial costs and discounted future expenditures for projects with a specified level of benefits, that are assumed to be equal among project alternatives (Rahman and Vanier, 2004; U.S. Department of Transportation [DOT], 2002). LCCA is defined as the total cost of an asset, represented in present value (PV) terms, including capital (e.g. land purchase costs, legal services, design fees, construction costs, lost opportunity costs), ownership (e.g. energy, maintenance, repair, and replacement costs), and social (e.g. disruptions of services) costs, evaluated over a user-specified life cycle (Rahman and Vanier, 2004). Figure 4.1 depicts the processes employed in LCCA. While LCCA reveals the lowest cost alternative, this may not necessarily be the alternative selected by the user, as risk, budget, political, or environmental considerations may influence the selection process (Rahman and Vanier, 2004).

Lemer (1999) defines municipal infrastructure as a complex technical system that delivers valuable and essential services to the public. It is therefore essential that researchers and infrastructure managers develop tools and techniques to determine asset condition and predict remaining service life, and prioritize and develop maintenance and capital renewal schedules to sustain adequate provisions for services (Vanier and Rahman, 2004). While the principles of LCCA have been used in decision-making since the 19th century (Transportation Research Board, 2003), it has emerged in sectors including aerospace, defense, transportation, and energy (DOT, 1996, 1998; Chewning and Moretto, 2000). The Institute for Research in Construction (IRC) undertook a 3-year study on municipal infrastructure investment planning. As part of this research, Canadian infrastructure managers and owners were surveyed, and it was revealed that: (1) 91% of respondents want decision support tools to help manage their assets, (2) 24% identified LCCA as a potentially useful decision support tool, and (3) 70% stated that they believe LCCA could decrease high levels of deferred maintenance (Rahman and Vanier, 2004). A growing body of literature is demonstrating that LCCA has effectively aided managers in a variety of infrastructure management sectors, when tasked with comparing and selecting the most appropriate alternative given budget restrictions on capital investment, maintenance, and renewal decisions (Rahman and Vanier, 2004). However, in completing the literature review for this paper, no applications of LCCA were identified for evaluating capital investments related to municipal green infrastructure (e.g. parks and open space, urban food production), despite the potentially high capital and operational costs of these public assets/amenities. This manuscript presents a systematic design methodology and prototype decision support tool for the evaluation of green infrastructure investments. While this application was developed to assist green infrastructure managers and operators, it was also designed to serve the growing need of community groups to evaluate design alternatives and determine feasible, low-cost, redevelopment options for vacant and underutilized land in their neighbourhoods (which may be temporary or permanent in nature).

4.4 DECO Decision Support System Design Methodology

There are two methods employed in LCCA to address uncertainties: risk analysis, which employs the probabilistic approach, or sensitivity analysis, which uses the deterministic approach (Ozbay et al., 2003). The deterministic approach assigns each input variable a fixed, distinct value in both time (e.g. life cycle length = 30 years) and cost – the value that is most likely to occur for each input parameter, and is typically based on historical evidence or professional judgment (DOT, 2002; Rahman and Vanier, 2004). Limitations of both approaches are well documented (Christensen et al., 2005; DOT, 2008; Rahman and Vanier, 2004). While the deterministic approach requires significant data input, it is widely viewed as an effective decision support tool if based on accurate data, comprehensive research, and logical processes, and if it is packaged in a user-friendly tool (Rahman and Vanier, 2004). DECO employs a deterministic approach to LCCA, where input data are based on historical evidence and professional judgment, the computation process is straightforward and quasi-automated, and a sensitivity analysis can be completed by the user to identify the variables that make the largest difference in the result. The decision to use a deterministic approach was based predominantly on the combination of intended end-users for DECO, being municipal decision-makers and/or community groups (lay persons). In developing a piece of scientific software (and compiling the related data) that was accessible/low-cost, transparent, understandable (interpretation of inputs/outputs), easy to use (user interface with software), and readily adaptable, the deterministic approach presented the most rational option.

The life cycle cost analysis developed for municipal green infrastructure in DECO was modeled after the life cycle phases for municipal infrastructure presented in Rahman and Vanier (2004), as shown in Figure 4.2. While these phases were developed for "hard" civil engineering infrastructure elements, these processes are also applicable to "soft" or "green" infrastructure elements/systems, and are of particular importance when making capital investment decisions for the temporary reuse of vacant and underutilized land. The present value (PV) method is used in DECO's LCCA model to bring all future expenditures back to a present value, using the constant dollars method and employing a user-specified discount rate. The present value calculation used in DECO is shown in equation 4.1.

Present Value Calculation (adapted from Dell'lsola and Kirk, 2003):

$$PV = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t} + \sum_{t=0}^{n} \frac{S_t}{(1+i)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+i)^t} \tag{4.1}$$

Where:
PV = Present Value of life cycle costs
C_t = sum of all costs occurring in year t (e.g. acquisition costs + capital costs + maintenance costs + renewal costs)

S_t = sum of all salvage values occurring in year t
R_t = sum of all revenue values occurring in year t
t = number of years in the future when the cost will be incurred
n = total number of years under analysis (life cycle length)
i = real discount rate (nominal interest rate - expected inflation)

Remaining service life (RSL) was not included in the life cycle cost analysis in DECO. While this would typically lead to a bias toward one alternative over another, RSL is only included in LCCA when alternatives remain in operation after the end of the life cycle length analyzed (DOT, 2002). As DECO is intended for the temporary reuse of vacant and underutilized land (as a holding strategy to stabilize and revitalize neighbourhoods, until higher-order development occurs), it was assumed that the project would be decommissioned at the end of the analysis period (with materials being salvaged, where appropriate). While it may be important to include social costs, when completing a comprehensive LCCA, there is a significant lack of information on costs related to service disruption, business loss, customer compensation, environment, and health (Rahman and Vanier, 2004), and as such, these costs have not been included in DECO. The process flow diagram for DECO is depicted in Figure 4.3. There are 7 main components of the decision support tool:

- Step 1: Creating a scaled, generic design drawing
- Step 2: Amending existing cost data/adding new cost data
- Step 3: Mapping the cost data to layers on the design drawing
- Step 4: Generating a range of alternatives for analysis
- Step 5: LCCA performed (automated)
- Step 6: Sensitivity analysis (iteration: return to Step 4)
- Step 7: Exporting/importing design drawings and cost data

DECO is a customized scientific software application, developed using the Visual Basic for Applications (VBA) programming environment in Microsoft Excel®. A customized graphical user interface has been created to guide the user through the steps required for the completion of DECO. While all built-in data in DECO is adjustable/customizable, default data values exist within the tool, and were obtained from a variety of sources: the capital and maintenance cost data were obtained from RSMeans (2011), maintenance schedules for a variety of maintenance modes (high and low frequency modes) were adapted from Asheville Parks and Recreation (2008), service life data for various materials were obtained from Dell'lsola and Kirk (2003), while the design layers used in the graphical portion of the tool were adapted from Doull (2011). Cost data can be added using four units of measure: length, area, volume, or per item/unit. It is important to note that the user should review and amend the cost data on a regular basis to ensure that the life cycle cost analysis is based on current, reliable data. City Location Factors are used to adjust the life cycle costs for cities within North America (RSMeans, 2011).

The first step in completing DECO involves the completion of a scaled, generic site design drawing for each vacant and underutilized site under analysis. A series of default design layers have been included in a library in DECO, with the built-in capacity to create and add new layers to the library. Prior to initiating the life cycle cost analysis routine, the user is required to map all design layers to the costing data and verify that the capital, maintenance, and revenue costs have been entered correctly, and confirm that a maintenance mode is selected for each alternative analyzed.

For each maintenance cost item in DECO, the user is required to specify the frequency of maintenance for six different maintenance modes. These modes are described as follows (Asheville Parks and Recreation, 2008):

- Mode I - Entails state of the art maintenance applied to a high quality, diverse landscape. High traffic urban areas such as public squares, malls, high coverage parks.

- Mode II - Entails high level maintenance associated with well-developed park areas with reasonably high usage.

- Mode III - Entails moderate level maintenance associated with moderate or low development of parks, moderate or low levels of usage.

- Mode IV - Entails low level of maintenance associated with undeveloped or remote parks with low usage.

- Mode V - Entails maintenance for natural areas associated with possible recreation.

- Mode VI - Entails maintenance of minimum level for undeveloped properties.

Once a set of design alternatives (i.e. materials selection choices) have been specified in DECO, the LCCA can be initiated. While this routine is predominantly automated, the user will be prompted for inputs, as required. For example, the user will be prompted for the life cycle cost period. In addition to this, the user will be prompted if a cost is not mapped to an existing layer on the design page. In this case, the user will be asked to verify that this is correct, and if correct, DECO will prompt the user for the dimensions and units (e.g. length or depth) of the design element, as not all costs need to have a costing layer associated with them. Finally, if the life cycle for the design element is greater than the life cycle period under analysis, the user will be prompted for a salvage value (which requires the user to specify a value as a percentage of the original capital cost value for the corresponding item). Any revenue generated from a reuse strategy can be added in DECO (and subsequently used to offset the costs in the LCCA). When the LCCA is complete, an itemized list of present value capital, maintenance and revenue costs is presented in a spreadsheet, for each design alternative under consideration. The design drawing, associated cost data, as well as the summary of present value outcomes for each design alternative, can be exported as a separate Excel file. This file can be imported into DECO, amended and further sensitivity analyses performed at any future point in time.

Given that DECO was developed using the Visual Basic for Applications programming language in Microsoft Excel®, some of the notable strengths include its user-friendliness, adaptability, and maintainability. The prototype tool is predominantly automated, and generates both a detailed and simplified summary of the LCCA outcomes quickly. Figure 4.4 depicts a summary of the potential analyses that can be initiated by the user. DECO has the potential to aid decision-makers in making well-informed decisions for investment in municipal green infrastructure.

4.5 Application of Decision Support Tool

DECO can be used to design and cost potential reuse strategies (design alternatives) for vacant and underutilized urban land. In the application discussed herein, an assumption was made that land leasing costs were not incurred, as a precedent exists for using these hydro corridor lands (a few hundred metres north of the application site) for urban agriculture purposes (J. Chapman, personal communication, December 16, 2011). The discount rate employed in this application was 3%.

Two design alternatives were developed to evaluate the potential for using a 10-acre underutilized hydro corridor site for urban agriculture purposes: (1) a raised planting bed design and (2) a traditional in-ground planting design (depicted in Figure 4.5). In the raised planting bed scheme, 360 raised planters, measuring 10-feet long by 5-feet wide by 2-

feet high were evaluated. Each bed consisted of rot-resistant wood, with geo-textile lining and nutrient-rich soil medium. In the in-ground planting design, 66 rows measuring 5-feet wide by 100-feet long, with alternating 4-feet wide, 4" deep, wood-chipped pathways were implemented. The area occupied by planting beds, or alternatively, planting rows, is approximately 1.4 acres. The remaining land comprised several common elements in both designs, including an active and passive parkland feature (with play structure), a passive parkland feature, including a mix of deciduous and coniferous trees, orchards on the west and south perimeter (pear, apple, apricot, raspberry), trails, perennial beds, benches, garden sheds, bike racks, garbage receptacles, and compost bins.

Recognizing that these are active utility lands, requiring routine maintenance, a grid of 10-feet wide, 4" deep, wood-chipped pathways were included to assist maintenance vehicles/personnel in traversing the land in a manner that would provide access to the hydro structures, while having minimal impact on the growing space and parkland features included in each design. Given the proximity of the hydro lands site to an arterial roadway (several hundred metres to the north), an elementary school, secondary school, post-secondary institution, places of worship, and a variety of low, medium, and high density residential uses, this location was deemed to be a potentially valuable focal point and outdoor learning centre for the community, serving as a mixed-use example of how to effectively reuse underutilized urban land. A mix of uses were employed in the design, in an effort to generate continuous activity and "eyes-on-the-street" throughout the day, fostering strong community relationships and safe neighbourhoods.

The two alternatives were designed using DECO and subsequently compared using LCCA. Two sensitivity analyses were explored for each design (referred to as S1 and S2 in the tables presented herein): (i) the inclusion/exclusion of capital and maintenance costs for two different maintenance modes/frequencies and (ii) alternative pathway materials selection. The objective of these applications is to better understand the cost-effectiveness of the two design alternatives, and to determine whether changes to the lease length, maintenance modes, or pathway materials produce different preferred alternatives.

Four life cycle lengths were analyzed for each of the design alternatives: 5, 10, 15, and 20 years, as it is important to understand the impact of lease length agreements on the life cycle cost outcomes for the alternatives under analysis.

Representative capital and maintenance expenditures and a range of maintenance regimes (high and low frequency maintenance schedules) were evaluated for this application; however, detailed output tables have not been presented in this manuscript due to space restrictions. Revenue and salvage streams, while potential cost off-setting streams in DECO, were not included in any of the applied scenarios, thus making the outcomes discussed in Section 5 conservative LCCA estimates.

4.6 Discussion of Results

Table 4.1 and Table 4.2 summarize the output from DECO for scenarios S1 and S2 (Cases 1-9). The in-ground planting scheme resulted in the lowest cost alternative in 28 of 36 applications. Case 1 includes both capital and maintenance costs, and was evaluated using a high-frequency maintenance schedule (Maintenance Mode I). Case 2 includes capital costs only, and assumes that maintenance costs will not be incurred, based on a community-supported stewardship model for the parcel. Case 3 is evaluated using high-frequency maintenance, and assumes that all capital expenditures will be donated. Case 4 includes both capital and maintenance costs, and uses a reduced maintenance frequency schedule (Maintenance Mode IV). Case 5 was evaluated using low-frequency maintenance, and assumes that capital expenditures are donated (same as Case 3, but employs a reduced maintenance frequency).

Case 5 represented the least expensive scenario evaluated for Scenarios S1 and S2 (Cases 1-9). Raised planting beds were the least expensive alternative in Cases 3 and 5, for all evaluated life cycle lengths, when compared to the in-ground, cultivated planting rows scenario. Case 3 produced life cycle costs of $CAD 337,000 to $CAD 1,258,000, while case 5 produced life cycle costs of $CAD 134,000 to $CAD 478,000 for the raised planting bed design. Maintenance costs for Case 3 are 151% to 163% more expensive than Case 5 due to the high frequency maintenance schedule employed in Case 3.

In total, 15 out of 20 maintenance items were reduced on average 64% from Case 3 to Case 5 to achieve the above-noted cost reductions. This demonstrates the significance of maintenance costs (and the potential for stewardship-based maintenance models) when evaluating green infrastructure alternatives, as significant costs savings can be realized by reducing the frequency of maintenance. Alternatively, by applying specific treatments before distress occurs, preservation activities could potentially delay the onset of deterioration and increase the useful life of infrastructure elements (DOT, 2002). The impact of increased maintenance on the increasing service life of various infrastructure elements was not analyzed or presented within this paper; however, it should be noted that DECO could be used for carrying out an analysis of this nature.

For the in-ground planting design, the most expensive alternative, Case 1, was approximately 413%, 289%, 242%, and 250% more expensive than

Case 5, for life cycle lengths of 5, 10, 15, and 20 years, respectively, thus revealing the significant savings achievable by obtaining donations for capital cost items. When comparing Cases 1 and 4 for in-ground plantings, in which capital and maintenance costs were included but different maintenance modes were applied, the resulting LCCA revealed that the more expensive alternative (Case 1) was approximately 25%, 39%, 48%, and 47% more expensive, for life cycle lengths of 5, 10, 15, and 20 years, respectively. Capital costs for Case 1 (Maintenance Mode I) comprise 60%, 46%, 38%, and 39% of the total cost for life cycle lengths of 5, 10, 15, and 20 years, respectively. Capital costs for Case 4 (Maintenance Mode IV) comprise 75%, 64%, 57%, and 58% of the total cost for life cycle lengths of 5, 10, 15 and 20 years, respectively. As anticipated, this reveals that capital costs comprise a larger percentage of the total life cycle costs when the maintenance schedule is reduced. Similar results are obtained when evaluating the raised bed planting cases.

When comparing the in-ground planting scheme to the raised bed planting scheme for Case 1 (high-level maintenance; capital and maintenance costs included), raised beds were approximately 29%, 14%, 31%, and 22% more expensive than the in-ground planting design for life cycle lengths of 5, 10, 15, and 20 years, respectively. These results are useful for decision-makers in better understanding the financial implications of applying additional safety requirements to ensure that human health concerns are adequately addressed (e.g. raised beds as a solution to mitigate contact with potentially contaminated soil).

Table 4.2 summarizes the results obtained from evaluating the impact of 4 different pathway materials on the total LCC outcome for the two reuse strategies. In all cases (6-9), Maintenance Mode IV was applied and both capital and maintenance costs were included. The alternatives are ranked as follows (lowest cost to most expensive): Dirt Path, Ceramic Chips, Pea Gravel, and Woodchips. In all cases, the in-ground planting design produced the least expensive alternative. When comparing the least to most expensive alternative, it was found that the most expensive alternative, the wood-chipped path system, was 92%, 90%, 72%, and 65% more expensive than the alternative that utilized a dirt path system for life cycle lengths of 5, 10, 15 and 20 years, respectively. This demonstrates the importance of understanding the implications of lease length, as short-term leases may result in a greater disparity between life cycle costs that may dampen as the lease length increases. While ceramic chips and pea gravel represented the next, lowest-cost alternatives, and while these alternatives were remarkably close in terms of total LCCs, this was not obvious to the user during the materials selection process in DECO. DECO provides the flexibility to enter costs for materials, labour and equipment using four different units of measurement.

4.7 Conclusions

Municipal infrastructure managers are tasked with allocating budgets for capital investments, maintenance, and replacement of infrastructure elements. LCCA can be utilized to investigate design and material alternatives, reducing both initial construction and long-term preventive maintenance costs.

This paper describes an augmentation to an existing prototype decision support tool, known as C-SAP. C-SAP contains 3 tools for identifying and inventorying the location and condition of vacant and underutilized land, determining the relative suitability of each identified site for a suite of parks and open space, urban agriculture, and stormwater management uses, and a method for allocating reuse strategies to the inventoried land (Kirnbauer and Baetz, 2011a, 2011b). The augmented capacity discussed within this manuscript presents a systematic approach to LCCA for municipal green infrastructure capital investment decisions. It is recommended that an approach similar to the one presented herein should be adopted as a best practice for strategic green infrastructure management.

The prototype decision support tool introduced in this manuscript was subsequently applied to an underutilized hydro corridor case study application. Two alternative designs were developed for urban agriculture applications, and compared using LCCA across 4 life cycle lengths: raised planting beds, and in-ground planting rows. Two sensitivity analysis scenarios were explored for each design: (i) the inclusion/exclusion of capital and maintenance costs for two different maintenance modes, and (ii) alternative pathway materials. DECO was able to generate scenarios quickly. The analyses carried out revealed that the raised bed planting scenario provided the least expensive design alternative, when all capital and replacement cost expenditures were donated, and the municipality provided the maintenance. This outcome was true for both the high and low-level maintenance frequencies analyzed. For all other cases analyzed, including the inclusion of all capital and replacement cost expenditures (and the evaluation of various pathway materials) the in-ground planting scheme provided the least expensive design alternative. This type of analysis revealed the cost-saving benefits that could be achieved by receiving capital and replacement cost donations, applying a reduced maintenance level coupled with a potential stewardship-based model (to make-up the balance of the required maintenance). This configuration brought the life-cycle costs for the 10-acre site with 360 raised planting beds to approximately $CAD 478,000, over a 20-year life cycle. There is a precedence for this community-based maintenance framework within the City of Hamilton, Ontario with plans to further move toward a stewardship-based model for community groups seeking to use city-owned land on a temporary basis for community gardens (City of Hamilton, 2010).

The decision support tool, including DECO, and accompanying files are available for no-cost downloading off of the McMaster University Sustainable Communities Research Group website, located at: www.eng.mcmaster.ca/civil/sustain/downloads.html.

4.8 Acknowledgements

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4.9 References

Allouche, E.N. and P. Freure. (2002). “Management and Maintenance Practices of Storm and Sanitary Sewers in Canadian Municipalities.” ICLR Research, Paper Series No. 18.

Asheville Parks & Recreation (2007). “Parks Maintenance Schedule and Operations Manual.” Asheville, NC.

Brown, K. H., Carter, A. (2003). “Urban agriculture and community food security in the United States: Farming from the city centre to the urban fringe, A Primer Prepared by the Community Food Security Coalition’s North American Urban Agriculture Committee.” Amherst, MA.

Chewning, I.M. and S.J. Moretto. (2000). “Advances in Aircraft Carrier Life Cycle Cost Analysis for Acquisition and Ownership Decision-Making.” *Naval Engineers Journal*, 112(3), 97-110.

Christensen P.N., Sparks, G.A., and Kostuk K.J. (2005). “A method-based survey of life cycle costing literature pertinent to infrastructure design and renewal.” *Canadian Journal of Civil Engineering*, 32(1), 250–259.

Cleveland Land Lab. (2008). “Re-imagining a more sustainable Cleveland: Citywide strategies for reuse of vacant land.” Prepared by the Cleveland Land Lab at the Cleveland Urban Design Collaborative, Kent State University. Cleveland, OH.

Cleveland Land Lab. (2009). "Re-imagining Cleveland: Vacant land reuse pattern book." Prepared by the Cleveland Land Lab at the Cleveland Urban Design Collaborative, Kent State University. Cleveland, OH.

Dell'lsola, A. J. and Kirk, S. J. (2003). "Life Cycle Costing for Facilities." Reed Construction Data, Kingston, MA.

de Zeeuw, I. H. (2004). "The development of urban agriculture; some lessons learnt." Keynote paper presented at the Urban Agriculture, Agro-tourism and City Region Development International Conference, Beijing.

Doull, D. (2011). Garden Planner 3 [Software]. Retrieved from http://www.smallblueprinter.com/garden/planner.html.

Friedman, A. (2007). "Farming in suburbia." *Open House International*, 32(1), 7-15.

Grimm, J. (2009). "Food urbanism: a sustainable design option for urban communities." Prepared by the Landscape Architecture and Environmental Studies Department, Iowa State University. Ames, IA.

Hamilton, City of (2010). "Community Garden Policy (PW10044)." Hamilton, ON.

Hamilton Food Share (2010). "Hamilton hunger count 2010." Hamilton, ON.

Heinegg, A., Maragos, P., Mason, E., Rabinowicz, J., Straccini, G., & Walsh, H. (2002). "Soil contamination and urban agriculture: A practical guide to soil contamination issues for individuals and groups." Prepared by McGill School of Environment. Montreal, QB.

Hohenschau, D. (2005). "Community food security and the landscape of cities." Master of Landscape Architecture thesis, University of British Columbia, Vancouver, BC.

Kirnbauer, M. C., Baetz, B. W. (2011a). "A prototype community-based planning tool for evaluating site suitability for the temporary reuse of vacant and underutilized land." Working Report, Prepared by the Department of Civil Engineering, McMaster University. Hamilton, ON.

Kirnbauer, M. C., Baetz, B. W. (2011b). "Allocating urban agricultural reuse strategies to inventoried vacant and underutilized land." *J. Env. Informatics.,* in press.

Langdon, P. (2008). “Newest eco-development model: ‘Agricultural urbanism’.” *New Urban News*, 13(4), 1; 8-10.

Lemer, A.C. (1999). “Building Public Works Infrastructure Management Systems for Achieving High Return on Public Assets.” *Public Works Management and Policy*, 3(3), 255-272.

Ozbay, K., Jawad, D., Parker, N. A., Hussain, S. (2003). “Guidelines for Life Cycle Cost Analysis. Report No FHWA-NJ-2003-012.” Piscataway, NJ.

Rahman, S. and Vanier, D. J. (2004). “Life cycle cost analysis as a decision support tool for managing municipal infrastructure. Report NRCC-46774.” Prepared by the Institute for Research in Construction (IRC), National Research Council Canada. Ottawa, ON.

Rideout, K. (2010). “Urban agriculture: Issues for public and environmental health.” [Powerpoint Slides]. Prepared by the National Collaborating Centre for Environmental Health, School of Environmental Health Seminar Series, University of British Columbia. Vancouver, BC.

RSMeans (2011). “Site Work & Landscape Cost Data.” (30^{th} ed.). Reed Construction Data, Norwell, MA.

Transportation Research Board (2003). “Bridge Life Cycle Cost Analysis. NCHRP Report 483.”

U.S. Department of Transportation. (1996). “Life Cycle Costing Manual for the Federal Energy Management Program. NIST Handbook 135.” National Institute of Standards and Technology, Gaithersburg, MD.

U.S. Department of Transportation (1998). “Life Cycle Cost Analysis in Pavement Design. Report No. FHWA-SA-98-079.” Prepared by the Federal Highway Administration.

U.S. Department of Transportation. (2002). “Life-Cycle Cost Analysis Primer.”

U.S. Department of Transportation. (2008). “Life Cycle Cost Analysis for Pavement Type Selection.”

Vanier, D.J. and Rahman, S. (2004). “MIIP Report: Survey on Municipal Infrastructure Assets. Report B-5123.2.” Prepared by the Institute for

Research in Construction (IRC), National Research Council Canada. Ottawa, ON.

Viljoen, A., Bohn, K., and Howe, J. (2005). "CPULs: Continuous Productive Urban Landscapes." Elsevier, Burlington, MA.

Table 4.1 Impact of capital costs, maintenance costs, and maintenance modes on LCCs

Life Cycle Length	Present Values for Scenario S1				
	Case 1	**Case 2**	**Case 3**	**Case 4**	**Case 5**
Design A: In-ground (planting rows, separated by woodchips)					
5 years	$CAD 913,000	$CAD 547,000	$CAD 366,000	$CAD 725,000	$CAD 178,000
10 years	$CAD 1,390,000	$CAD 640,000	$CAD 750,000	$CAD 997,000	$CAD 357,000
15 years	$CAD 1,753,000	$CAD 671,000	$CAD 1,082,000	$CAD 1,183,000	$CAD 512,000
20 years	$CAD 2,258,000	$CAD 890,000	$CAD 1,368,000	$CAD 1,536,000	$CAD 646,000
Design B: Raised Beds (5' wide x 10' long x 2' high, wood with geo-textile lining)					
5 years	$CAD 1,174,000	$CAD 837,000	$CAD 337,000	$CAD 971,000	$CAD 134,000
10 years	$CAD 1,591,000	$CAD 900,000	$CAD 691,000	$CAD 1,166,000	$CAD 266,000
15 years	$CAD 2,290,000	$CAD 1,295,000	$CAD 995,000	$CAD 1,675,000	$CAD 379,000
20 years	$CAD 2,749,000	$CAD 1,490,000	$CAD 1,258,000	$CAD 1,968,000	$CAD 478,000

Table 4.2 Impact of pathway materials alternatives on LCCs

Life Cycle Length	Present Values for Scenario S2			
	Case 6 (Dirt Path)	**Case 7 (Pea Gravel)**	**Case 8 (Ceramic Chips)**	**Case 9 (Woodchips)**
Design A: In-ground (planting rows, separated by woodchips)				
5 years	$CAD 454,000	$CAD 531,000	$CAD 528,000	$CAD 872,000
10 years	$CAD 639,000	$CAD 836,000	$CAD 829,000	$CAD 1,215,000
15 years	$CAD 831,000	$CAD 1,130,000	$CAD 1,120,000	$CAD 1,432,000
20 years	$CAD 1,115,000	$CAD 1,436,000	$CAD 1,426,000	$CAD 1,839,000
Design B: Raised Beds (5' wide x 10' long x 2' high, wood with geo-textile lining)				
5 years	$CAD 786,000	$CAD 839,000	$CAD 837,000	$CAD 1,072,000
10 years	$CAD 922,000	$CAD 1,056,000	$CAD 1,051,000	$CAD 1,315,000
15 years	$CAD 1,434,000	$CAD 1,638,000	$CAD 1,631,000	$CAD 1,845,000
20 years	$CAD 1,681,000	$CAD 1,900,000	$CAD 1,893,000	$CAD 2,175,000

Figure 4.1 Life Cycle Cost Analysis (LCCA) steps (DOT, 2002)

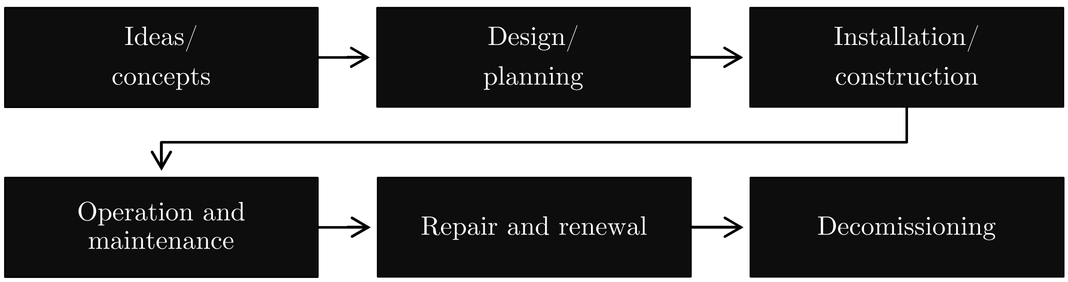

Figure 4.2 Life Cycle (LC) phases for municipal infrastructure (Rahman and Vanier, 2004)

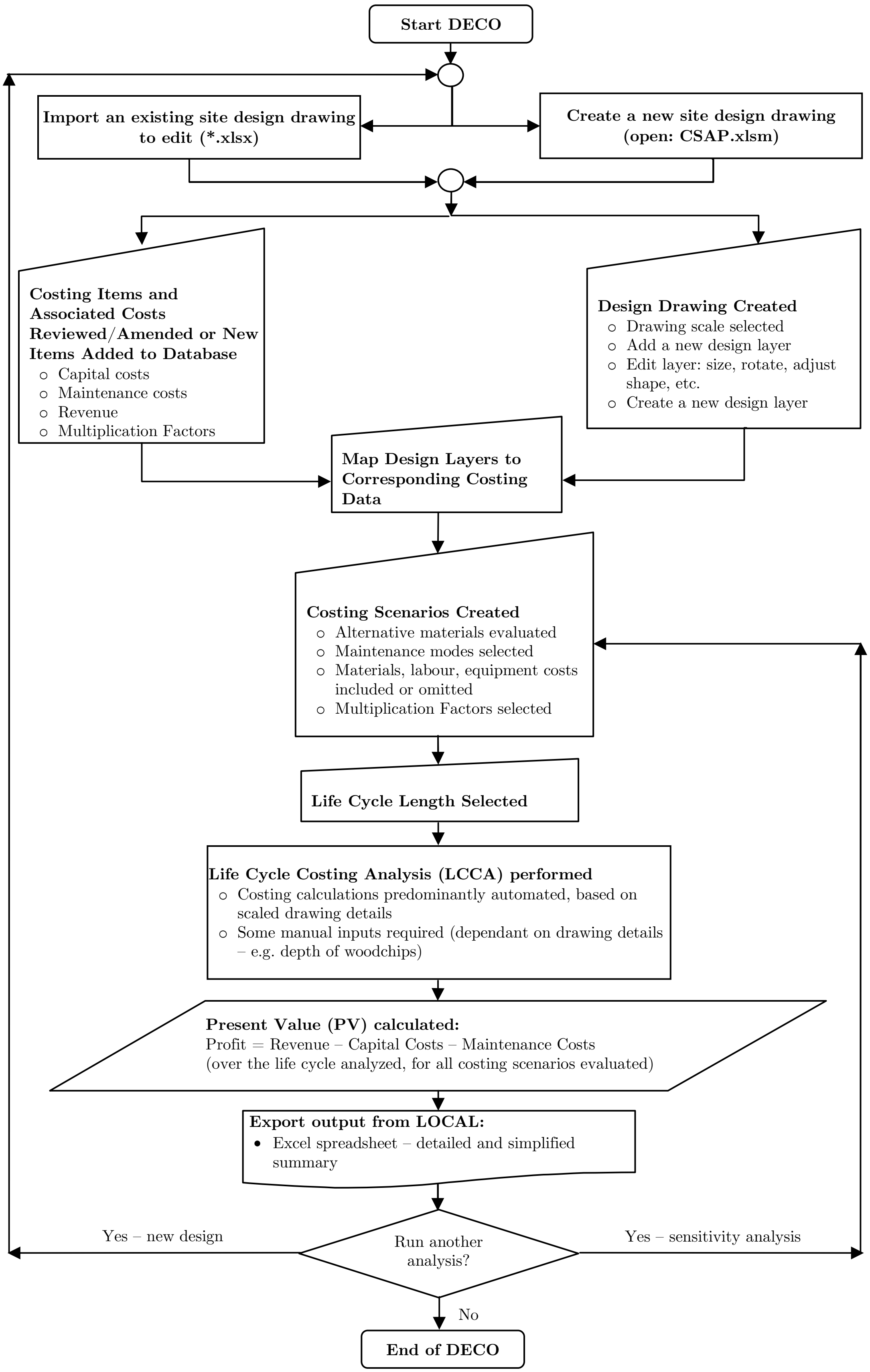

Figure 4.3 Process flow diagram for DECO

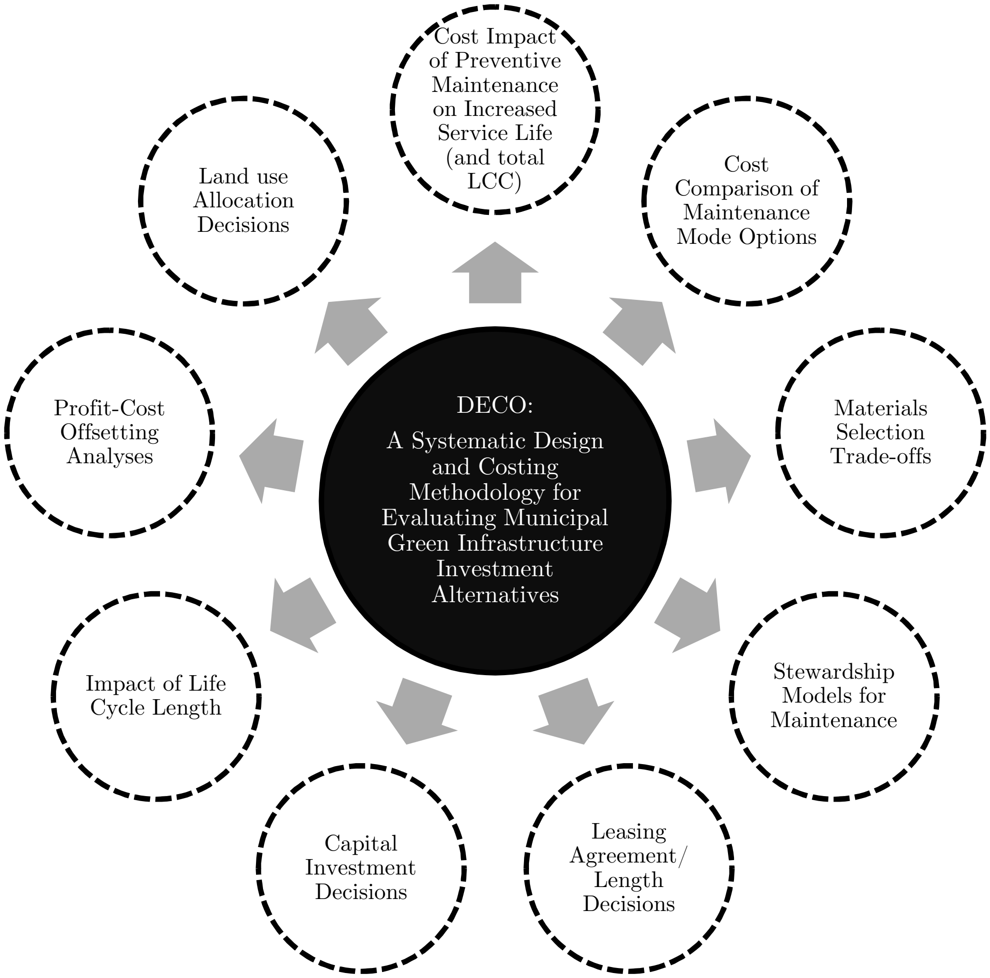

Figure 4.4 Analysis opportunities using DECO

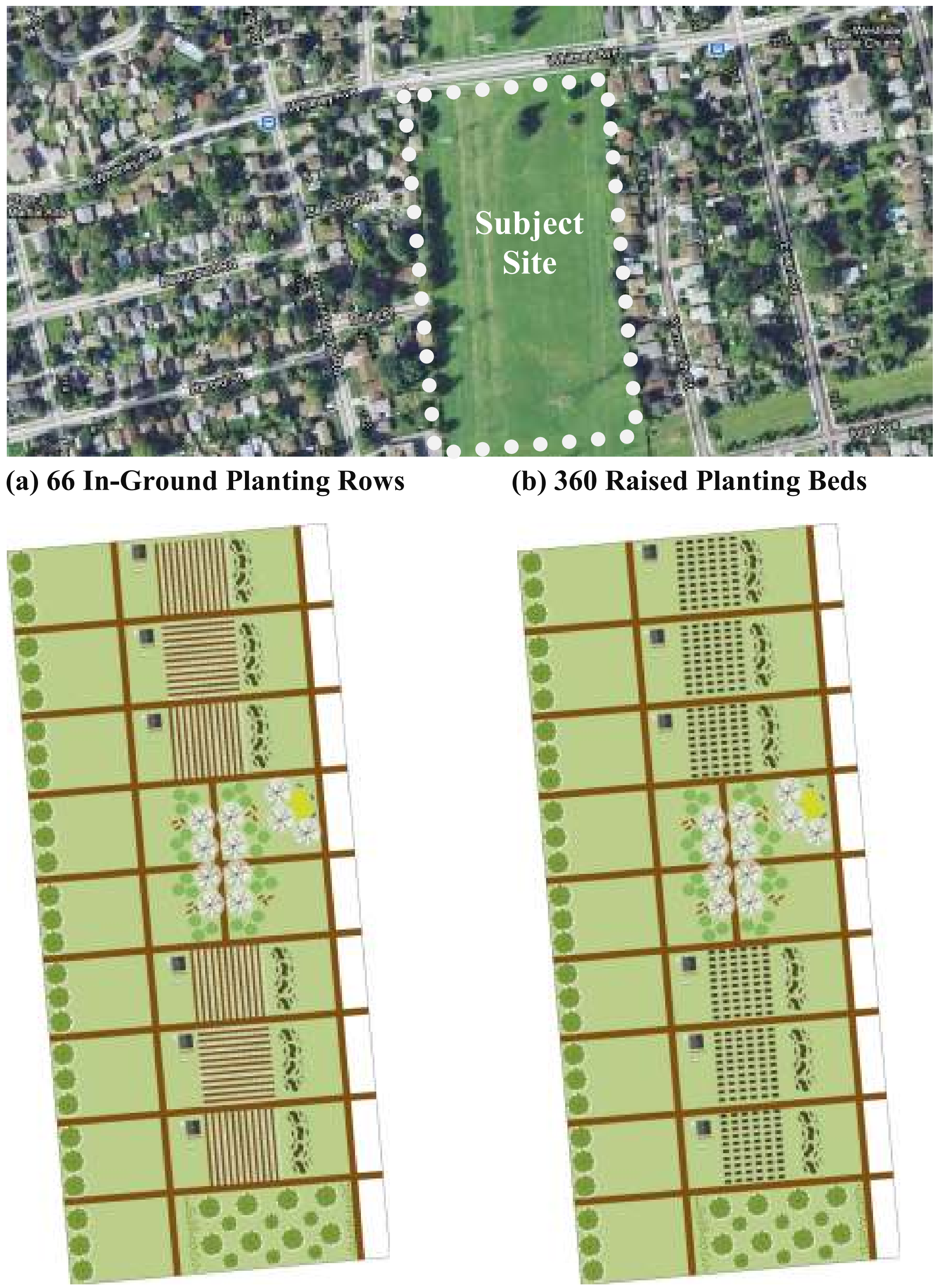

Figure 4.5 Site location and design alternatives (Hamilton, Ontario, Canada)

Chapter 5. Estimating the stormwater attenuation benefits derived from planting four monoculture species of deciduous trees on vacant and underutilized urban land parcels

5.1 Abstract

This paper presents the findings of research that was undertaken to understand whether planting deciduous trees on vacant and underutilized urban land, as a temporary reuse (or holding) strategy, provides significant hydrologic benefits for municipalities. Tree growth parameters for four monoculture planting schemes were modeled (*Ginkgo biloba, Platanus x acerifolia, Acer saccharinum, and Liquidambar styraciflua*). A water balance model was applied to each scenario to quantify the canopy attenuation potential and approximate direct site runoff, based on historical rainfall data in Hamilton, Ontario, Canada. To test the potential effects of the canopy in attenuating stormwater, a sensitivity analysis was subsequently conducted to observe the response of each of the four planting scenarios with respect to total canopy evaporation, by increasing the total rainfall amount by 5%-35%, with increments of 5%. The output from the models revealed that there is a significant benefit with respect to reduced stormwater runoff that is derived from canopies that are planted above hardscaped surfaces, while a combined canopy and turf layer produced similar stormwater attenuation benefits when compared to the turf layer alone. This work revealed that three of the species responded similarly, while one species (*Liquidambar styraciflua*) performed significantly better with respect to stormwater interception.

Keywords. Vacant and underutilized land; Stormwater attenuation; hydrologic benefits

5.2 Introduction

Between 2000 and 2005, the Province of Ontario, Canada experienced 10 storms that exceeded intensities of 1 in 100-year storms, resulting in damages exceeding CAD$ 360 million (Conservation Ontario, 2009). A recent report calls on agencies to develop strategies to assist in flood management, as Ontario's flood management system does not currently have the capacity to cope with the resulting changes in flood patterns (Conservation Ontario, 2009). Mekis and Hogg (as cited in Milly, 2008), studied trends in precipitation for the Lake Huron and lower great lakes drainage basin and found that total rainfall amounts in Spring, Summer and Fall have increased by statistically significant amounts. Potential reasons for the increased incidence of flooding include increased rainfall intensities, increased urbanization (hardscaped surfaces), aging urban infrastructure, and deficient infrastructure capacities (i.e. existing infrastructure was not designed for current rainfall intensities). As a result, the ability of watersheds to mitigate stormwater runoff in many planning jurisdictions around the world has decreased. We present findings from recent research that aims to clarify whether planting trees on vacant and underutilized land on a temporary basis can provide enhanced hydrologic benefits when compared to a simple grass layer with no tree canopy cover. The research revealed that urban trees can contribute significantly in terms of intercepting, attenuating and evaporating rainfall, particularly in hardscaped areas; however, the research also revealed that a grass layer with moderately high runoff potential when thoroughly wet, could achieve similar stormwater attenuation results over the same period of analysis, when compared to the canopy and grass layer scenario. It is important to note that there are numerous benefits that are derived from urban forests beyond stormwater interception including, air pollutant removal, reductions in building cooling loads, cooling summer air temperatures, removing carbon dioxide, and releasing oxygen into the atmosphere (McPherson, Simpson, Peper and Xiao, 1999). The study conducted by McPherson et al. (1999), which analyzed Modesto California's 90,000 urban trees, found that reductions in stormwater runoff of 292,000 m^3 resulted in a cost savings of USD$ 616,000 (or USD$ 7/tree or USD$ 2.11/m^3). Despite these numerous benefits, the discussion herein will be limited to a description of recent hydrologic modeling efforts and the corresponding results of four monoculture tree planting schemes that were modeled on a temporary basis: *Ginkgo biloba, Platanus x acerifolia, Acer saccharinum,* and *Liquidambar styraciflua*.

5.2.1 Vacant and Underutilized Urban Land

Many cities around the globe, regardless of size or geographic location struggle with the presence of vacant and underutilized land in the urban environment; to date long-term solutions that contribute to the recovery of declining areas have not been implemented on a consistent basis, if at all (Pagano and Bowman, 2000). Bowman and Pagano (2004) state that while all cities contain vacant land, the type and supply of vacant land and the condition of said land can vary greatly. The authors further state that the phenomenon of vacant land has not been widely studied and that cities continue to search for ways to best transform vacant spaces (Bowman and

Pagano, 2004). In an attempt to understand the complexity of the vacant land issue, Bowman and Pagano (2004) conducted a survey of planning directors in U.S. cities with populations of 50,000 or greater and found that on average approximately 15% of a city's land area can be classified as vacant or underutilized. This untapped resource presents enormous opportunities socially, environmentally and economically. One such opportunity would be to employ a reuse strategy such as a tree planting program.

5.2.2 Objective of Research

While there is great potential to utilize vacant land in a variety of productive ways, the opportunity to do so may be limited by the short-term (0-5 years), medium-term (5-10 years), or longer-term (10+ years) availability of said land (Cleveland Land Lab, 2009). These time frames recognize that an ultimate, higher-order purpose for a vacant parcel may be established at some point in the future. The question then remains as to how to reuse these spaces on an interim basis in meaningful and productive ways. Therefore, the objective of this research is to determine whether significant hydrologic benefits can be achieved by developing relatively intense planting schemes for vacant and underutilized land, recognizing the temporal nature of this reuse strategy. The methodology used for studying the hydrologic benefits of the urban forest canopy with respect to capturing and attenuating stormwater is described in the following section.

5.3 Methodology

The research described herein required the identification and selection of an underutilized lot in the City of Hamilton, Ontario, Canada, the selection of four tree species for analysis, the selection of a tree growth model to predict various tree parameters (leaf area, tree height, crown diameter, crown height, and diameter at breast height), and the application of a stormwater model (UFORE-Hydro) to quantify the hydrologic benefits of the four planting schemes. Finally, a sensitivity analysis was conducted to explore the potential implications of global environmental change on the ability of each species to respond to an increased amount of total rainfall. All modeling and analyses were carried out using Microsoft Excel®. Rainfall data was provided by the Hamilton Conservation Authority (2009) for the Christie Dam Station, having a latitude of 43°16'37''N and a longitude of 80°0'29''W.

5.3.1 Tree Planting Scenarios

To simplify the modeling required for this analysis, four monoculture tree planting scenarios were selected: *Ginkgo biloba, Platanus x acerifolia, Acer saccharinum,* and *Liquidambar styraciflua*. The four species were chosen from city street tree planting lists in the greater Toronto and Hamilton Area (GTHA). While the four species were generally favoured due to their tolerance to urban conditions, they have notable variations in leaf and branching structures, canopy size and shape, and growth rates (Gilman, 2007).

5.3.2 Water Balance using Historical Data

A water balance was carried out using 7 years (2002-2008) of hourly rainfall and mean temperature data in Hamilton, Ontario, Canada, for a 1.6-acre underutilized parking lot, theoretically designed with a turf layer and planted with four monoculture deciduous tree layers. Four unique planting schemes and water balance models were developed for the four species. The water balance models analyze the effects of the tree canopies in attenuating stormwater over a period from May 1 through November 19, as this period typically encompasses the budding/leafing, full leaf-on, leaf shedding, and full leaf-off processes for deciduous trees in the Province of Ontario (Elliot, personal communication, October 16, 2009). The amount of rainfall that falls through the canopy and becomes runoff was also calculated. Finally, a 'base case' scenario was evaluated to determine the total runoff without a canopy layer and only a grass layer.

5.3.3 Sensitivity Analysis

Prodanovic and Simonovic (2007) predict that rainfall magnitude and intensity will increase significantly as a result of climate change, while Cheng et al. (2007) posit that climate change could have the following results with respect to rainfall:

(i) number of days with measurable rainfall could increase by 20%;

(ii) frequency of future heavy rainfall events could increase anywhere from 25-50% during this century, and

(iii) seasonal rainfall totals (Apr-Nov) could increase by about 20-35%

The prediction outlined in item (iii) was used to conduct a sensitivity analysis. This was done by increasing the historical total hourly rainfall amounts by increments of 5% to an upper limit of 35%, while observing total evaporation and runoff from both the canopy and grass layer. In the discussion section of this manuscript, the historical model output and sensitivity analysis results are discussed and some observations are provided with respect to the potential benefits of planting trees on a short-term basis.

5.3.4 Models for Tree Growth Parameters

Three tree growth models were evaluated for use in this project. One was developed by the USDA Forest Service, and was based on observations of open-grown park trees in Chicago Illinois (Nowak, 1996). This model predicts total leaf area only. The other two models were developed for the urban forest in Modesto California based on observations of tree growth for 12 common urban trees, including the four species presented in this manuscript (Peper, McPherson and Mori, 2001). One model predicted diameter at breast height (cm), total tree height (m), crown width (m), and crown height (m), while the other model predicted the total leaf area (m^2). While the north-eastern model would appear to be more appropriate given Hamilton's geographic location and similar climatic conditions, this model was limited in that it could not predict the total leaf area for a species unless the parameters were within certain upper and lower bounds, as described below. The equation for the north-eastern model is found below.

Leaf Area (m^2) (Nowak, 1996):

$$Y_L = e^{-4.3309+0.2942H+0.7312D+5.7217Sh-0.0148S_c+0.1159} \tag{5.1}$$

Where:
Y_L is leaf area (m^2)
H is crown height (m)
D is average crown diameter (m)
Sh is the average shading factor (percent light intensity intercepted by foliated tree canopy)
S_c is based on the outer surface area of the tree crown ($\pi D(H+D)/2$)

This equation is appropriate for predicting leaf area for trees with a crown width of 1 to 14 metres, a crown height of 1 to 12 metres, a crown height to crown width ratio of 0.5 to 2.0, a diameter at breast height (dbh) of 11 to 53 cm, and a shading factor of 0.67 to 0.88 (Nowak, 1996). Due to the limitations of this model (i.e. the fact that it could not model younger trees with a dbh<11cm), it was not used for this particular research, whereby younger trees would be planted. Through the literature review conducted as part of this research, no model was found within a Canadian jurisdiction for modeling the necessary tree parameters required for this analysis, and as such the models from Modesto, California were used. The rationale behind using these models is that open-grown tree growth rates are highly variable within a country, province, region, city or even an area of a city. Tree growth parameters are influenced by a variety of site-specific factors, including but not limited to, climatic conditions, soil volume, physical and chemical properties, access to water, and seasonal weather and temperature variations, to name a few. No data were available for the region under analysis (Ontario, Canada), and as such, the coefficients described in Peper, McPherson and Mori (2001) for Modesto, California were applied in combination with a sensitivity analysis on the total leaf area for the four species. The equations used to predict tree growth parameters are described below.

Diameter at breast height (cm), tree height (m), crown diameter (m), crown height (m) (Peper et al., 2001):

$$Y_P = \exp\left(a + b \cdot \ln(\ln(age + 1)) + \left(\frac{c}{2}\right)\right) \tag{5.2}$$

Leaf Area (m^2) (Peper et al., 2001):

$$Y_L = \exp(a) \cdot \left(\exp(b \cdot dbh - 1) \cdot exp\left(\frac{c}{2}\right)\right) \tag{5.3}$$

The sensitivity analysis employed the predicted values for leaf area and increased/decreased these values by 5% increments to create bounds of +/- 20% around the predicted leaf area values. The results of this analysis are included in the discussion section of this manuscript.

Trees with a 50.8 mm caliper require approximately 18 months to fully establish, and established trees typically don't require additional irrigation (Gilman, 1997). Due to the anticipated limitations on budget for projects of this nature, a minimum caliper of 50.8 mm was selected for each theoretical planting scheme.

5.3.5 Tree Planting Algorithm

To allow each of the four monoculture plantings to grow at an optimal rate and to promote their maximum growth potential, trees were packed into the underutilized parcel using an automated hexagonal packing algorithm developed by Kirnbauer, Baetz, Kenney and Churchill (2009).

Each tree species was planted such that at the end of the 7 years, the canopies would be touching but not overlapping. This would ensure that there would be reduced competition for light, root space or above-ground crown growth, giving the trees the best opportunity to achieve the growth rates predicted by the models. Trees were planted within the parcel such that tree stems were permitted on the property line. By allowing this, some of the outer edge canopies would overhang onto the sidewalk and adjacent properties. Using this packing algorithm, four separate planting simulations were modeled using 450 *Ginkgo biloba*, 92 *Platanus x acerifolia,* 120 *Acer saccharinum,* and 434 *Liquidambar styraciflua* on the 1.6-acre parcel.

5.3.6 Tree Leafing Behavior

The Ontario Ministry of Natural Resources was contacted to obtain tree leafing information; that is, the period of time over which the urban trees begin to bud until full "leaf-on", and subsequently the period of time when trees begin to shed their leaves until full "leaf-off". Through personal communication with the Ministry, a leaf-on period from May 1 (approximately 1 month after snow melt) through June 30 and a leaf off period from September 15 through November 19 was provided as a "best estimate" (Elliot, personal communication, October 16, 2009). While these periods vary from species to species, and from season to season based on temperature, storm, wind, frost and ice events, these were deemed to be conservative estimates for this research project (as some trees could be in full leaf as early as mid-June and may not completely de-leaf until the beginning of December). It was assumed that the leaf-on and leaf-off periods followed a linear relationship.

5.3.7 Urban Forest Effects - Hydrology (UFORE-Hydro) Model

A simplified version of the Urban Forest Effects – Hydrology (UFORE-Hydro) model was used to study the hydrologic benefits of planting and growing trees on a temporary basis. The water balance was conducted on the parcel over a 7-year period, from May until November. This was done to observe the hydrologic effects of the four species from bud-break, leafing and full leaf-loss. While tree branches and tree trunk also intercept and evaporate stormwater, the bark area was not calculated and therefore not included as part of the water balance – again, this approach was deemed to be conservative.

A two-step procedure was employed for each of the four planting schemes using hourly rainfall and mean temperature data. Step one involved determining the total rainfall evaporated from each tree crown and subsequently, the total canopy throughfall (the amount of rainfall that falls through the canopy and reaches the ground) at the end of each hour. UFORE-Hydro equations were used to calculate this portion of the water balance (Wang, Endreny and Nowak, 2008). Step two of the water balance involved taking the direct rainfall that fell onto the grassed area of the site (the portion without canopy cover) and the canopy throughfall (calculated in step one, described above) and computing the total amount of direct runoff from the site, using the SCS Curve Number method. In the Curve Number method, runoff characteristics are related to land use, hydrologic soil group, hydrologic conditions, and antecedent soil moisture conditions (Viessman and Lewis, 1996). Limitations of this method include the fact that time (i.e. rainfall intensity) is not included in the estimate of runoff depth (Viessman and Lewis, 1996). Despite this limitation, this method is widely used and provides a good approximate method when runoff data are unavailable (Viessman and Lewis, 1996). The on-site slope was negligible and was therefore not evaluated, as land with slopes of less than 5% have minimal influence on the Curve Number method (Viessman and Lewis, 1996). All equations used in the water balance models are explained in further detail below, and the associated water balance diagram is provided in Figure 5.1. A description of each variable is included as well as the default values used (where applicable), and all relevant assumptions.

Canopy Storage at time, t (Wang, Endreny and Nowak, 2008):

$$C(t) = C_{(t-1)} + P(t) - R(t) - E(t) \text{ (mm)} \tag{5.4}$$

Where:
$C(t)$ is the water storage (mm) on the canopy at time t
C_{t-1} is the water storage (mm) on the canopy from the previous time step (the remaining amount that didn't evaporate in the previous time step)
$P(t)$ is the open-sky precipitation (mm) at time t
$R(t)$ is the canopy throughfall precipitation (measured in mm; prior to reaching C_{max}, $R(t) = P_f(t)$, after reaching C_{max}, $R(t) = P(t)$, *that is, when storage is at its maximum, throughfall equals precipitation*)
$E(t)$ is the evaporation from the wetted canopy at time t (mm)

Free Throughfall (Wang, Endreny and Nowak, 2008):

This represents rainfall through the tree canopy, without leaf contact.

$$P_f(t) = P(t) \cdot (1 - c_f) \text{ (mm)} \tag{5.5}$$

Where:
P(t) is defined above and c_f is defined below.

Canopy Cover Fraction, c_f (van Dijk and Bruijnzeel, 2001 as cited in Wang, Endreny and Nowak, 2008):

$$c_f = 1 - e^{-k \cdot LAI_T} \text{ (dimensionless)} \tag{5.6}$$

Where:
k is a light extinction coefficient, which ranges between 0.6 and 0.8 in forests (Wang, Endreny, and Nowak, 2008). The UFORE-hydro default value is 0.7. This value was also used in this project.

LAI_T *is* the total leaf area index when the canopy is in full-leaf (one sided leaf area per unit ground area in broadleaf canopies)

Maximum Storage Capacity, S (Wang, Endreny and Nowak, 2008):

$$S = S_L \cdot LAI_T \text{ (mm)} \tag{5.7}$$

Where:
S_L denotes specific leaf storage which is the maximum depth of water that can be retained and stored by the leaves of a particular tree species per unit leaf area. Based on reported averages from Dickinson, 1984, as cited in Wang, Endreny and Nowak (2008), S_L = 0.0002m (UFORE default value).

When C = S, the canopy has reached its maximum storage capacity and when this occurs, all subsequent rainfall becomes canopy throughfall (Wang, Endreny and Nowak, 2008). Also, when C=S, or in other words, $C=C_{max}$, it was assumed that no further evaporation would occur from the crown until the rain had ceased (Wang, Endreny and Nowak, 2008). Again this is a conservative approach, as a minimal amount of rainfall would be evaporated even when the canopy is fully saturated.

Leaf Area Index during leaf-on and leaf-off transitional periods (Wang, Endreny and Nowak, 2008):

$$LAI_F = F_L \cdot LAI_T \text{ (dimensionless)} \tag{5.8}$$

Where:
F_L is the fraction of the total canopy in leaf and is calculated using linear interpolation for the leaf-on and leaf-off periods (May 1 through June 30 and September 15 through November 19). The choice to linearly interpolate to obtain the value of F_L was believed to be a conservative assumption.

LAI_F is the fraction of the total leaf area index.

Evaporation (Deardorff (1978) and Noilhan and Planton (1989), as cited in Wang, Endreny and Nowak, 2008):

$$E_F(t) = \left(\frac{C(t)}{S}\right)^{2/3} E_P \text{ (mm)} \qquad (5.9)$$

Where:
$E_F(t)$ is the evaporation flux (canopy interception removed through the process of evaporation)
$C(t)$ is the canopy storage at time t
S is the maximum canopy storage, and
E_P is the potential evaporation (the amount of evaporation that would occur if a sufficient water source were available)

Blaney-Criddle formula for potential evaporation, E_p (Viessman and Lewis, 1996):

This formula calculates the potential evaporation; that is, the evaporation that could occur if a sufficient amount of water is available. It requires two input variables: mean daily temperatures in °C and the daytime hours coefficient, p.

$$E_p = \frac{p\ x\ (0.46 \cdot T + 8)}{24} \text{ (mm/hour)} \qquad (5.10)$$

Where:
T is temperature in °C and p is the daytime hours coefficient. Values of p for the studied months were taken from Viessman and Lewis (1996).

Mean daily temperature values were obtained from Environment Canada's historical data web page. Data was recorded at the 'Hamilton A' station, which has a latitude of 43°10'12''N and a longitude of 79°55'48''W (Environment Canada, 2009).

Runoff – SCS Curve Number Method (Viessman and Lewis, 1996):

$$Q = \frac{(P-I_a)^2}{P-I_a+S_s} \text{ (inches)} \quad (5.11)$$

Where:
Q is runoff (inches)
P is rainfall (inches) – step two of two-step water balance: P = direct rainfall onto grass + canopy throughfall
I_a is the initial abstraction (infiltration/interception from the grass layer); assumed to be equal to 0.2S (inches)
CN = 74 (based on Group C soils which have low infiltration and subsequently moderate to high runoff – infiltration rates between 0.05 to 0.15 inches/hr when wet (USDA, 1986)).
S_s is the potential maximum soil moisture retention after runoff begins:

$$S_s = \frac{1000}{CN} - 10 \text{ (inches)} \quad (5.12)$$

5.4 Discussion of Results

The following sections highlight the significant observations for canopy evaporation and site runoff from the four tree planting schemes based on the historical data (water balance, scenario 1).

5.4.1 Water Balance – Historical Data

A review of the model output revealed that the *Acer saccharinum* planting scheme resulted in the least amount of canopy evaporation (565 m^3) and the most site runoff (704 m^3) over the 7-year study period. In total, 2.7% of the total rainfall was evaporated by the *Acer saccharinum* tree stand and 3.4% of the total rainfall became runoff during the 7-year period. The *Ginkgo biloba* planting scheme had the second lowest canopy evaporation (675 m^3) and the second highest site runoff (701 m^3). In total, 3.3% of the total rainfall was evaporated by the *Ginkgo biloba* tree stand and 3.4% became runoff. The *Platanus x acerifolia* stand had the second highest canopy evaporation (743 m^3) and the second lowest runoff (697 m^3). In total, 3.6% of the total rainfall was evaporated by the *Platanus x acerifolia* canopy and 3.4% became runoff. The largest canopy evaporation resulted from the *Liquidambar styraciflua* planting scheme (1280 m^3) as well as the lowest runoff (684 m^3). In total, 6.2% of the total rainfall was evaporated from the *Liquidambar styraciflua* canopy and 3.3% became runoff. Table 5.1 provides a summary for the 7-year period of study (2002-2008) for the

Liquidambar styraciflua stand. Similar tables were prepared and analyzed for all planting scenarios, but due to space limitations, are not included within this manuscript.

5.4.2 Sensitivity Analysis – Effects of Increased/Decreased Leaf Area on Canopy Evaporation Potential

A sensitivity analysis was completed on the predicted total leaf area values to observe how changes in leaf area affect canopy evaporation across the evaluated time frame (2002-2008). Predicted leaf area values were incrementally increased and decreased by 5% to +/-20%. Table 5.2 provides a summary of the results from this analysis. This analysis revealed that increases to leaf area resulted in a 3.1% to 12.1%, 4.7% to 14.7%, 4.4% to 15.7%, and 4.0% to 14.6% increase in canopy evaporation potential for the *Liquidambar styraciflua*, *Platanus x acerifolia*, *Acer saccharinum*, and *Ginkgo biloba* stands, respectively. Decreases to leaf area resulted in a 3.2% to 13.5%, 4.4% to 16.3%, 3.6% to 15.7%, and 4.6% to 16.2% decrease in canopy evaporation potential, for the *Liquidambar styraciflua*, *Platanus x acerifolia*, *Acer saccharinum*, and *Ginkgo biloba* stands, respectively. There are numerous challenges when predicting tree growth parameters. This sensitivity analysis demonstrated that, when varying the predicted leaf area values by +/- 20%, the resulting ability of the canopy to attenuate and evaporate rainwater increased or decreased by 3.1% to 16.2%. This variability was believed to be reasonably acceptable and as such, the results presented below were derived from the models (and coefficients) presented in Peper et al. (2001).

5.4.3 Evaporation – Historical Rainfall Data

Several observations were made with respect to the historical rainfall data and the evaporation potential of each planting scheme. Firstly, the ability of a tree to evaporate rainwater increases with size (Leaf Area). The greatest margin of difference is noted with the *Liquidambar styraciflua* planting scheme, which is able to evaporate more than two times as much as the *Acer saccharinum* planting scheme (in 2008, the *Liquidambar styraciflua* trees evaporated approximately 11% of the total rainfall on the parcel - evaporating a total of 1280 m^3 over the 7-year period). The *Platanus x acerifolia* stand was the next best performing tree (evaporating 743 m^3 over a 7-year period) followed by the *Ginkgo biloba* stand (675 m^3) and the *Acer saccharinum* stand (565 m^3). The value of canopy evaporation divided by total rainfall on the canopy (expressed as a percentage) is more difficult to draw conclusions from. The best performing tree (*Liquidambar styraciflua*) had values ranging from 17% -

26.9%, meaning that the tree stand could evaporate this percentage of the total annual rainfall that fell directly onto the canopy layer (note: this value is different from the "total rainfall on the parcel" (discussed above – total rainfall also includes rainfall that fell directly onto the grass in areas with no tree cover). The evaporative abilities are not based solely on the age of a tree stand (even though evaporative capacities of trees do typically increase with age). This value also depends on the intensity and duration of each storm event. For reasons discussed above, 2005, 2006 and 2008 were typically the worst performing years in terms of evaporation. All tree species evaporate more water when total hourly rainfall values are low and storm durations are shorter (2002, 2003, 2004, and 2007 performed well in terms of canopy evaporation/total rainfall on the canopy). Higher intensities result in canopy saturation and subsequent throughfall and subsequently less evaporation compared to total overall rainfall (2005, 2006 and 2008).

5.4.4 Runoff – Historical Rainfall Data

Likewise, several observations were made with respect to the historical rainfall data and the runoff potential of each planting scheme. Firstly, the total amount of runoff from the site (2002-2008 inclusive) does not differ drastically from species-to-species (the *Liquidambar styraciflua* planting scheme results in 20 m^3 less runoff over the 7-year study period than the worst performing tree – the *Acer saccharinum*). This is due to the fact that the second layer of vegetation (the grass layer) was able to intercept a large portion of the rain that fell through the canopy, resulting in similar total runoff values for each species. There is an increasing volumetric trend with respect to runoff from the years 2002-2008, with 2007 being the exception (see explanation below), despite the fact that the tree canopies and subsequently total crown leaf area are increasing as the trees age. In 2007, considerably less total rainfall fell than all other years, with only 286 mm falling. There were also significantly fewer rainfall events with hourly totals between 2.2 mm and 6.5 mm (only 21 in the entire year versus 55 in 2003, 59 in 2008, and 70 in 2005, for example). The increasing volume of runoff might be indicative of longer storm durations and/or higher total hourly rainfall events (which were noted in 2003, 2005 and 2008, as mentioned above; however, this observation could not be distinctly made for any other year). The value of the total runoff saved through evaporation and infiltration due to the two vegetative layers (canopy and grass layer) was calculated to be approximately USD$ 40,000 (McPherson et al., 1999). It should also be noted that the majority of the hydrologic benefits in terms of runoff are derived from the grass layer. Using an estimated savings of USD$ 2.11/m^3 (McPherson et al., 1999) of stormwater attenuated over the 7-year period, the *Ginkgo biloba*, *Platanus x acerifolia*, *Acer saccharinum*, and *Liquidambar styraciflua* tree stands would save approximately USD$ 1424, USD$ 1568, USD$ 1192 and USD$ 2700, respectively in stormwater capture and treatment.

5.4.5 Sensitivity Analysis

To conserve space, Table 5.3 presents the results of the sensitivity analysis for the *Liquidambar styraciflua* stand only. To complete the sensitivity analysis for all four species, historical hourly rainfall values were incremented from 5% - 35%, by increments of 5%. Table 5.3 highlights key output from this analysis, including but not limited to, the total volume intercepted and evaporated from the canopy layer and the total runoff from the parcel for both water balance scenarios.

Based on the 2002-2008 summaries, the *Ginkgo biloba* tree stand was able to evaporate 0.4% more rainfall based on the 5% increment for a total of 678 m^3 and approximately 5.7% more rainfall based on a 35% increment in total rainfall for a total of 714 m^3. The *Platanus x acerifolia* was able to evaporate 0.6% more rainfall based on a 5% increment for a total of 747 m^3 and 5.5% more rainfall based on a 35% increment in total rainfall for a total of 784 m^3. *Liquidambar styraciflua*, once again, performed the best evaporating approximately 1% more rainfall with a 5% increment for a total of 1292 m^3 and 6.0% more rainfall based on a 35% increment in total rainfall for a total of 1357 m^3. Finally, *Acer saccharinum* was able to evaporate approximately 0.9% more rainfall based on a 5% increment for a total of 570 m^3 and 6.1% more rainfall based on a 35% increment in total rainfall for a total of 599 m^3. The following bullet points highlight the significant observations for evaporation and runoff from the four tree species based on the sensitivity analysis.

5.4.6 Sensitivity Analysis – Effects of Increased Historical Rainfall Amounts on Evaporation

While all species averaged approximately a 6% increase in total evaporation at the 35% increment level, there is a substantial difference with respect to the *Liquidambar styraciflua* tree stand; while each of the other three species evaporated approximately 40 m^3 more than the historical values, when the total rainfall was increased by 35%, the *Liquidambar styraciflua* tree stand was able to evaporate approximately 80 m^3 more than the historical values at the same increment level. It was observed that the total volume evaporated by each of the four tree stands increased over time. This was expected as leaf area increases over time and therefore evaporative potential, with the exception of the species and years highlighted below.

- 2006, *Ginkgo biloba*, 5%-30% increments: the total volume evaporated was -3.5% to -0.3% less than the historical values;

- 2006, *Platanus x acerifolia*, 5-35% increments: the total volume evaporated was -3.6% to -0.04% less than the historical values.

This phenomenon is explained as follows. If the total rainfall is incremented by a given percentage and the canopy storage capacity has not reached a maximum, additional rainfall will be evaporated; however, this is offset by other rainfall events where the canopy was close to capacity, or simply due to the pattern of the historical rainfall (e.g. there were several time steps of light rain followed by additional time steps of light rain). When incremented, the tree reaches its capacity earlier than what it would have historically. Given the assumption made in the evaporation flux equation that once the canopy storage capacity had been reached, all subsequent rainfall becomes canopy throughfall and evaporation does not begin again until there is an hour where there is no rainfall, it becomes clear as to why the above-noted species/years resulted in evaporation values that were slightly less than the historical values.

5.4.7 Sensitivity Analysis - Effects of Increased Historical Rainfall Amounts on Runoff

In terms of total runoff, the *Liquidambar styraciflua* stand performed the best over the 7-year study period – with a 5% increase in rainfall, 801 m^3 of runoff would result and with a 35% increase, 1709 m^3 of rainfall would runoff. This was followed by the *Platanus x acerifolia* stand with 813 m^3 and 1735 m^3 of runoff generated for the same increments, *Ginkgo biloba* with 821 m^3 and 1744 m^3, respectively and *Acer saccharinum* with 823 m^3 and 1748 m^3 of runoff, respectively. Due to the increased rainfall amounts (5%-35%), it was found that 17% more runoff would result from a 5% increase and approximately 148% more runoff would be expected for a 35% increase in relation to the total historical runoff. These percentages were virtually the same for all four tree stands; however, there is a difference between the *Liquidambar styraciflua* stand and all other stands. The *Liquidambar styraciflua* stand avoided approximately 25 – 40 m^3 of runoff with an increment of 35% in total rainfall (when compared to the other three species) and 12 – 22 m^3 of runoff with an increment of 5% (when compared to the other three species).

5.4.8 Base Case Water Balance Scenario – Grass Layer

A 'base case' scenario was also evaluated, whereby a theoretical grass layer was planted without a canopy layer. Under this scenario, it was observed that the grass layer performed quite well across the evaluated years. In fact, the tree layer captured only 35.58 m^3 more than the grass layer alone across the seven years evaluated, using the historical data (a difference of approximately 0.2%). Similar results were observed for the sensitivity analyses. It is apparent from these analyses that while trees, when planted over hardscaped surfaces, have significant stormwater attenuating benefits, it may be more appropriate to green vacant and underutilized land through the application of a grass layer and smaller plantings, limiting larger deciduous plantings to perimeter areas where there is a reduced likelihood of disturbance during future construction/use of the site. As mentioned previously, the long-term availability of vacant and underutilized land is often unknown, and can be affected by market forces locally, nationally and/or internationally, and as such careful consideration is recommended prior to implementing any reuse strategy on a temporary basis.

5.5 Concluding Remarks

This research was conducted to understand whether planting trees on a relatively short-term basis resulted in significant hydrologic benefits for municipalities. This work is part of an ongoing discussion on how to use vacant and underutilized land productively. This work illustrated that while many of the tree species responded similarly, one species (*Liquidambar styraciflua*) performed substantially better in terms of rainfall mitigation. While the actual values may be uncertain because of a lack of local data, the approach warrants further investigation.

This manuscript discussed two planting scenarios on a vacant parcel of urban land: (i) a base case was analyzed whereby only a grass layer was planted and the attenuating benefits observed, and (ii) four water balance models were derived using 7 years of historical hourly rainfall data and four monoculture tree planting scenarios, in combination with a grass layer. To test the potential effects of the tree canopy in attenuating stormwater, a sensitivity analysis was conducted to observe the response of each of the four planting scenarios with respect to total canopy evaporation by increasing the total rainfall amount by 5%-35%.

The analyses presented herein demonstrate that a combined canopy and grass layer had quite similar results when compared to the grass layer alone. The tree canopy layer was able to intercept and evaporate approximately 6.5% to 11% of the total rainfall that falls onto the crown across the 7 years studied, for the *Ginkgo biloba*, *Platanus x acerifolia* and *Acer saccharinum* tree stands and 17% to 27% for the *Liquidambar styraciflua* tree stand.

The research conducted for this manuscript does not capture the multitude of other benefits provided by the urban forest canopy and is not in any way recommending that reuse strategies should be evaluated without consideration of such benefits (e.g. evaporation and transpiration which acts to cool surrounding air temperatures, particulate removal, CO2 removal, improved pedestrian environments, reduced soil erosion, improved water quality, wildlife habitat, etc.). Other considerations for land use management decision-makers include the cost of establishing and maintaining a plantation of trees, as tree plantations may be costly and not have a significant impact from a stormwater management perspective when compared to a grass layer alone. When establishing perimeter plantings over hardscaped surfaces such as sidewalks, parking lots, or roadways, this research revealed that different species have varying impacts on stormwater attenuation potential. The selection of a species (or variety of species) that maximizes stormwater attenuating benefits may be important to land use decision-makers whose policies support the use of green infrastructure for stormwater management. It is important to note that the analyses completed for this manuscript were based on younger trees that had not reached maturity, and as such the ability of these species to attenuate stormwater at maturity would be significantly higher than the reported values presented herein. Obtaining a lease for the use of a property on a temporary to potentially long-term basis for tree plantations is therefore important for decision-makers, as it will impact the potential tree canopy benefits that can be achieved from this reuse strategy.

This research also revealed that the theoretical grass layer alone was able to capture and infiltrate/evaporate virtually the same amount of rainfall that fell onto the parcel when compared to the combined tree and canopy layer (with a site slope of $< 5\%$). This is a central finding as it reveals the importance of basic turf maintenance (e.g. soil aeration to facilitate improved infiltration, minimizing bare earth patches to reduce runoff, etc.) that, if neglected, could contribute to increased parcel runoff. Further, grass roots also contribute to the binding of soil, thereby reducing the potential for on-site and off-site erosion.

An important lesson that can be learned from this project is that one cannot rely on total values of leaf area for a given species to make decisions about the benefits of planting a certain type of tree stand on a temporary basis. As observed, one would have made different decisions had this been the sole indicator used in the decision-making process. *Acer saccharinum*, for example, had the highest leaf area 30 years after planting, while the *Liquidambar styraciflua* had the second highest (Peper et al., 2001). As discussed above, the *Liquidambar styraciflua* stand performed the best, while the *Acer saccharinum* stand performed the worst during the years evaluated. This is due to the fact that there was more leaf area per unit ground area for the *Liquidambar styraciflua* species during the first 7 years of growth after planting. Thus, the rate at which a species grows, the leaf area index of the species, and the total number of trees to be planted need to be determined to truly understand the behavior and potential benefits of different planting schemes. It was assumed in this evaluation that an unlimited number of each species could be planted, with the horizontal area available for planting being the governing factor on the upper limit in each planting scheme.

Future research, including the modeling of additional trees species, may be useful in better understanding how different species perform during their growth periods and which species are most appropriate for a given region based on historical rainfall data and predicted future trends.

5.6 Acknowledgements

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5.7 References

Bowman, A. O'M., Pagano, M. A., 2004. Terra Incognita: Vacant Land and Urban Strategies. Georgetown University Press, Washington, D.C.

Cheng, C. S., Li, G., Li, Q., Auld, H., MacIver, D., 2007. Climate Change and Extreme Rainfall-related Flooding and Surface Runoff Risks in Ontario. Plain Language Summary Report, Climate Change Impacts and Adaptation Program, Report No. A901, Environment Canada, Toronto, ON.

Conservation Ontario, 2009. Protecting People and Property: A Business Case for Investing in Flood Prevention & Control. Retrieved October 20, 2009 from http://www.conservation-ontario.on.ca/projects/floodstatus/pdf/Protecting%20People%20%20Property_ExSum09.pdf

Environment Canada, 2009. 2002 - 2008 Mean Daily Temperature Data, Hamilton, Ontario. National Climate Data and Information Archives, Retrieved October 20, 2009 from http://www.climate.weatheroffice.ec.gc.ca/climateData/canada_e.html

Gilman, E.F., 1997. Trees for Urban and Suburban Landscapes. Delmar Publishers, Albany, New York.

Hamilton Conservation Authority, 2009. 2002 – 2008 Hourly Rainfall Data – Christie Dam, Hamilton, Ontario. Retrieved November 15, 2009 from. P. Coulibaly, McMaster University, Hamilton, ON.

Hamilton, City of, 2009. Street Tree Planting Choices. Public Works Department – Street Tree Planting Program. Retrieved October 2, 2009 from http://www.hamilton.ca

Kirnbauer, M.C., Kenney, W.A., Churchill, C.J., Baetz, B.W., 2009. A prototype decision support system for sustainable urban tree planting programs. Urban Forestry and Urban Greening, 8(1): 3-19.

McPherson, G.E., Simpson, J.R., Peper, P.J., Xiao, Q., 1999. Benefit-Cost Analysis of Modesto's Municipal Urban Forest. Journal of Arboriculture, 25(5): 235-248.

Milly, P.C.D., 2008. Stationarity is dead: whither water management. Science, 319(1):573-574.

Nowak, D.J., 1996. Estimating Leaf Area and Leaf Biomass of Open-Grown Deciduous Urban Trees. Forest Science, 42(4): 504-507.

Pagano, M. A., Bowman, A. O'M., 2000. Vacant land in cities: An urban resource. Brookings Institution Survey Series, Centre on Urban and Metropolitan Policy, Washington, D.C. Retrieved November 15, 2009 from http://www.mrsc.org/artdocmisc/paganofinal.pdf

Peper, P.J. McPherson, E.G., Mori, S.M., 2001. Equations for Predicting Diameter, Height, Crown Width, and Leaf Area of San Joaquin Valley Street Trees. Journal of Arboriculture, 27(6): 306-317.

Prodanovic, P., Simonovic, S.P., 2007. Development of rainfall intensity duration frequency curves for the City of London under the changing climate. Water Resources Research Report no. 058, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, ON. Retrieved on October 21, 2009 from http://publish.uwo.ca/~pprodano/WGReport_rev1.pdf

Toronto, City of, 2009. Help keep our Urban Forest Growing. Let us plant a tree. Parks, Forestry and Recreation Department. Retrieved October 2, 2009 from http://www.toronto.ca

USDA Soil Conservation Service, 1986. TR55: Urban Hydrology for Small Watersheds. Retrieved October 15, 2009 from http://www.cpesc.org/reference/tr55.pdf

Viessman, W., Lewis, G. L., 1996. Introduction to hydrology (4th ed.). New York: Addison Wesley Educational Publishers, Inc., Addison, NY.

Wang, J., Endreny, T.A., Nowak, D.J., 2008. Mechanistic Simulation of Tree Effects in an Urban Water Balance Model. Journal of the American Water Resources Association, 44(1): 75-85.

Table 5.1 *Liquidambar styraciflua* Water Balance – Historical rainfall data

Year	Total Rainfall (mm)	Total Rainfall (m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	% Canopy Evaporation (based on total rainfall across the entire parcel)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	Parcel Runoff (m^3) with grass layer only	% Parcel Runoff
2002-2008	3119	20611	18	6	12199	1280	7132	19331	684	720	3
2002	378	2495	27	2	2242	54	199	2441	42	43	2
2003	482	3185	20	3	2632	92	461	3093	78	80	3
2004	396	2616	21	5	1926	120	570	2496	81	83	3
2005	534	3528	15	5	2222	166	1139	3362	132	143	4
2006	452	2985	15	6	1524	192	1270	2793	111	116	4
2007	286	1890	24	12	717	225	948	1665	20	24	1
2008	592	3912	17	11	935	431	2545	3480	219	230	6

Table 5.2 Sensitivity Analysis: Effects of incremental increases/decreases to Leaf Area (LA) on canopy capture potential

% Increase/Decrease (x%)	Canopy Capture Potential (%) - Low estimate (- x %)	Canopy Capture Potential (%) - Model estimate	Canopy Capture Potential (%) - High estimate (+ x %)
Liquidambar styraciflua			
5	6.0	6.2	6.4
10	5.8	6.2	6.6
15	5.6	6.2	6.8
20	5.4	6.2	7.0
Platanus x acerifolia			
5	3.5	3.6	3.8
10	3.3	3.6	3.9
15	3.2	3.6	4.0
20	3.0	3.6	4.1
Acer saccharinum			
5	2.6	2.7	2.9
10	2.5	2.7	3.0
15	2.4	2.7	3.1
20	2.3	2.7	3.2
Ginkgo biloba			
5	3.1	3.3	3.4
10	3.0	3.3	3.5
15	2.9	3.3	3.7
20	2.8	3.3	3.8

Table 5.3 *Liquidambar styraciflua* Water Balance – Sensitivity analysis (increased precipitation values 5%-35%)

Year	% Canopy evaporation (based on total rainfall falling directly on canopy)	% Canopy Evaporation (based on total rainfall across the entire parcel)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Runoff with trees and grass layer	Parcel Runoff (m^3) with grass layer only	% Runoff grass layer only
2002-2008	14-17	5-6	12809 - 16468	1293 - 1357	7540 - 9999	20348 - 26468	801 - 1710	4 - 6	841 - 1778	4 - 7
2002	20-25	2	2354 - 3027	54 - 56	212 - 285	2566 - 3312	52 - 122	2 - 4	53 - 125	2 - 4
2003	15-19	2-3	2764 - 3554	93 - 99	487 - 647	3251 - 4201	93 - 218	3 - 5	95 - 223	3 - 5
2004	16-20	4	2022 - 2600	121 - 129	603 - 803	2625 - 3403	93 - 186	3 - 5	95 - 190	3 - 5
2005	11-14	4	2334 - 3000	167	1204 - 1595	3538 - 4595	157 - 359	4 - 8	169 - 378	5 - 8
2006	11-14	5-6	1600 - 2057	194 - 198	1340 - 1776	2940 - 3832	132 - 289	4 - 7	137-297	4 - 7
2007	18-23	9-11	753 - 968	226 - 240	1005 - 1343	1758 - 2312	26 - 75	1 - 3	30 - 84	2 - 3
2008	13-16	9-11	982 - 1263	438 - 468	2688 - 3551	3670 - 4813	249 - 461	6 - 9	262 - 481	6 - 9

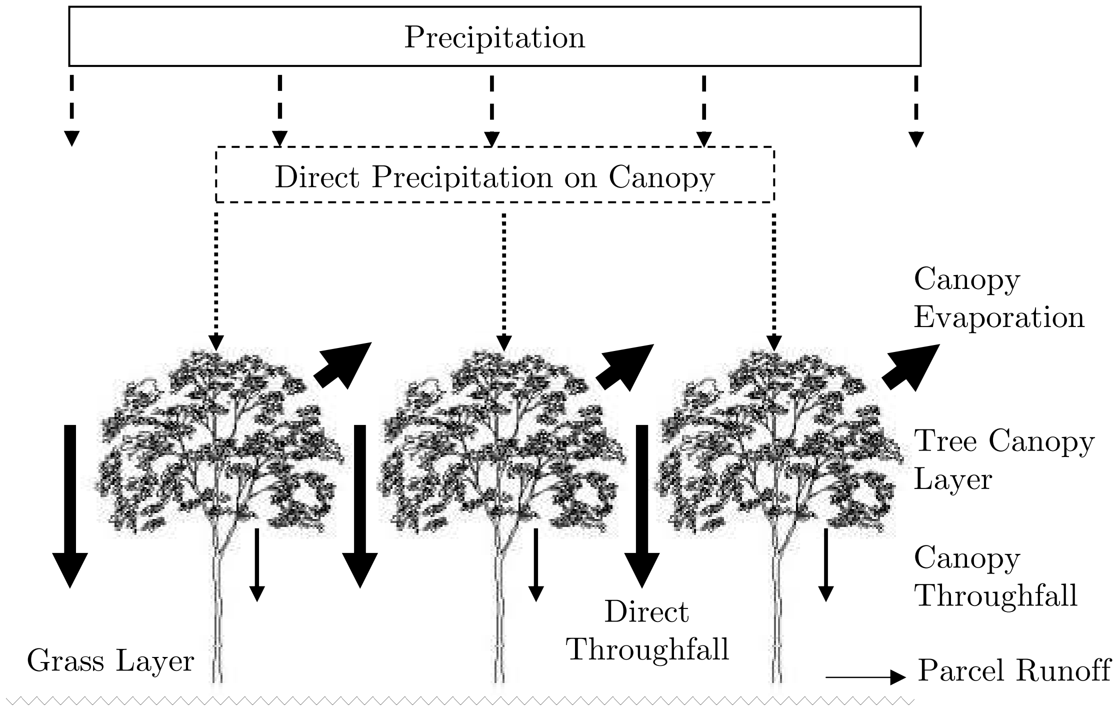


Figure 5.1 Simplified water balance diagram

Chapter 6. Conclusions

6.1 Concluding Remarks

Vacant and underutilized urban land can be viewed by urban planning policy-makers as a wasted resource, or alternatively, an urban resource. The latter perspective was the focus of this thesis. The framework for a community-based decision support tool for vacant land reuse has been described in this doctoral thesis. Given emerging urban growth pressures, provision for adequate, accessible, and equitable public spaces will be of fundamental importance to sustainable community growth in many jurisdictions around the globe. The proposed decision support software described herein uses expert knowledge and best practices to help make well-informed, cost-effective decisions with respect to turning vacant and underutilized land into temporary and permanent productive resources for a neighbourhood. Synthesizing vacant land reuse strategies from a growing body of literature on the topic, this doctoral research (Chapters 2-4, inclusive) introduced a suite of decision support modules, including: (i) a neighbourhood-based inventory of vacant and underutilized land, (ii) the determination of ‘site suitability’ for each potential strategy, (iii) a methodology for related location-allocation decision-making, and (iv) a design and life-cycle-cost analysis tool for individual reuse strategies. Chapter 5 introduced a detailed water balance analysis that could be done for a number of alternative strategies that include trees (e.g. tree nurseries, tree plantations, parks/open space, etc.) for any given parcel. While the stormwater modeling component was not included as an automated module in C-SAP, it demonstrates a methodology for quantifying some of the derived benefits of the urban forest canopy, and represents an important exercise in the valuation of vacant and underutilized urban lands.

Based on the literature review conducted on vacant land reuse strategies, a decision support tool of this nature has not been previously developed and as such it would be the first of its kind in the urban planning research arena. This tool has a multitude of environmental, social and economic implications for a wide range of stakeholders; however, perhaps most notably it has the potential to empower neighbourhoods to take action with respect to urban renewal projects in their own backyard. This will not only create a renewed sense of ownership and pride in these areas but will have the potential to spur economic development in depressed areas and generate growth in social and natural capital.

6.2 Research Contributions

A summary of the main contributions of this research are highlighted below for each manuscript.

A prototype community-based planning tool for evaluating site suitability for the temporary reuse of vacant lands:

- Developed a comprehensive vacant and underutilized land inventory (VULI) for identifying and inventorying the physical and spatial attributes (i.e. location and condition) of vacant and underutilized land across the urban environment;
- Developed and presented a methodology (SSI) for evaluating the suitability of vacant land for a suite of reuse strategies;
- The information derived from VULI and SSI can be used by community groups to generate meaningful discussions and help articulate and quantify/qualify the inherent potential of these spaces for future reuse;
- If this methodology was adopted at the municipal level, the prototype tool has the potential to expedite applications to reuse city-owned lands on a temporary basis (e.g. output from VULI and SSI could be included in the application package filed with a municipality).

Allocating urban agricultural reuse strategies to inventoried vacant and underutilized land:

- Developed a multi-objective, binary-integer programming formulation (LOCAL) for the allocation of reuse strategies across the urban environment; LOCAL provides the user with 'good' near-optimal solutions;
- This methodology facilitates the allocation of multiple strategies to a single parcel, to achieve a mix of green infrastructure uses at each site, if desired;
- Provides users with the ability to readily generate "what-if" scenarios based on user-specified allocation constraints (e.g. minimum separation distance between identical uses, number of allocations permitted, minimum area requirements, etc.);

- Aids in community-focused solutions (by clarifying the needs of the community) for the efficient reuse of vacant and underutilized land.

A prototype decision support system for the designing and costing of municipal green infrastructure:

- Developed a prototype tool (DECO) for municipal green infrastructure managers, tasked with the design of green infrastructure projects, allocating budgets for capital investments, maintenance, and replacement of infrastructure elements;

- DECO can be utilized to design and investigate material alternatives ("what-if" scenarios), maintenance schedules, and different cost regimes, reducing both initial construction and long-term preventative maintenance costs;

- A systematic approach of this nature could be adopted by municipal decision-makers as a best management practice for green infrastructure investment decision-making.

Estimating the stormwater attenuation benefits derived from planting four monoculture species of deciduous trees on vacant and underutilized urban land parcels:

- The tree canopy layer was found to intercept and evaporate approximately 6.5% to 11% of the total rainfall that fell onto the crown across the 7 years studied, for the *Ginkgo biloba*, *Platanus x acerifolia* and *Acer saccharinum* tree stands, and 17% to 27% for the *Liquidambar styraciflua* tree stand;

- A combined canopy and grass layer had quite similar results with respect to site runoff, when compared to the grass layer alone;

- The total leaf area of a tree species at maturity should not be solely used when making land use management decisions related to tree species selection for temporary tree plantations. If this had been the indicator used for tree species selection in this study, *Acer saccharinum* would have been selected [Peper et al., 2001]). As discussed above, the *Liquidambar styraciflua* stand performed the best, while the *Acer saccharinum* stand performed the worst during the years evaluated;

- While the actual leaf area values may be uncertain because of a lack of local tree growth data, the approach warrants further investigation.

6.3 Research Challenges and Lessons Learned

There were several research and design challenges that arose during the completion of this thesis; these challenges are described below.

- Two challenges encountered during the development of C-SAP were: (i) ensuring it was applicable to a diverse group of end-users, and (ii) ensuring it was easily adaptable to suit specific user-needs. While effort was made to satisfy these two requirements, there were areas where C-SAP was scoped (or simplified), to balance the complexity of the required programming to facilitate this level of functionality and to ensure that C-SAP would run efficiently (e.g. limited the number of constraint variables in LOCAL; capped the number of total reuse strategies evaluated at fifteen).

- The prototype decision support tool presented in this thesis was developed for community leaders/champions, with potential applications for municipal planning departments. As such, it was necessary to ensure that this software was readily accessible to users, at low or zero cost, and easily understandable with minimal prior technical knowledge. This presented a considerable challenge. To tackle this challenge effectively, C-SAP was predominantly automated to guide the user through the input requirements. C-SAP was developed with numerous prompts and guided user interfaces, and included extensive user help files to facilitate this process and minimize the potential for input errors.

- Due to time constraints, the acceptance testing conducted for C-SAP was limited to four colleagues at McMaster that specialize in decision support systems. These individuals cannot be considered "lay persons", and as such the testing did not provide clear assurances that the system would be appropriate for a lay person to use, interpret, and execute commands. A testing regime that includes community leaders from a variety of neighbourhoods with varying socio-economic structures, as well municipal planning staff, would be recommended, and is the subject of future work (beyond the scope of this thesis) to refine and further enhance the functionality and usability of the prototype tool.

- DECO uses a deterministic LCCA method, and while it is an effective method if based on reliable data (Rahman and Vanier, 2004), there are several limitations of this approach. For LCCA to contribute to meaningful, responsible decision-making, infrastructure managers require access to reliable cost data. The value of the technique depends on the quality of input data. Decision-makers are required to anticipate and organize a range of key data variables, including land acquisition expenses, future costs, maintenance schedules, and the service life of various materials (Rahman and Vanier, 2004). A deterministic approach can be data-intensive and there can be uncertainty in the input values (Rahman and Vanier, 2004). Predicting future costs can be difficult due to uncertainty in future costs, interest rate and future events (e.g. repair and replacement of infrastructure elements). Determining the service life of municipal infrastructure adds further complexity to the LCCA outcomes, although these can be estimated using professional judgment and the observed probability of failure (Rahman and Vanier, 2004). To further complicate this form of analysis, in practice, infrastructure elements may be replaced before the end of their technical service life, making forecasting difficult (Rahman and Vanier, 2004).

- While sensitivity analyses can be useful in understanding the effect of changes to individual model variables on the LCCA outcomes, decision-makers do not gain an understanding of the combined influence of several variable changes on the results and variable rankings using a deterministic approach (Christensen, Sparks and Kostuk, 2005; DOT, 2008). Sensitivity analysis may also fail to identify a dominant alternative among the design options (Christensen et al., 2005). Without assigning probability distributions to variables, it is not possible to explore the likelihood that particular values will occur. A probabilistic approach addresses many of these shortcoming (Christensen et al., 2005); however, for transparency purposes and knowledge requirements (i.e. the generation and application of probability distribution curves for various variables – knowledge/understanding that a lay person may not have), risk analysis (i.e. a probabilistic approach) was not employed in DECO, as this was viewed to be a potential barrier to the overall usability of this tool.

6.4 Suggestions for Future Work

The following section provides a summary of potential future work, related to the sustainable reuse of vacant and underutilized urban land.

- The development of a methodology that provides decision-makers with the capacity to design and strategically implement continuous productive urban landscapes (CPULs) throughout the urban environment (continuously connected green infrastructure elements, connected through linear systems, or 'veins');

- Develop an augmented capacity to C-SAP that can facilitate a city-wide spatial analysis of productive uses to allow abutting neighbourhoods to communicate information with each other relating to the efficient use of vacant urban lands at a city-wide planning scale;

- Develop an augmented capacity to C-SAP that provides shadow analysis capabilities, which could be used prior to conducting a life cycle cost analysis in DECO (e.g. to maximize or minimize solar access);

- Evaluate a range of complex to simplistic vacant land inventories to determine if a simplistic approach results in similar allocation scenarios (thereby reducing the user input requirements and system run time of C-SAP);

- Investigate the integration of C-SAP with GIS software to facilitate a wider use of the system among urban planning professionals, and a wider range of potential outputs (e.g. maps, enhanced spatial analysis, statistics, etc.);

- Develop a series of audit tools for user patronage and maintenance requirements for sites that have been brought into productive reuse, to aid decision-makers in better understanding which parcels to strategically acquire for their permanent municipal green infrastructure inventory.

6.5 References

Christensen P.N., Sparks, G.A., and Kostuk K.J. (2005). "A method-based survey of life cycle costing literature pertinent to infrastructure design and renewal." Canadian Journal of Civil Engineering, 32(1), 250–259.

U.S. Department of Transportation (DOT). (2008). "Life Cycle Cost Analysis for Pavement Type Selection."

Vanier, D.J. and Rahman, S. (2004). "MIIP Report: Survey on Municipal Infrastructure Assets. Report B-5123.2." Prepared by the Institute for Research in Construction (IRC), National Research Council Canada: Ottawa, ON.

Appendix A. System Requirements Document

This appendix contains the System Requirements Document that was prepared prior to the development of C-SAP. This document articulates the prototype decision support system purpose, scope, capabilities, conditions and constraints. The articulation of this information translated into a scientific software product that addresses system performance, information management, maintainability, and life-cycle sustainment of the prototype tool.

System Requirements Document

Document Prepared: June 16, 2010

1.1 System Purpose

The purpose of the enclosed system requirements documentation is to determine the system requirements for a prototype community-based self-assessment planning (C-SAP) tool for the temporary re-use of vacant and underutilized land. This tool will demonstrate the potential to create temporary community amenity spaces that will be productive (socially, environmentally, and/or economically) during a short- to medium-term planning horizon, until a higher-order, ultimate/long-term land use is established (e.g. residential, commercial, industrial or institutional uses). Vacant and underutilized land exists in every city to varying degrees and varying conditions. There is a growing body of literature that states that these parcels hold great opportunities to not only stabilize declining neighbourhoods but to become vital public amenity spaces if allocated and designed with regard for the existing/future spatial and social context of a community. Temporary re-use strategies and their associated costs and planning horizons are identified through five (4) tools within the C-SAP interface. The C-SAP interface will (i) guide users through the process of conducting a vacant and underutilized, field-level land inventory at the neighbourhood planning scale, (ii) determine the "best uses" for said land parcels based on expert knowledge of urban planning and design practices, (iii) execute a location-allocation methodology, and (iv) determine preliminary costs for the selected re-use strategy.

1.2 System Scope

The decision support system, known as C-SAP, will serve as a prototype and will consist of a customized, guided user interface (GUI), and a collection of databases that store land use planning data as well as design and costing data. The system will be developed using the Microsoft Excel® software platform, using the built-in Visual Basic for Applications (VBA) programming environment to execute the functions and sub routines required to complete each of the modules in the tool. The user will be required to have an internet connection at several key points during the use of this tool, in order to interface with existing tools that will assist in completing C-SAP (e.g. geocoder, Google earth). The C-SAP software application will be equipped with a variety of functions to assist the user in navigating the interface and completing each task. This will be done through embedded help files and messages that will appear to the user under a variety of circumstances (e.g. roll-over, pop-up, and status bar messages). It is anticipated that this will assist the user in navigating the interface relatively seamlessly. It is anticipated that the C-SAP interface will be accessed via a windows-based tablet PC. Provincial Legislation (and associated regulations), municipal and provincial policies, zoning by-laws and guideline and other planning documents that affect the re-use of vacant land, will not be built into C-SAP system. Rather, when required, the user will be prompted for generalized land use information. This decision was made due to the nature of legislation, policies, and guidelines, which are complex in nature, can vary across a city (and by land use), and are subject to regular amendments, which would have required that the user of the system (for C-SAP it is assumed to be a lay person) follow all relevant municipal and provincial amendments and further manipulate and update the relevant components of C-SAP.

1.3 Definitions, acronyms and abbreviations

1.3.1 Definitions and abbreviations

Neighbourhood Association refers to a group of citizens who work together with a president and committee to carry out a variety of functions for the betterment of their neighbourhood and the city in which they live.

User refers to the user of the prototype system, known as C-SAP. The system was developed for lay persons, neighbourhood association presidents or a designate from their committee, municipal planning staff, and/or land owners who occupy vacant or underutilized land and wish to explore the potential opportunities stored within this parcels.

System refers to the C-SAP decision support tool in its entirety, including all associated files and folders, the customized graphical user interface, built-in databases, and macros that carry out all functions and sub routines (e.g. data manipulation, storage and computations) within the C-SAP tool.

Interface refers to the suite of components that make-up the C-SAP interface. C-SAP consists of several customized graphical user interfaces, developed in the VBA environment. The interface consists of forms for data entry, input box prompts, message box prompts, roll-over messages that provide a message to the user when they roll-over a specific cell or area in a worksheet, status bar messages that convey information to the user with respect to the status of a task that has been executed, links to help files, and reference photos to assist in conveying information to the user for the completion of each module.

Vacant land refers to publicly or privately held residential, industrial, commercial, institutional, agricultural, open space and parkland that is not utilized (greenfield), or abandoned (including derelict buildings or remnants of buildings). Vacant land may be contaminated (i.e. land that cannot be used productively without remediation), whether perceived or actual.

Underutilized land refers to publicly or privately held residential, industrial, commercial, institutional, agricultural, open space and parkland that is not utilized to its full potential. Understanding the past orientation of a space and the current needs of neighbourhoods can assist in bringing underutilized land back into a productive, value-enhancing amenity space for neighbourhoods.

Productive reuse refers to the act of bringing a vacant or underutilized parcel back into a socially, economically and/or environmentally productive capacity for the betterment of a neighbourhood.

Temporary refers to the temporary (i.e. not permanent) nature of reuse strategies.

Batch geocoder refers to the automated process of converting a "batch" (more than one) of municipal addresses (municipally assigned street number and street name) to a set of coordinates (latitude and longitude: degrees, minutes, seconds). This is done using street-level addressing data and interpolating between addresses, based on the range of addresses along a particular cross-section of the street network (i.e. geocoders are not based on parcel geometry or parcel centroid, but rather street cross-section, municipal address range and the process of interpolation). The user will be encouraged to use an internet-based free batch geocoder website to complete the task of geocoding addresses for use in the C-SAP system.

"Higher-order" or "ultimate land use" refers to the Official Plan designation for a parcel of land. These terms, used synonymously, refer to the fact that a planned, higher-order use for vacant and underutilized parcels may be known and documented in the Official Plan policies (The land use planning policy document for Ontario cities). However, the timing of this development may be unknown and as such, these parcels may hold valuable opportunities on a temporary basis.

Workbook refers to a single Microsoft Excel file, known as a workbook.

Worksheets refers to individual worksheets, or "spreadsheets", within a workbook.

Databases/tables refers to worksheets within the C-SAP interface that were developed for the user and store information that is used to execute functions and sub routines stored in the C-SAP macros (i.e. code modules), written in the Excel VBA programming environment.

Click-event refers to when a user has completed a section or all of a fill-able form on the customized GUI, and upon completion, is required to click a button to proceed to the next step. This process, known as a click-event, will execute code that will perform a task (e.g. copying data, comparing data, validating information, searching a database, etc.)

Subject site refers to the vacant or underutilized parcel that is potentially re-usable on a temporary basis.

1.3.2 Acronyms

C-SAP – Community-based self-assessment planning tool for identifying and designing reuse strategies for vacant and underutilized urban land

VULI – Vacant and Underutilized land inventory (Task 1 in C-SAP)

SSI – Site Suitability Indices (Task 2 in C-SAP)

LOCAL – Local-allocation modeling (Task 3 in C-SAP)

DECO – Design and costing (Task 4 in C-SAP)

GUI – Graphical User Interface

VBA – Visual Basic for Applications programming language

VBE – Visual Basic Editor (used to write and store all code within Microsoft Excel)

1.4 System Overview

As outlined in sections 1.1 and 1.2, the system known as C-SAP consists of four (4) tools that were developed to fit a tablet PC that is capable of running the Windows operating system and Microsoft Office software suite. The user interfaces with the system via a customized user interface in Microsoft Excel®. A collection of software modules reside within Excel's embedded Visual Basic for Applications programming environment. A series of databases and tables reside within worksheets and are used to perform calculations and execute other functions, carry out a variety of sub routines, and convey meaningful information to the user to aid in decision support related to vacant and underutilized land reuse.

2 General System Description

2.1 System Context

C-SAP is predominantly a self-contained system that has minimal technology and software requirements. The user will need to have access to a PC that: (i) is portable (such as a tablet PC or laptop), (ii) has the Windows operating system installed, (iii) has the processing power, space, and license to operate Microsoft Excel®, (iv) has mobile internet access (via a USB device, WiFi, or 3G network), and (v) has a battery storage capacity sufficient for conducting a neighbourhood-level inventory. Once the above requirements have been met, the user will access the Microsoft Excel® workbook, which will display a customized GUI upon opening the workbook and will subsequently prompt the user to open a "Read Me" document that will contain all of the user requirements for navigating the C-SAP interface and completing each task within the built-in tools. As mentioned, there will be several instances throughout the completion of C-SAP that require the user to utilize existing tools that are external to the C-SAP system (e.g. Google Earth drawing tools, geocoder). This will be done via links in the customized GUI that activate each application automatically, providing step-by-step directions.

2.2 System Modes, States and Capabilities

Mode 1. Non-operational
The C-SAP tool has not been downloaded from McMaster's web server to a laptop or tablet PC.

Mode 2. Set-up
The C-SAP tool and all associated/linked files have been downloaded to a laptop or tablet PC.

Mode 3. Initialized
The system is initialized when the Excel-based, C-SAP parent file has been opened.

Mode 4. Prompting
The system begins prompting the user for inputs for Task 1 (VULI), upon initialization. This is done via a customized GUI via a fill-able form.

Mode 5. Collecting and storing inputs
When a user has responded to a prompt command, C-SAP (depending on the command executed) will collect, organize, and store the data inputs in various locations within both public and semi-hidden worksheets.

Mode 6. Data Manipulation: searching, selecting, copying, pasting and validation
In some instances when click-event procedures are executed by the user, C-SAP may execute a function such as a search/find, copy, paste, and validate function. Essentially C-SAP is organizing the data for computational and visual display purposes.

Mode 7. Computing and evaluating
C-SAP is capable of evaluating the neighbourhood spatial context using geo-coded vacant and underutilized land coordinates as well as built-in spatial databases (e.g. areas and centroids of key neighourhood features such as parks). The C-SAP tool performs calculations when a click-event procedure is linked to a macro that contains computational instructions in VULI, SSI, LOCAL, and DECO.

Mode 8. Saving and Outputting Scenarios
The C-SAP tool has the capability to save scenarios in the parent workbook (i.e. the C-SAP interface). This was done to avoid saving the workbook as a separate document each time a user wishes to perform a neighbourhood analysis. The user can output a summary of the results for each module (VULI, SSI, LOCAL, and DECO). Summary output will include recommended re-use strategies, site suitability indices, location-allocation results, and LCCA analyses.

2.3 User Characteristics

C-SAP was developed for the following end-users:

1. A Neighbourhood Association President (or designated representative). The president or president's designate are the primary users of this system, and as such the system has been designed to meet their needs (i.e. a lay person).

2. **A landowner holding full title or partial title to a piece of vacant and underutilized land:**
Landowners are also considered likely users of this system. It is believed that some owners will take the initiative to carry out the tasks required for the completion of C-SAP in order to better understand how their land can be used more effectively in the short-, medium- or long-term planning horizon.

3. Consultants that perform services such as waste removal, site grading, landscaping, gardening and design expertise may be required to provide input to C-SAP in the form of a costs table that can be updated on an as-needed basis to perform life cycle cost analyses.

4. Municipal Planning Staff may potentially interface with C-SAP to complete VULI, SSI, LOCAL, and DECO, or to collect the relevant data from neighbourhood associations for further analysis/evaluation.

2.4 Operational Scenarios

There are three operational scenarios: (i) C-SAP is completed by a Neighbourhood Association president or their designate, or (ii) C-SAP is completed by a vacant or underutilized landowner, or (iii) C-SAP is completed by municipal planning staff. The system requirements are identical for all three scenarios and are described in further detail in Section 3, below. Note: in these operational scenarios, the user has the opportunity to update costing information by providing a standard template to a variety of consultants. The completed template would be returned to the user and imported into C-SAP for use in DECO.

3 System Capabilities, Conditions and Constraints

3.1 Physical, Durability and Environmental Conditions

Physical, Durability

To ensure that C-SAP functions as expected, the user is strongly encouraged to have the Windows operating system and Office 2007 installed on a portable PC. The use must meet the following hardware requirements:

- Purchase/utilize a portable computer with that:
    - Has mobile internet capabilities (USB port, WiFi, or 3G)
    - Has a battery life (toggling between the internet and Excel) for 4-5 hours minimum
    - Has video and camera capabilities
    - Is waterproof (essential for field inventory – VULI)
    - Can withstand falls (shocks to hard drive)
    - Has an 10" screen at a minimum

Environmental Conditions
VULI is limited to late spring, summer or early fall, seasons where the ground is free from snow and tree foliage is either leafing, in full leaf, or in a leaf-off period (suggested time for inventory June through September). This is essential for the user to understand surface and shading conditions. Running the portable device for long periods of time in extreme hot (full sun) or cold weather events is strongly discouraged as it could overheat and irreparable damage to the hardware. The remaining tools that comprise C-SAP can be carried out from an indoor office, home, or library setting.

3.2 System Performance Characteristics

The following list outlines specific system performance requirements:

1. Run-time of code event procedures (functions and sub routines) – while much of the code will appear to execute almost instantaneously, 90% of the automated event procedures (e.g. click-event procedures) will take no more than 10 seconds to execute.

2. Completion of C-SAP – VULI will be developed such that the time it takes to obtain the required in-field information (for further out-of-field analysis) will take no more than 4 hours, given the delineated neighbourhood boundaries found in the City of Hamilton. In areas containing many vacancies or underutilized land, the user may require access to a bike, vehicle or public transit during the inventorying process to cover larger tracts of land. While the speed at which the remaining tools (SSI, LOCAL, and DECO) will be executed depends largely on the user's preparation/comprehension of the tasks (i.e. reading the user guide and help files) and comfort/speed with computers, they will be developed with the aim that it should take no longer than 30-minutes per tool.

3. Size of input window – C-SAP will be built to fit a minimum screen size of 10” (i.e. a 10-inch tablet)

4. Computer Settings – the user is required to ensure that permission is given to enable all macros in the C-SAP workbook (the user may need to access Excel Options, followed by the Trust Centre to adjust this setting)

3.3 System Security

The following steps will be taken to ensure the integrity of the C-SAP system:

- Security will be provided by minimizing access to sensitive data, by guiding the user to the worksheets that can be amended;
- The majority of the worksheet cells will be locked (non-fillable/amendable), as the main route of user inputs will be through customized, fillable forms;
- All fillable cells will be denoted with the same colour (green) for consistency and ease of use.

3.4 System Operations

Non-Functional Requirements
C-SAP will be quick to launch and easy to use. The interface will consist of a logical step-by-step process, advancing the user through the tool relatively seamlessly. There is a requirement that 90% of all first-time users will be able to complete the tasks within the C-SAP interface.

Functional Requirements
Upon opening C-SAP, the customized GUI will launch and the user can begin completing the required tasks. A link will also appear when the parent Excel file is opened; this link, if selected by the user, will launch the user specifications documentation. All inputs will be received by C-SAP as per the description found in Section 2. C-SAP will be developed to detect errors with respect to input variables (e.g. reject string inputs if C-SAP is expecting an numeric inputs). If the user is struggling with what to input, help buttons, when selected, will recommend an action to the user. Procedures that are not carried out instantaneously will have a message appear in the status bar, located along the bottom of the screen on the user interface. C-SAP will step the user through the interface, providing

indicators with respect to what percentage of the inputs have been completed and what is remaining. This will be done via messages at the top of user forms that indicate the user is on "Step 1 of 12", for example, along with the estimated time required to complete the task. By conveying this information, the user can gauge whether they have enough time to complete that particular section of the tool or whether they should come back to it later. When C-SAP is completed in its entirety (VULI, SSI, LOCAL, and DECO), it will prompt the user to select their preferred format for the output. Once selected, it will prompt the user to save the scenario. Refer to section 3.4.2 for details relating to information management and maintainability. Detailed input requirements for each component of C-SAP are described below.

3.4.1 Human Factors

Users must have a solid understanding of their neighbourhood characteristics. They should be aware of neighbourhood needs and demographics such as socio-economic breakdown and cultural diversity.

Users are required to have a basic working knowledge of Microsoft Excel®. They will also need to know how to access and browse the internet in order to navigate Google Earth and the geo-coding websites. Users will require access to a portable computer that, preferably, runs the Windows XP operating system and has Excel 2007 installed (part of the Office 2007 package), or a later version.

Users will be required to read the user specifications documentation, which will explain the "how-to's" of downloading, opening, and interfacing with the system, as well as completing all required tasks.

3.4.2 Information Management and Maintainability

Information Management

C-SAP has the capability to save scenarios in the parent workbook, to be displayed as desired. This was done to avoid saving the workbook as a separate document each time a user wishes to perform a neighbourhood analysis, as the workbook and all of its associated macros will take up a large amount of the hard drive capacity (typically 1GB) on a tablet PC.

Maintainability

The system will be developed in such a way that future researchers (e.g. M.Eng candidates or summer research students) will be able to adapt C-SAP relatively easy (e.g. add a component or amend existing components). To ensure that it will be possible for future researchers to adapt the system with relative ease, all code modules will be properly divided into blocks (as appropriate) and all code will be well documented (via commenting within the code). In the future, this project may also be well-suited in the open source community to ensure meaningful and applicable refining.

Costing data are subject to frequent changes and as such, this information will be stored in a public database format (via an Excel worksheet) that can be amended by the user of the system on an as-needed basis. There will be an external template available to email to consultants for their completion. This information will then be imported into C-SAP by the user with the click of a button. *It is important to note that a consultant will not be able to change the structure of the costing database only the costs will be amendable.*

Users will not have access or the ability to amend the expert knowledge sections of C-SAP. While changes to these sections could be made by the developer of C-SAP, requests for such changes would be evaluated and if deemed appropriate, and time-permitting, be carried out.

3.4.3 Reliability

The system is expected to function as per the specifications outlined in sections 2.4, 3.1 and 3.4. The user should ensure that they have their Excel settings set to "macros enabled".

3.5 Life-cycle Sustainment

Due to the nature of this system, being research for a doctoral degree, maintenance will be provided upon request, and carried out (i) if deemed necessary (blatant errors/omissions), (ii) if deemed appropriate (i.e. would significantly enhance the value of the system for end users), and (iii) time-permitting. Maintenance requests meeting the aforementioned criteria will be offered for a minimum period of 2 years after the completion and release of the C-SAP tool on the McMaster University Sustainable Communities Research Group website. This system is intended to be a prototype and is not intended for use outside the scope of the previously defined users.

4 System Interfaces

The primary system interface for C-SAP is the customized GUI developed using the VBA programming language in Microsoft Excel®. C-SAP will also require the user to interface with two websites: (i) BatchGeo, and (ii) Google Earth. Adobe Acrobat Reader will be required for viewing all help files.

Appendix B. Vacant and Underutilized Land Inventory (VULI) Development

This appendix is divided into two parts: Part 1 - the draft methodology, which was distributed for review/comment, and Part 2 - the final (refined/revised) inventory employed in C-SAP. As part of completing VULI, input from experts in the fields of urban planning, parks planning, urban agriculture, urban design, and engineering was solicited over a 4-month period in 2010.

Part 1: Draft Community-based Self-assessment Planning Tool (C-SAP)

for identifying reuse strategies for vacant and underutilized urban land

Document Prepared and Distributed: August, 2010

This draft methodology was sent to the following review team participants for their input (*Members of the review team that provided input)

*Brian Baetz: Professor of Civil Engineering, McMaster University, Hamilton, Ontario

*Cam Churchill: Assistant Professor of Civil Engineering, McMaster University, Hamilton, Ontario

Emily Reisman: Urban Planner; Associate, Urban Strategies, Toronto

*Shawna Milanovic: Wastewater Engineer, City of London; former Stormwater Management Engineer, City of London

Sean Galloway: Urban Designer, City of London

Sarah Wakefield: Professor of Geography, University of Toronto (Urban Food Security)

*Dale Wood: Contract Program Manager, Special Projects, Recreation Division, City of Hamilton

*Theresa Phair: City Housing Hamilton, Community Garden Facilitator, City of Hamilton

Brian Morris: Business Development Consultant, City of Hamilton, Economic Development & Real Estate Division

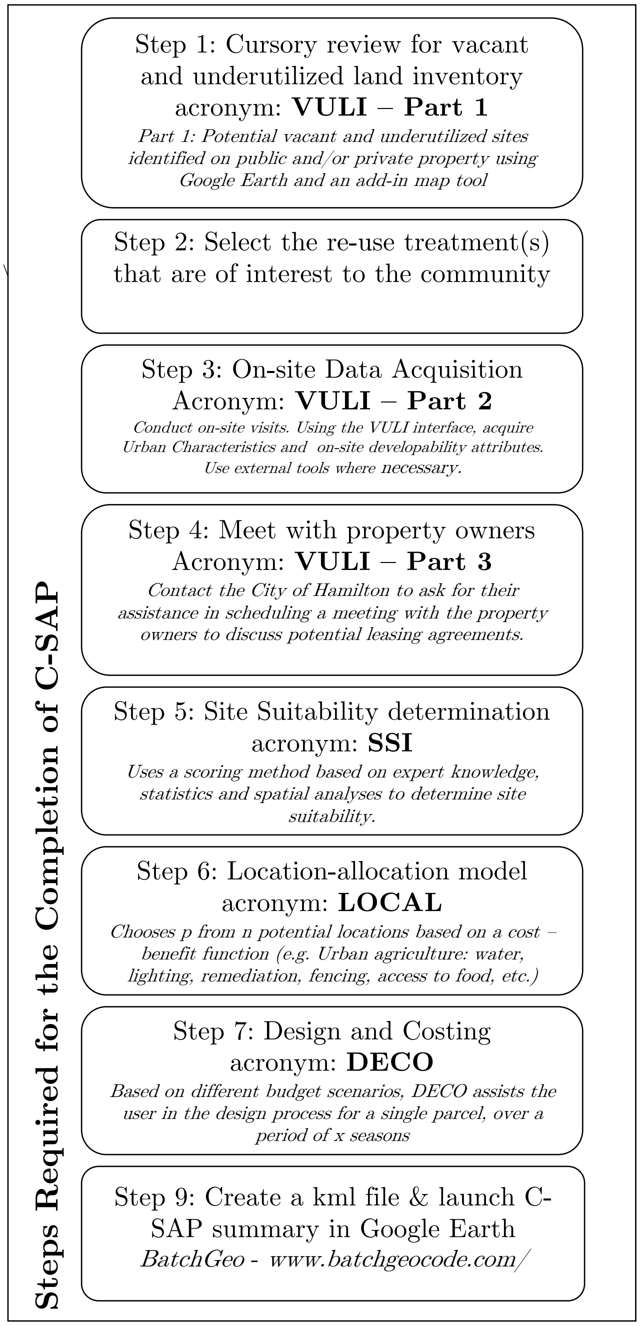


Figure B.1 Overview of C-SAP Planning Tool

Impetus for Research

Many cities across the globe, regardless of size or geographic location struggle with the presence of vacant and underutilized land in the urban environment; to-date long-term solutions that contribute to the recovery of declining areas have not been implemented on a consistent basis, if at all (Pagano and Bowman, 2000). To take full advantage of vacant land, it is critical that its location and characteristics are identified (Pagano and

Bowman, 2000). The term *vacant land* can hold many meanings for municipal and provincial stakeholders. It has been used in an urban context to describe publicly or privately held residential, industrial, commercial, institutional, agricultural, and open space lands (preserved/not-preserved) that are not utilized (greenfield), under-utilized, or abandoned (including derelict buildings or remnants of buildings). Vacant land may be contaminated (i.e. land that cannot be used productively without rehabilitation), whether perceived or actual (Bowman and Pagano, 2004: 145). Bowman and Pagano (2004: 19) state that while all cities contain vacant land, the type and supply of vacant land and the condition of said land can vary greatly. The authors further state that the phenomenon of vacant land has not been heavily studied and that cities continue to search for ways to best transform vacant spaces (Bowman and Pagano, 2004: 7; 10). In an attempt to understand the complexity of the vacant land issue in American cities, Bowman and Pagano (2004: 7; 25) conducted a survey of planning directors in U.S. cities with populations of 50,000 or greater and found that on average approximately 15% of a city's land area can be classified as vacant, as per the open-ended definition above. This untapped resource presents enormous opportunities socially, environmentally and economically for cities with stable, growing, or shrinking populations. The transformation of these spaces has a multitude of benefits: they can stabilize lots and neighbourhoods thereby mitigating the often precipitous economic and social decline in these areas, improve the public realm, create productive landscapes, support sustainable transportation initiatives, introduce new pedestrian connections, attenuate stormwater, clean the air and soil, create networks for locally grown food, increase social capital (relationships among citizens that generate social, environmental and economic returns for a community), and provide places for recreation and quiet retreat.

Short-term strategies (0-5 years) (Strong Market – likely to develop for a higher-order land use)	• Clean and basic greening • Soil remediation: Bio-remediation, myco-remediation, and phyto-remediation • Carpooling lots, bike lock-ups • Parking lot garden plots • Greening parking lots • Bagriculture (gardening within compostable, moveable bags), moveable gardens • Centralized garbage pick-up
Medium-term strategies (5+ years) (Weak Market – likely to sit idle until redevelopment potential improves)	• *Treatment options listed under short-term strategies (0-5 years)* • Community garden plots • Outdoor farmers' markets • Mid-block and multi-block pathway connections • Passive parks and open space • Tree/plant nursery • Composting sites
Long-term preservation strategies (Land transferred to private or city ownership, land trust, or long-term lease/easement)	• *Treatment options listed under short- and medium-term strategies (0-5+ years)* • Neighbourhood farms, urban farms • Active parks and open space • Orchards • Solar fields • Public square • Gateway into a neighbourhood • Stormwater management (rain gardens, rainwater collection and storage, stormwater management ponds, swales, stream daylighting) • Linear pathway expansion • Lot-splitting (conveying half of a residential vacant lot to adjacent property owners) • District energy facility

Figure B.2 Timeline for Reuse Strategies
(Adapted from KSU, 2009)

Symbol Definitions:

1. Obtain information on-site (i.e. while standing at the edge of the potential area for reuse) 

2. Obtain information from the landowner(s) 

3. Obtain information from the City City

4. Launch Google Earth Google Earth

5. Open C-SAP interface C-SAP

VULI: Step 1. Cursory Google Earth inventory

You need: Google Earth C-SAP

Grimm (2009) stated that agricultural producers believe it is a good idea to create an inventory that identifies potential vacant or underutilized land for food production within the urban boundary. Planning staff interviewed in Ames, Iowa stated that studying existing aerials and parcel data was the best way to locate vacant or underutilized parcels (Grimm, 2009). Mendes et al. (2008) propose the use of aerial photographs to inventory various characteristics of vacant land including tree cover, the presence of buildings, and parking. Following this cursory review, a suitability ranking would then be assigned, and a more detailed, on-site analysis and collection of site attributes would follow for each candidate site to determine their overall reuse potential. A simplified approach is being suggested herein whereby the user reviews the satellite imagery provided in Google Earth and adds "pushpins" to demarcate locations where there is potentially vacant or underutilized land available for reuse. The user should look for and add pushpins to sites that have:

- few or no buildings
- grass, bare earth, gravel, asphalt, concrete, or a mixture of these as groundcover
- have a sizeable area available for reuse (minimum 300m^2)

Vacant and underutilized land uses may vary and can include:

- Abandoned single-detached houses, semi-detached houses, and row houses
- Occupied mid- and high-rise residential structures (with open space or underutilized parking)

- Commercial and industrial lands
- Places of worship
- Schools
- Offices
- Hospitals
- Underutilized parkland
- Underutilized parking lots
- Public right-of-way (e.g. adjacent to sidewalks)

After the user has carried out this cursory review, they will either take a tablet computer into the field (or printouts from C-SAP) and carry out a more detailed site analysis.

VULI: Step 2. Short-list potential reuse strategies

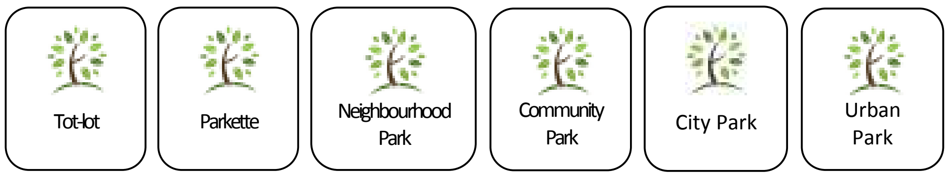
You need: 

The user will open the C-SAP interface, and select the reuse strategies that they (or their community group) are interested in pursuing. The following symbols are used throughout this document to identify the reuse strategies available.

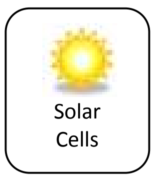
***Green Infrastructure* Reuse Strategies:**

Urban Food Production

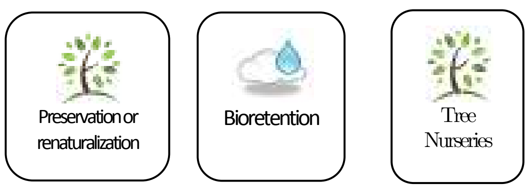
Parks



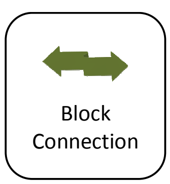
Renewable Energy



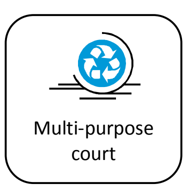
Stormwater Management



Block connection



Multi-purpose court



A customized inventory will be displayed based on the user's selections. The user can either print this inventory n times representing n sites to be inventoried (based on the push-pin locations) or the user can take a tablet computer into the field and enter the results from the inventory directly into C-SAP.

A Brief Introduction to the *Green Infrastructure* Reuse Strategies developed in C-SAP

Urban Food Production

The VULI and SSI tools were built to capture the potential for reusing vacant and underutilized land for the following urban food production elements: Community garden plots, neighbourhood/community farms (which includes learning gardens, institutional gardens and gardens organized for not-for-profit groups – e.g. food co-ops and victory gardens), commercial farms (including CSAs), orchards, and outdoor farmers' market locations, by applying a hybrid of Hohenschau's (2005), Grimm's (2009) and Kent State University's (2008 and 2009) best practices guidelines.

Duany Plater-Zyberk (2009) developed a vision for food production along, what has been dubbed by the Congress for New Urbanism as, the Urban-Rural Transect Zone. The appropriateness of each food production element within the various Transects has been incorporated into VULI. Note: Urban Centre represents the core of a neighbourhood or town centre, while Core represents an area that services the region – typically the central business district. Duany Plater-Zyberk also define a concept known as "Agricultural Urbanism". The premise of C-SAP is to find ways to productively reuse vacant and underutilized land across all urban transects, thereby intensifying, in suitable locations, the agricultural activity across the Transect – which aligns with the following definition.

> *"The basic premise of Agricultural Urbanism is that when farmland is built upon, one third will be urbanized while the production of the whole will be tripled. This is achieved by intensifying the agricultural activity across the Transect, from window boxes, balcony and roof gardens in the more urban Transect Zones, to the progressively larger community gardens, yard gardens, small farms, and ultimately large farms in the more suburban and rural Transect Zones" (Duany Plater-Zyberk, 2009).*

Hohenschau (2005) and Grimm (2009) introduce a variety of urban food production elements that interact within urban environments – these are summarized in the table, below. Ancillary elements that support urban food production include composting, community baking ovens, community kitchens, retail stores, and Farmers' Markets (Hohenschau, 2005), as well as other supporting infrastructure, including processing areas (for cleaning and packaging), storage areas (e.g. refrigeration). Grimm (2009) proposes a continuous connection between urban food production spaces through growing and selling food along food boulevards (pedestrians and cyclists only), and market boulevards (public transit, pedestrians and cyclists only).

Table B.1 Urban Food Production Typology

Urban Food Production Type	Size (minimum)	Recommended Standard
Community garden plots	Plot area of 1m x 2m; community garden area of 18.6m^2 (Hohenschau, 2005); less than or equal to $\frac{1}{2}$ acre (Grimm, 2009); 4000ft^2 (KSU, 2008)	One community garden for every 2,500 residents (Seattle Land Use Plan, 1994); one community garden within $\frac{1}{2}$-$\frac{1}{4}$ mile radius of all residents (Grimm, 2009); 6.5 plots/1000 residents 18.5 m^2 minimum) (Hohenschau, 2005)
Community farms; neighbourhood farms	300 m^2 (Hohenschau, 2005); 1acre* (1 to 3.5 acres) (Grimm, 2009)	Provide 50% of all residential units that do not have access to 100ft^2 of growing space, with a garden plot (Hohenschau, 2005)
Commercial farms/market garden/urban farms	1200m^2 (Hohenschau, 2005); >3.5 acres (Grimm, 2009); 1 acre (KSU, 2009)	No standard cited in literature
Fruit trees and orchards	Larger lot (KSU, 2008); size varies – need minimum width of 3 metres per planting (Hohenschau, 2005)	No standard cited in literature
Farmers' Markets	1500m^2 to 2500m^2; 12-14 metres (one-sided) and 22 metres (two-sided); 10x6 metres for each stall; ample nearby parking (Hohenschau, 2005)	Trade area of 4.8-11.2km (3-7 miles) (Hohenschau, 2005); minimum of 10 stalls (Hohenschau, 2005)

*can be smaller than 1 acre and still yield a significant amount of produce for sale or personal consumption (Grimm, 2009; Hohenschau, 2005; KSU2008)

Solar Cells

The Ontario Power Authority (OPA) encourages small-scale renewable energy projects (MicroFIT projects) in collaboration with members of the community (ex. School, community centre, place of worship, library, non-profit, neighbourhood group, etc.). MicroFIT projects are projects that are less than 10kw in terms of capacity. FIT projects are projects that are larger than 10kw (Ontario Power Authority, 2010).

Bioretention areas

With increased urbanization, much of our green spaces like wetlands and forests were paved over with hard surfaces that channel large amounts of rainwater at increased rates into our sewer systems. Bioretention areas such as swales and rain gardens help capture stormwater and either detain or retain it, reducing the frequency of combined sewer overflows and potentially recharging groundwater and contributing to the biodiversity or a particular cross-section of the urban landscape. Bioretention can be a low-cost treatment (and relatively straight forward to design), and as such it was deemed an appropriate strategy for community groups to initiate. Areas that are heavily paved, or have many roof collection surfaces are excellent candidates for bioretention.

Tree Nurseries

Tree nurseries are perceived to be a short- to potentially long-term reuse treatments for vacant or underutilized lots. While the trees are growing (for ultimate street tree plantings, for example), they provide a variety of benefits including carbon sequestering, particulate removal and stormwater attenuation. Due to their abilities to intercept, transpire and evaporate rain, they have been included in stormwater management category.

Block Connections

Block connections were included as a *Green Infrastructure* strategy to help promote walking and cycling, by placing the emphasis on the pedestrian over the automobile. By providing stronger linkages throughout the urban fabric, in areas that are difficult to navigate (given the elongated nature of blocks and curvilinear road networks), more people will be encouraged to walk or bike to their ultimate destination, thereby creating healthier communities.

Parks/Open Space Classification

The City of Hamilton Parks and Open Space Master Plan states that parks serve three general functions (Hamilton Parks and Open Space Master Plan, 2002):

- they contribute to the protection of natural areas, features and ecosystems,

- help beautify the City, and
- provide areas for outdoor recreation

In addition to this, a continuous landscape of parks and open spaces, connected via linkages and trail corridors provides an opportunity for alternative transportation opportunities (Hamilton Parks and Open Space Master Plan, 2002). The City of London Parks and Open Space Master Plan emphasized an approach to working with local

> "*partners (e.g., school boards, conservation authorities, private landowners, etc.) to find creative non-acquisition based strategies to improve the functional supply of parkland, open space, and recreational opportunities available to residents, particularly in those areas of the City that fall below the recommended targets" (City of London Parks and Open Space Master Plan, 2009)*

The City of Hamilton Parks and Open Space Master Plan (2002) stresses the importance of working with neighbourhood groups to identify and meet local needs. The Ontario Planning Act recognizes the importance of, and need for active and passive park spaces in the urban environment by giving municipalities the authority to acquire 5% of residential (or 1 ha per 300 units, whichever is greater) and 2% of commercial and industrial lands that are undergoing development (provided that parkland has not been previously acquired for these lands) for parkland purposes. With that being said, many neighbourhoods remain deficient in their access to parkland, especially in heavily urbanized areas (e.g. core areas and inner rings of cities). To combat this, one reuse strategy titled "multi-purpose courts" looks at how to create multi-purpose playing courts on top of already-paved surfaces (such as parking lots) in highly urbanized areas of the City. Several patents for such courts already exist. While the City of Hamilton's parkland acquisition strategy focuses on acquisition through future residential and commercial applications (City of Hamilton Parks and Open Space Master Plan, 2002), the plan also recommended that the City adopt a policy framework that pursues the acquisition of new parkland, both in growth areas (such as Hamilton's Urban Growth Centre – which encompasses the downtown core area of Hamilton) and established communities, to tackle existing deficiencies. It is important that, when addressing deficiencies, more emphasis is placed on providing a variety of leisure opportunities, rather than sheer quantity, and a higher priority should be given to providing services to those populations not yet receiving any (smaller interest groups/vulnerable populations) (City of Hamilton Parks and Open Space Master Plan, 2002).

VULI: Step 3. Carry out the on-site inventory

You need: 

The decision-making framework for the vacant and underutilized land inventory (VULI) is modeled after a hybrid scoring methodology used by Rosenberg and Esnard (2008) for transit site selection, whose work is originally adapted from Cutter et al. (1997). The criteria used are shown in the figure below and include Urban Characteristics, Developability, Social Impact, Transportation, User Experience, and Proximity. I have adapted the criteria (originally scoped to Visual Quality, Proximity and Developability, by Rosenberg and Esnard (2008)) to address how to best rank the suitability of vacant and underutilized land for a subset of the reuse strategies, described below.

A two-step approach is employed, as suggested by Van Herzele and Wiedemann (2003), whereby a subset of preconditions are inventoried, prior to collecting the entire suite of vacant and underutilized land characteristics. Similarly, Adams, Baum, and MacGregor (1988) introduce the concept of endogenous and exogenous constraints when reviewing vacant land as a potential resource. Endogenous constraints are site specific (e.g. landlocked), while exogenous constraints are defined as not being specific to an individual site (e.g. extension of municipal infrastructure required). These constraints are addressed throughout the inventory.

The Umbrella criteria used in the hybrid scoring methodology for the temporary reuse of vacant and underutilized urban land are depicted in the following figure (adapted from Rosenberg and Esnard, 2008).

Umbrella criteria

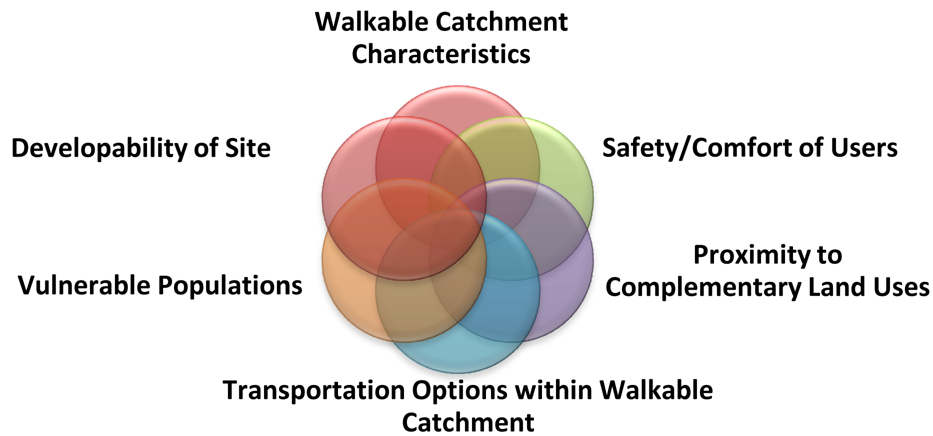


Figure B.3 Umbrella Criteria

Walkable Catchment Characteristics

Understanding the context of the elements that surround a vacant or underutilized parcel is vital to effectively selecting and planning an appropriate reuse strategy on a temporary basis. Three existing pedestrian audit tools were reviewed prior to the creation of the simplified urban characteristics audit tool, found below: *NEWS-A, PEDS and Urban Design Qualities Related to Walkability*. These tools, downloadable from the Active Living Research website, which is administered by the San Diego State University Research Foundation, measure features of the built environment as they relate to the walkability of street segments. They attempt to link the built environment to physical activity by understanding the extent to which it lends itself to pedestrian activity. VULI was built to minimize the use of qualitative statements that require user-perceptions, as this can lead to biases in scoring. Qualitative descriptions can be confusing and are understood differently by different people, and as such the user is asked to make predominantly binary statements with respect to the presence or absence of physical elements in the urban environment. A similar method was used by Rosenberg and Esnard (2008) in a hybrid scoring methodology for transit station site selection. Each question was intended to capture independent attributes of the neighbourhood or site.

Developability Potential of Site

This section of the inventory requires the largest number of inputs from the user, as there are sometimes different elements that make a site more readily developable than another site for the subset of reuse strategies selected for this prototype system. Sites in public ownership are deemed "ideal" in terms of developability versus sites in private ownership, for example. The rationale for this is that there is a historical precedence in Hamilton of sites in public ownership that have been leased to grass-roots and community organizations for urban food production purposes. The negotiation process is therefore developed and generally understood by the participants. The developability potential of a given site is related to many specific physical/spatial elements of the site, and are summarized in the questions below.

Proximity to complementary/synergistic uses

This criterion requires minimal user inputs. The built-in databases are Hamilton-specific and include: the locations of city-wide pedestrian-oriented mixed-use commercial areas, elementary and high schools (both separate and public school boards), colleges and universities, access to food (including food banks, grocery stores, specialty food stores, variety stores, farmers' markets, community garden plots, community kitchens/hot meals, etc.), homes for the aged, Hamilton City Housing, Good Shepherd Housing, places of worship, parkland, hospitals, and community centres. Based on the municipal address entry of the vacant or underutilized parcel as well as the Dissemination Area code (as per the Statistics Canada dissemination area designation), C-SAP will search the hidden databases for existing neighbourhood elements that are within a straight-line (geodesic) distance to the subject site (400-metre radius, or 5-minute walk is ideal) – elements which may provide beneficial synergies when combined with various reuse treatment options.

Vulnerable populations

This criterion looks at the proximity of vulnerable sub-populations within each Dissemination Area, as this is relevant to some reuse treatments (e.g. community gardens). A custom-built Statistics Canada database of vulnerable population sub-groups is built into the C-SAP interface. The user will be given the option to select the statistic that they feel best represents vulnerability in their neighbourhood: number of persons living in apartments; prevalence of female lone-parent, low income families; number of persons aged 65 years and older, % new immigrants that fall within the low income bracket; or, the prevalence of low income private households, or a combination of several, where permitted (and where there would be no overlap in statistics if combined). Unlike the previously described proximity methodology, C-SAP does not search within a 400-metre distance for the vulnerable population sub-groups; rather, it detects the degree to which the Census Tract is "vulnerable" and subsequently determines if the recommended minimum vulnerable population is present to support the proposed reuse treatment. For example, it is recommended that community gardens have a minimum of 8-10 participants on a 370m^2 (4000ft^2) plot of land (6 x 3 metre plots + space for a tool shed, paths, and seating/gathering area) to ensure adequate community support (Kent State University, Cleveland Land Lab, 2008). The Renfrew Collingwood area in Vancouver, British Columbia studied the potential to develop a stronger local food system, based on the prevalence of low income households and a need to have access to healthy food, and in doing so found that approximately 10% of their urban land was vacant or underutilized (Hohenschau, 2005). There is significant social capacity for food production in Vancouver – an estimated 44% of Vancouver residents grow some food at home (Hohenschau, 2005). The Renfrew Collingwood area reports on the potential to achieve 6.5 – 20 garden plots/1000 persons, given the available residual spaces in this area (Hohenschau, 2005). C-SAP aggressively plans for a 40% participation rate among the vulnerable population. For example, if 40% of the vulnerable sub-group is less than or equal to {10 x [potential area for reuse/370m^2]}, C-SAP assigns a score of 0 (not ideal), otherwise it will assign a score of 1 (ideal). It is assumed that the Dissemination Area boundary represents a walkable distance for the residents living within this DA (typical dissemination areas consist of 400 to 700 people, but can vary and be upward of 2000 people). This is not to say that residents would not cross the DA boundary to participate in food production; however, under this assumption, the participants from other DAs would not represent the majority of the participants if the vacant or underutilized area is beyond their DA boundary.

Safety/Comfort

User Experience refers to the user's experience when on-site. The volume of traffic on adjacent roadways, the noise level, odors, and land uses are several of the variables that area addressed in this criteria.

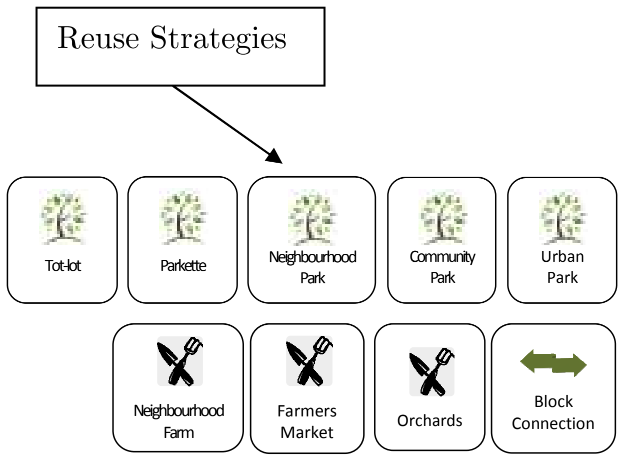
Transportation

This criteria addresses the opportunities available for accessing the potential area for reuse (e.g. bus, rapid transit, bike paths, recreation trails, the Bruce Trail). In some situations it may be important to have access from a high-frequency bus service with headways between 10 to 15 minutes (e.g. farmers' markets), or to have parkland in close proximity to recreational trails.

How to interpret the following inventory

Summary of what the question captures

Summary of Scoring



- **THE QUESTION**

Supporting references and special notes for the review team are located in the italicized text – this highlighted text provides some rationale with respect to (a) why I asked the question in the first place, (b) why I included the reuse strategies that I included, (c) why I scored the way I did (although this was somewhat subjective). I could use your help with respect to weighting certain questions, only where it is absolutely necessary to add a weight – i.e. something is significantly more important than something else). Remember, points are not added across the three criteria – so weights need only be applied if a question within a criterion is significantly more important than a question within the same criterion.

General Input. Required for each vacant or underutilized land area

Census Tract (CT) code 

Dissemination Area (DA) code 

Neighbourhood Name C-SAP

Ward Number C-SAP

Municipal address On-site

Coordinates for each potential area for reuse Google Earth

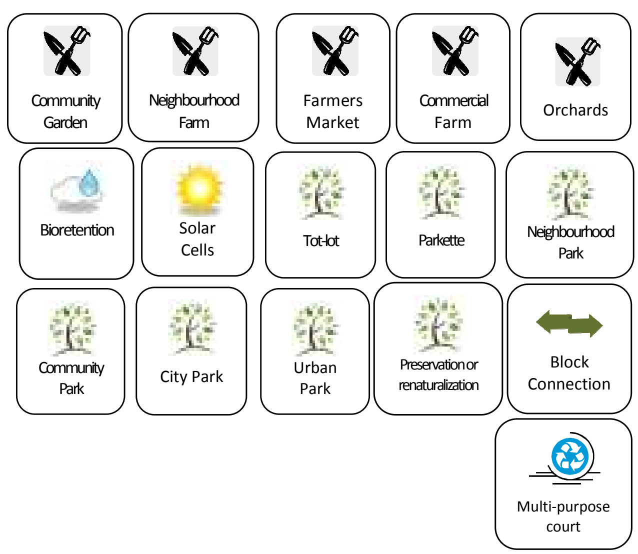
Preconditions

For **EACH** vacant and underutilized land parcel identified, **NOT** including single-detached and multi-attached houses (e.g. semi-detached, triplex, fourplex, row houses), the user will complete the following section. That is, for available land surrounding social housing land, apartment buildings, schools, places of worship, underutilized parks, underutilized or vacant commercial, industrial, and institutional lands, underutilized parking lots, and the public right-of-way, the user will complete the following inventory.

Note: If there are many divided, sub-areas for potential reuse on a particular parcel of land, this section must be completed for each sub-area.

Size (and shadows) Google Earth

If a potential reuse treatment does not meet the minimum size requirement, the user will be notified and asked if they want to relax this constraint and continue (i.e. keep the reuse treatment as an option even though it does not meet the recommended size requirement)



- Each potential area for reuse MUST be idealized as a rectangle. There may be several areas for potential reuse within a given parcel that are broken up due to buildings, parking, and other obstructions. The user will be required to enter:
- The x-y coordinate that represents the origin of the rectangle (a graphic will be provided for the user)
- The width of the potential area for reuse (i.e. the width of the rectangle)
- The height of the potential area for reuse (i.e. the height of the rectangle)

Shadows
The user is not required to consider shadow patterns; C-SAP will run a routine that calculates the shadows that affect the potential areas for reuse, across the growing season (May – October), and subsequently adjust the area for potential reuse based on treatments that require full sunlight. To run the shadow mapping routine, the user will be required to enter the:

- Centre point (x-y coordinate) and the anticipated mature tree height and width for all trees on and adjacent to the subject property that are specimens to be retained (i.e. in good health, large in size, and exemplary specimens for foliage and/or fruit, including nuts). The user SHOULD NOT include the centre point of any trees that they anticipate will be removed due to disease, decline or death.
- 4 pairs of x-y coordinates, representing all structures on or adjacent to the subject property (note: each building, regardless of shape, will be idealized as a rectangle), and the storeys (or if known, the height of each structure)

Urban food production uses (with the exception of Farmers' Markets) require full sun (source: KSU, 2008 or 2009)

It is ideal that rain gardens have sunlight conditions that range between partial to full sun (they should not be directly below a tree canopy)

Urban parks should be generally rectangular (KSU, 2008; 2009), with a length-to-width ratio between 1:2 and 1:3 (Corbett, 2004) – a warning will be provided to the user if these conditions do not exist; the user will have the option to remove an urban park as an option.

A recommendation to provide fewer but larger park facilities was put forth as part of the City of Hamilton Parks and Open Space Master Plan (2002). The user will receive a warning if the area is not deficient in terms of parkland (and will ask the user if they wish to delete these reuse treatments as an option), or, if the potential area for reuse does not meet the minimum size requirements, a warning will appear stating that the City is shifting toward fewer, but larger park facilities.

Neighbourhood parks act as a replacement for private open space, they provide opportunities for families to engage in activities that they would do in their own yards if they were sufficiently large. In that respect, their size and the components in them should vary somewhat with the density of the neighbourhoods (Hamilton Parks and Open Space Master Plan, 2002). C-SAP will be designed to take this into account.

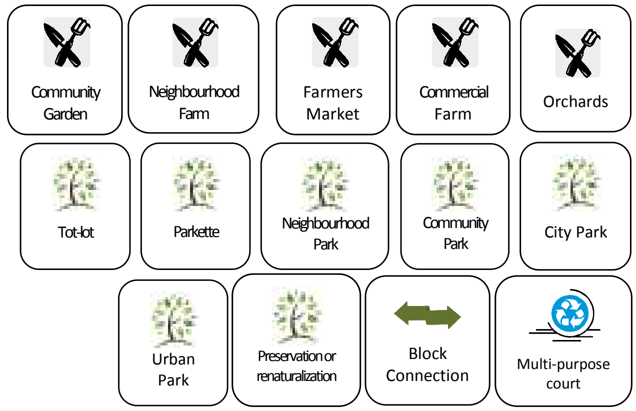
Neighbourhood Parks, as far as is reasonably possible, be rectangular in shape (Hamilton Parks and Open Space Master Plan, 2002).

The OPA encourages MicroFIT project development in collaboration with members of the community (ex. School, community centre, place of worship, library, non-profit, neighbourhood group, etc.). These projects have traditionally been roof-mounted applications (MicroFIT overview document)

Multiple FIT (>10kW) contracts of the same technology, including incremental projects, are not permitted on the same property. Section 7.3 (e) of the FIT Rules prohibits applicants from splitting one project into smaller projects for the purpose of obtaining a higher price or any other benefit (FIT program overview document). As such, if the user attempts to enter multiple sub-parcels for a particular municipal address, they will be flagged for solar fields, and the user will be asked to select one only for evaluation purposes.

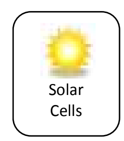
Capacity allocation-exempt projects are small FIT projects connected to the distribution system that can proceed to a direct FIT contract after an application is filed. Exempt projects are not subject to transmission and distribution availability tests; however, they must meet the commercial operation deadline of 3 years and be less than 500kW with respect to the amount of power generated (FIT program overview document). A message to this effect will appear to the user, notifying them of this possibility if they are 5 acres or smaller, and advising them to use the www.pvwatts.org or www.retscreen.net websites to better estimate their output potential.

Dissemination area population
A minimum residential density must exist to support urban food production and recreation uses (based on the service area for each use)



- The dissemination area(s) population will be calculated automatically and compared to the size of the potential are for reuse to ensure there is a sufficient base population available to support each use.

Agricultural land classification
For Class 1 and 2 lands, based on land area inputs (if greater than 100kW), a warning will appear stating that this use will be removed as an option, or that the user will be limited to a 100kw operation using only a portion of the potential area for reuse; If Class 3 is entered, the user will be required to contact the OPA for further information; If built-up is selected, the tool will proceed with no warnings



- The potential area for reuse is located on:

- Built-up areas (urbanized)
- Canada Land Inventory Class 1 Lands for agriculture
- Canada Land Inventory Class 2 Lands for agriculture or specialty crop areas
- Canada Land Inventory Class 3 lands for agriculture (must check with OPA)

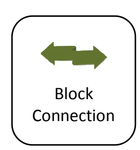
There are restrictions on land classification for all systems over 100kW in size. The OPA may not enter into FIT contracts for ground-mounted solar PV greater than 100 kW where those facilities are located on Classes 1 and 2 soils and Specialty Crop Areas (white area on maps provided). Class 3 soils (green area on maps provided) may be used up to a capped limit. The remaining area, comprised of Classes 4 to 7 soils (beige area on maps provided) and Unclassified Land (grey area – urbanized areas – on maps provided), can be used for ground-mounted solar PV.

Several estimates were received from solar panel installers. The estimates ranged from $CAD 700,000 to $CAD 1,000,000 to install panels that would produce 100kW to 189kW on 1 acre of land, respectively (personal communication, Bruce Knight and Stan Yankoo). This was based on the estimate that 1kW of panels could produce approximately 1120kWh/year (MicroFIT document), and was based on two different panel configurations, including different panel sizes, sunlight, and output potential for southern Ontario.

The user will be required to open the map(s) provided to determine the classification. This classification needs to be confirmed with the OPA. To estimate the output potential, the user will be directed to use the www.pvwatts.org or www.retscreen.net websites to better estimate their output potential.

Block configuration

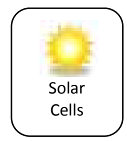
If the lot is neither of the options listed below, block connections will be removed as a reuse treatment option.



- Is the parcel:
    - A "through lot" (i.e. a lot that cuts through an entire block, either street-to-street or street to public rear lane), that is located near the mid-point of an elongated grid or curvilinear road (200+ metres in length), or
    - A corner lot (i.e. a lot that is located at the corner of two intersecting streets)

The City of Hamilton Parks and Open Space Master Plan (2002) stresses the importance of increasing linear linkages between parks and cultural/recreational buildings.

Distance to utility connection



- Is the potential area for reuse within 300-800 feet of a hydro pole or underground connection?

A message will appear for the user, based on the potential area for reuse that will guide the user to either contact their local service provider or use the OPA's online mapping tool (this will be based on the approximate scale/size of the potential area for reuse)

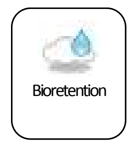
- *300 feet of a hydro pole or underground connection (look for a green transformer box as an indicator) with a voltage less than 15kv (for smaller-scale projects <250kW)*
- *300 feet from a hydro pole or underground connection with a voltage greater than 15kv – (for medium-scale projects <=500kW)*
- *300 feet from a transmission line with available capacity (note: you will need to create an account and login to the OPA's transmission system mapping tool to retrieve this information) (for larger projects - >500kW)*

It is ideal to be within 300 feet of a pole, but 800 feet can still be done with a bit more cost and a bit of loss in the line (personal communication, Bruce Knight).

Projects 10 MW and less typically connect to the distribution system (locally operated) and not the transmission system. You can use the OPA's local distribution company locator tool to find the applicable local distribution company to inquire about capacity- www.oeb.gov.on.ca. Projects greater than 10 MW typically connect to the transmission system. Use the following mapping tool to determine if capacity is anticipated to be available at the transmission system level in your area (note: you will have to create an account to view the capacity available on transmission line systems, but this process is free of charge and quick) http://fitapp.powerauthority.on.ca/OntarioTransmissionSysMap.aspx.

Rainwater collection surface areas

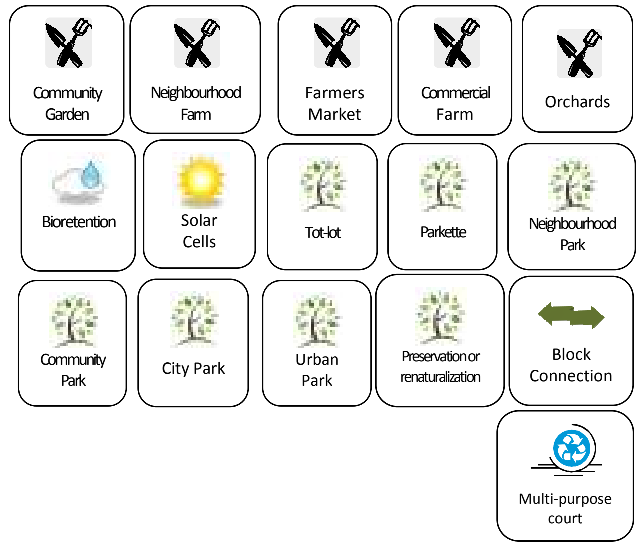
At least one of these must be checked prior to including bioretention as a potential reuse strategy



- The following rainwater collection surface areas exist either on or abutting the parcel that contains the potential area for reuse:
    - Residential rooftop(s) (single, semi-, duplex, triplex, or 4-plex)
    - Residential rooftop (s) (apartments)
    - Rooftop, other (e.g. commercial, industrial, institutional)
    - Parking pad/lot

Using trees, vegetation, and wetlands, or engineered systems that mimic natural landscapes, green infrastructure manages stormwater at the source by capturing runoff and retaining it before it can reach the sewer system. Hamilton has approximately 600 kilometres of combined sewer system. When combined sewer overflows (CSOs) occur, they are diverted to Hamilton Harbour, Cootes Paradise, Chedoke Creek and Red Hill Creek at 23 locations.

Topography
(Mostly flat or mild hills – keep all uses; Mostly steep hills – keep renaturalization only)



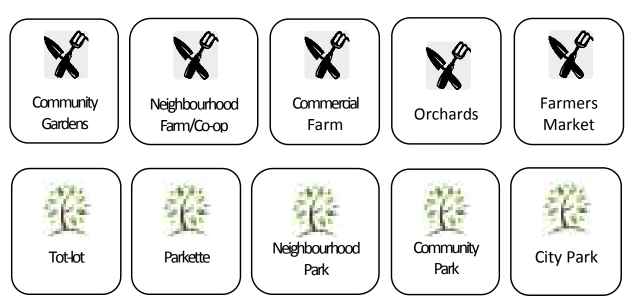
- The topography of the land can be described predominantly as having:
  - Steep hill(s)
  - Mostly flat
  - Mild hill(s)

Measure the slope using two stakes, a string, a plumb bob and a measuring tape.

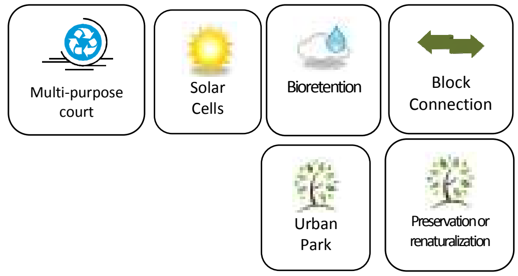
Slopes can work for urban food production purposes, but more labour and materials will be required (Hohenschau, 2005).

Neighbourhood parks should be relatively flat for 80% of the surface area (Hamilton Parks and Open Space Master Plan, 2002).

On-site land use(s)
(warning to be provided to the user if the on-site land use is likely to result in some level of contamination – a recommendation to remove specific treatments will be

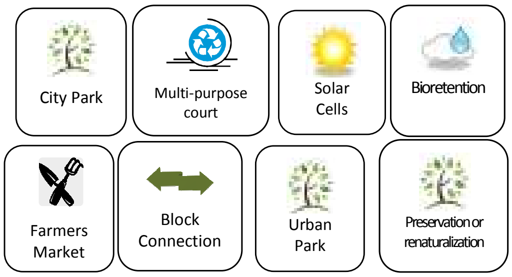


provided to the user)



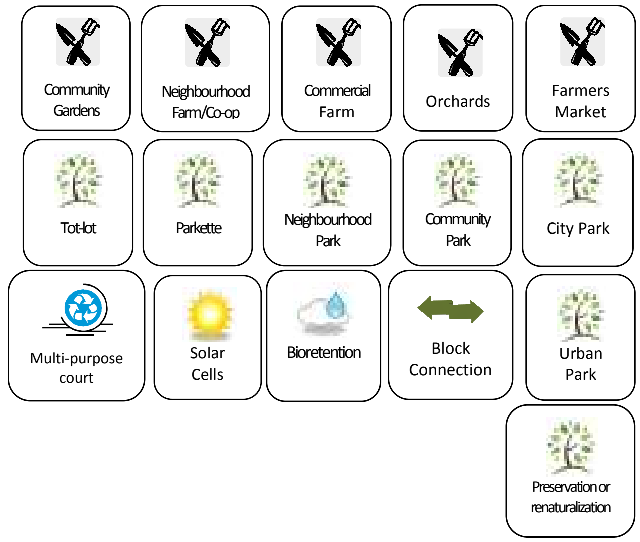
- The on-site land use contains (select all that apply):
  - Industrial or Warehousing
  - Commercial, Automotive/Gas/Dry Cleaning
  - Commercial, Retail
  - Institutional – Place of Worship, Elementary or High School, College or University
  - Residential, Multi-family/apartment
  - Residential, single-family/semi-/duplex/triplex/fourplex
  - Office
  - Parks and Open Space
  - Institutional – Educational
  - Institutional – Hospital
  - Institutional – Place of Worship
  - Utility Corridor or R.O.W
  - Parking lot

Abutting land use(s)
(same as above)



- The abutting land uses contain (select all that apply):
    - Industrial or Warehousing
    - Commercial, Automotive/Gas/Dry Cleaning
    - Commercial, Retail
    - Institutional – Place of Worship, Elementary or High School, College or University
    - Residential, Multi-family/apartment
    - Residential, single-family/semi-/duplex/triplex/fourplex
    - Office
    - Parks and Open Space
    - Institutional – Educational
    - Institutional – Hospital
    - Institutional – Place of Worship
    - Utility Corridor or R.O.W
    - Parking lot
    - Active/inactive rail corridor
    - Cemetery
    - Highway/freeway

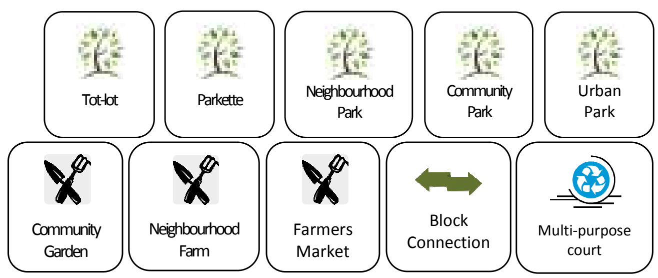
Historic land use(s)
(same as above)



- Historic land uses within 200-metres of the subject site are deemed to be "potential sites for contaminant exposure"

Criteria 1. Urban Characteristics

Street Enclosure
1 point maximum
(Yes – 1, No – 0)

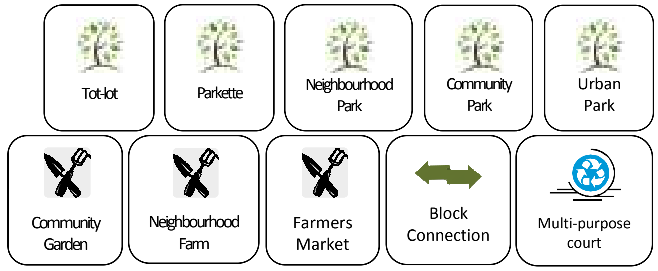


- Are streets well-framed by buildings, with few gaps?

Note: is the road width + building setback is approximately equal to building height on either side of the street

Enclosure is the degree to which streets and other public spaces are visually defined by buildings, walls, trees, and other vertical elements. Enclosure was identified as an urban design quality related to walkability in mixed-use commercial areas (Ewing, R. and Handy, S., 2008)

Major Landscape Features
1 point maximum
(Yes – 1; No – 0)

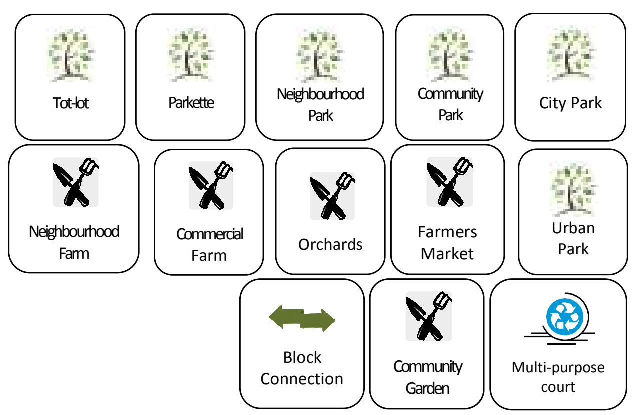


- Are major landscape features visible within a 5-minute walk of the subject site?

Prominent natural landscape views like bodies of water, escarpment views, and significant natural heritage features (or man-made features that incorporate the natural environment) serve as natural landmarks for orientation or reference. Parks do not count as major landscape features (Ewing, R. and Handy, S., 2008).

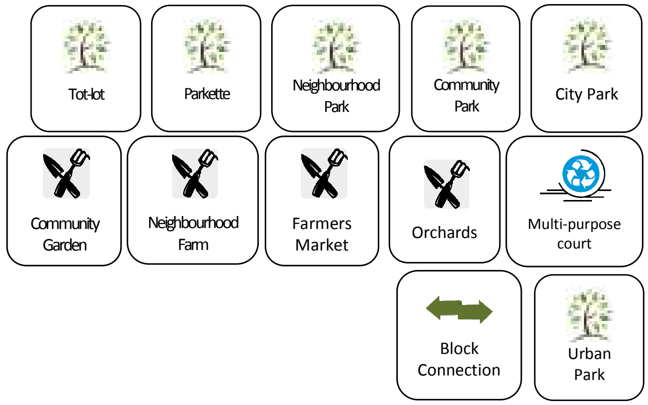
Sixty-seven Environmentally Significant Areas have been identified in the City of Hamilton (including the Escarpment, harbor area, Waterfront Trail, Pier 4, and Bayfront Park and other areas of provincial level significance, which are all important features – connecting parks and open spaces and creating a continuous green infrastructure is one objective in the City's suite of parkland policies (City of Hamilton Parks and Open Space Master Plan, 2002).

Vegetative Cover Along Street Edge
1 point maximum
(Yes-1; No-0)



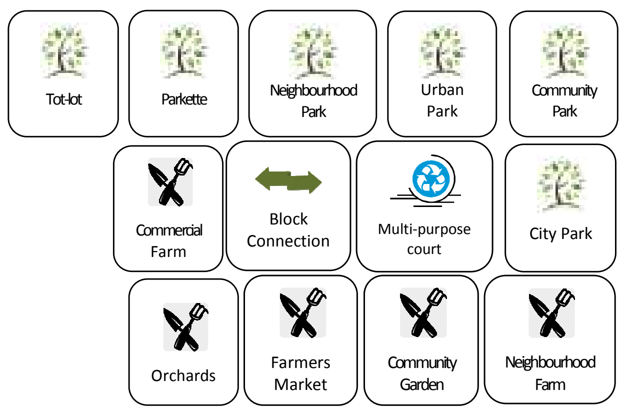
- Streets are lined with mature trees, creating a relatively continuous canopy adjacent to sidewalks.

Eyes on the neighbourhood
1 Point Maximum
(Yes – 1; No – 1)



- The majority of buildings in the neighbourhood have street-level windows that look onto the neighbourhood.

Street Road Network
1 point maximum
(Yes-1; No-0)



- The street network is characterized by a grid network (intersecting streets every 100-metres to 200-metres)

Tot lots should be located in the heart of subdivisions, directly accessible by bicycle, walking, and should not be subject to frequent vehicular traffic (Hamilton Parks and Open Space Master Plan, 2002)

Hamilton's sidewalks and neighbourhood streets act as linkages to recreational facilities and access to open space and natural areas (Hamilton Parks and Open Space Master Plan, 2002)

Neighbourhood parks should be mostly accessible without a vehicle (i.e. walking or cycling) (Hamilton Parks and Open Space Master Plan, 2002)

Walkable communities centered around multiple modes of food distribution (and ensuring there is enough density to support these modes) is key to a sustainable community (Hohenschau, 2005)

Acquisitions which will serve to create a more continuous or linked park system are a priority (City of Hamilton Official Plan, City of London Official Plan)

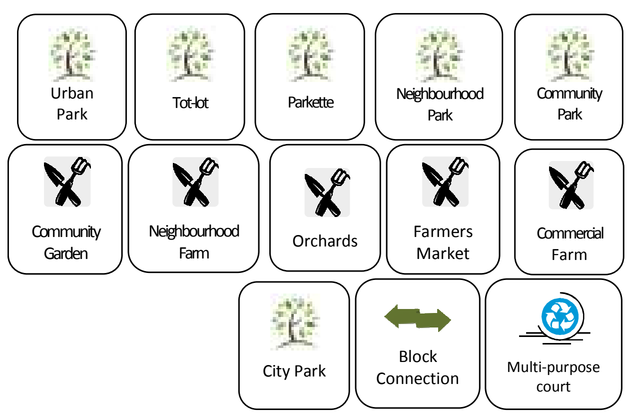
Block connections: priority should be given to road network patterns that currently have reduced walkability – for example, curvilinear streets, elongated subdivision blocks, or blocks dominated by loops and lollipops (KSU, 2008 or 2009)

Inconvenient changes in direction should not be taken to find an urban park – there is a need for an accessible arrangement of buildings, streets and blocks (to relate well to patterns of movement) (Corbett, 2004)

It is important to provide linkages between new and existing Neighbourhood Parks (Hamilton Parks and Open Space Master Plan, 2002)

There is a need for an accessible arrangement of buildings, streets and blocks (to relate well to patterns in movement) for urban parks to succeed (Corbett, 2004)

Decreased Property Tax Base
1 point maximum
(Yes – 1; No - 0)

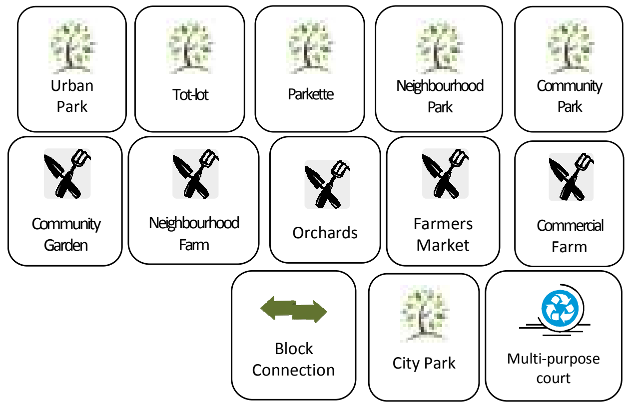


- Are there more than 10 properties within a 5-minute walk of the subject site that have seen a property tax base decrease of more than 15% in the past year?

  Note: user to open the Tax Base Map provided.

Note: a score of 1 was assigned, as this is deemed to be a more vulnerable area, and therefore may benefit from a reuse strategy that acts to stabilize the lot and/or street.

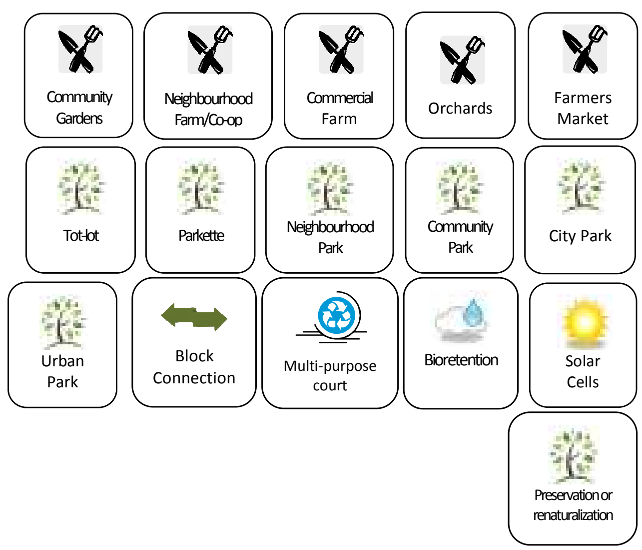
Abandoned and/or Vacant Land
1 point maximum
(Yes – 1; No - 0)



- There are more than 5 abandoned or vacant lots within a 5-minute walk from the subject site.

Note: a score of 1 was assigned, as this is deemed to be a more vulnerable area, and therefore may benefit from a reuse strategy that acts to stabilize the lot and/or street.

Active Neighbourhood Association
1 point maximum
(Yes-1; No-0)



- Is an active neighbourhood association present?

Active neighbourhood associations typically represent a strong community driving force. They symbolize leadership in efforts to forge stronger communities socially, environmentally and economically. They also represent stability in the community, as populations and demographics change.

Combined sewers

1 point maximum
(Yes -1; No-0)

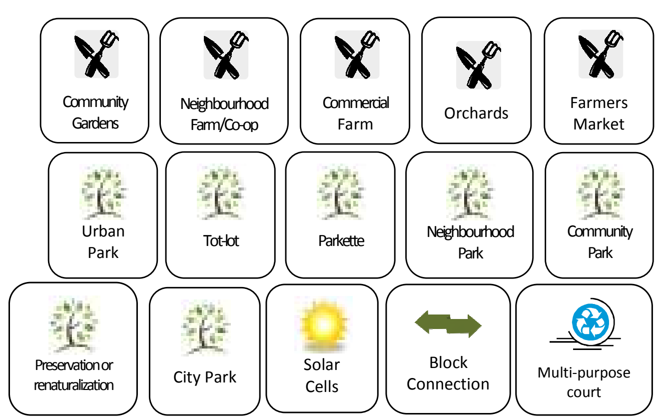
- Is the site located in a part of the city where there is a combined stormwater and wastewater sewer? (note: user to open the City of Hamilton's combined sewer map)

Using trees, vegetation, and wetlands, or engineered systems that mimic natural landscapes, green infrastructure manages stormwater at the source by capturing runoff and retaining it before it can reach the sewer system. Hamilton has approximately 600 kilometres of combined sewer system. When combined sewer overflows (CSOs) occur, they are diverted to Hamilton Harbour, Cootes Paradise, Chedoke Creek and Red Hill Creek at 23 locations.

Criteria 2. Social Impact

Vulnerable population sub-groups in the Dissemination Area

10 points maximum
(0-10% of population is in the vulnerable category - Score: 2; 11-20% - Score: 4; 21-30% -



Score: 6; 31-40%- Score:
8; >40% - score 10)

- Select which population sub-group (from the bolded list below) you feel would benefit most from close proximity to each of the above-noted reuse treatments (select one per reuse treatment – 15 total):

Tenure
- % dwellings rented (all housing forms)

Dwellings by structural type
- % apartment building units (owned and rented)

Visible Minority
- % population – visible minority

Single-parent families
- % female, lone-parent families
- % male, lone-parent families

Number of families living under one roof:
- % households – multiple family
- % households – non-family members

Prevalence of low-income after tax:
- % couple families – prevalence of low income after tax
- % female, lone parent families – prevalence of low income after tax
- % male, lone parent families – prevalence of low income after tax
- % persons 65 and older – prevalence of low income after tax

Immigration status:

- o % immigrants – immigrated between 1961-2006

  Select a sub-category, if desired:
  - % immigrants – immigrated before 1961
  - % immigrants – immigrated before 1961 to 1970
  - % immigrants – immigrated before 1971 to 1980
  - % immigrants – immigrated before 1981 to 1990
  - % immigrants – immigrated before 1991 to 2000
  - % immigrants – immigrated before 2001 to 2006

Education level – College or University:

- o % total population with a college diploma or university degree
  - ▪ Select a sub-category, if desired:
    - % population aged 15 to 24 with a college diploma or university degree
    - % population aged 25 – 64 with a college diploma or university degree
    - % population aged 65 or older with a college diploma or university degree

Education level – No post secondary:

- o % total population without a diploma or degree
  - ▪ Select a sub-category, if desired:
    - % population aged 15 to 24 with no diploma or degree
    - % population aged 25 to 64 with no diploma or degree

- % population aged 65 or older with no diploma or degree

Youth 6 to 18 years old:
- % population aged 6 to 18

Seniors:
- **Aged 65 and older**

20% of Hamilton's residents are living in poverty (as of 2007). Rates are even higher for children under 14 (24%), Seniors age 65 and older (24%), the Aboriginal community (37%), and recent immigrants (50%) (Hamilton Roundtable for Poverty Reduction, 2007)

In 2009, 47% food bank users were families with children (27% single parent families and 20% dual parent families); 44% were singles; 9% were couples with no children (Hunger Count Report, 2009)

Community gardens should be established in neighbourhoods with a density greater than 20 units per acre (KSU, 2008 or 2009; Hamilton Community Garden Network); Farmers' markets should also be located within close proximity to high densities – e.g. apartment dwellings (Hohenschau, 2005)

Equitable access to food should not rely on personal ownership of car or the need to leave the neighbourhood to find basic goods and services - food production should not be a privilege enjoyed by owners of detached homes with yards (Hohenschau, 2005)

Population characteristics such as age, ethnic considerations and income should be taken into account when allocating sites for parkland (City of London Official Plan)

Identify and ensure access to parkland for low-income residents (City of Hamilton Parks and Open Space Master Plan, 2002)

Focus resources on active living opportunities for children and youth 6 to 18 years old (City of Hamilton Parks and Open Space Master Plan, 2002):

"One of the greatest challenges in Canada in general, and in Hamilton in particular is the rapidly declining activity level of our youth and the

resulting impacts on long-term health. Research has shown that active living for adults starts with teaching and engendering active lifestyles in youth. In the past decade, there is evidence of an alarming increase in the number of overweight and obese children and a crisis in many related diseases such as type II diabetes".

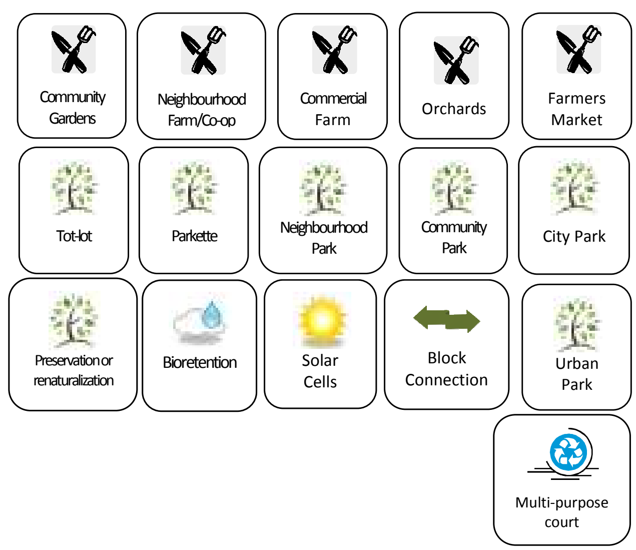
"The 6-18 year old population is the market segment of the population that needs the most focus over the next ten years. Strategies developed by the City of Hamilton and others to get children and youth more active must begin by recognizing the shifts in behavior patterns towards individual, informal activities".

Respondents with annual household incomes in the $CAD 75,000 - $CAD 100,000 range were most likely to indicate a need for waterfront parks, sports fields, paths/trails, outdoor pools/spray parks or public squares (Hamilton Parks and Open Space Master Plan, 2002)

Opportunities for recreation are in need in highly urbanized, high density areas (urban core areas)

Criteria 3. User Experience/Comfort

Anticipated Activity Level in the Area
1 point maximum (different scores for different potential reuse treatments – yet to be determined)

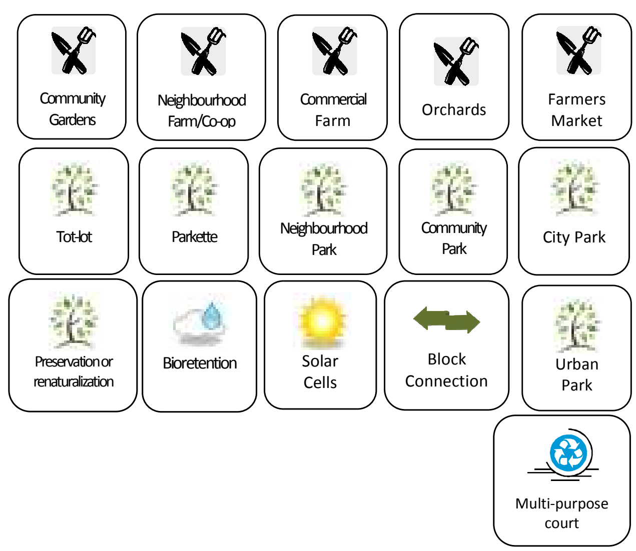


- According to the City of Hamilton Urban Structure Plan, the potential area for reuse is located in a:

- Neighbourhood (Score: 1 for community gardens, neighbourhood farm, orchards, block connections, multi-purpose courts, solar cells, tot lots, parkette)
- Employment area (Score: 1 for solar cells, city park, commercial farms)
- Major activity centre (Score: 1 for farmers' markets, commercial farms, block connection,
- Major open space (Score: 1 for preservation)
- Downtown UGC (Score: 1 for preservation, bioretention, multi-use courts, urban park)
- Community (Score: 1 for farmers' markets, orchards, neighbourhood farms, community gardens, parkette, tot lots, community park)
- Primary Corridor (Score: 1 for preservation and bioretention and farmers' markets)
- Secondary Corridor (Score: 1 for preservation and bioretention and farmers' markets)

Note: user to open urban structure plan map.

Road Classification
1 point maximum



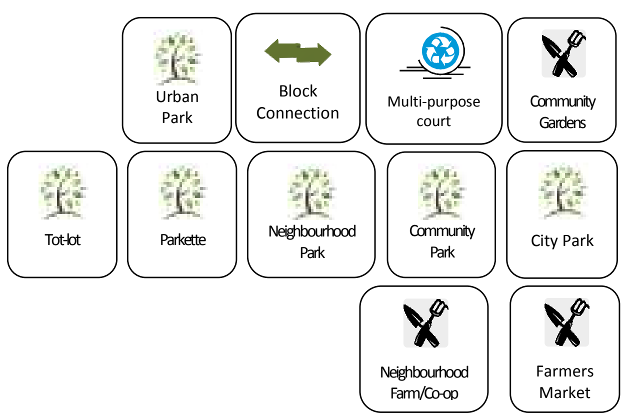
- According to the City of Hamilton's Road Classification system, the potential area for reuse is located adjacent to an existing or proposed:
    - Major or Minor Arterial (High volume – 8000+ cars/day) (Score: 1 for farmers' markets, urban park, community park, city park, block connection, bioretention)
    - Collector (medium volume – 2500-8000 cars/day) (Score: 1 for farmers' markets, block connection, urban park, parkette, community park, multi-purpose courts, bioretention)
    - Local (low volume – less than 2500 cars/day) (Score: 1 for community gardens, neighbourhood farms, commercial farms, block connection, orchards, tot lot, parkette, neighbourhood park, multi-purpose courts, bioretention)
    - Note: if a corner lot, pick the higher capacity/busier road

    Also, select one of the following if the potential area for reuse is within 800-metres from the following (bonus point):

    - Parkway (Score: 1 – farmers' market, commercial farm, solar cells)
    - Provincial Highway (Score: 1 – farmers' market, commercial farm, solar cells)

The classification of the road that abuts the potential area for reuse is important as it relates to the safety, visibility, experience and comfort of users.

Strategic views
1 point maximum
(Yes – 1; No – 0)

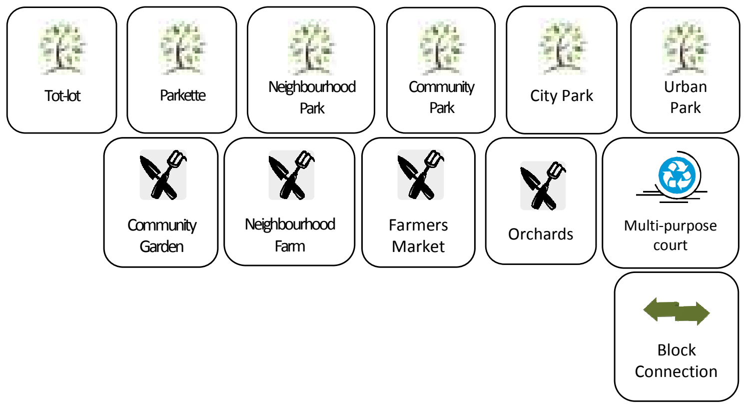


- Could the potential area for reuse support interesting view corridors (both natural or human-made) both on- and/or off-site?

A good urban park (square or plaza) has positions within it with multidirectional strategic views, in proportions to the scale of the square and along lines of potential movement into and through the park (Corbett, 2004)

Noise Level

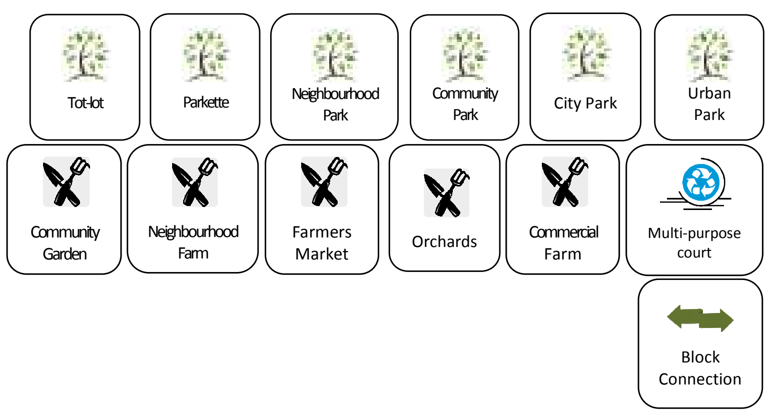
1 Point Maximum
(Quiet/Normal – 1;
Loud - 0)



- The noise level, as heard from standing at the edge of the subject site, is:
  - Quiet
  - Normal
  - Loud

Odour

1 Point Maximum
(Yes – 0; No - 1)



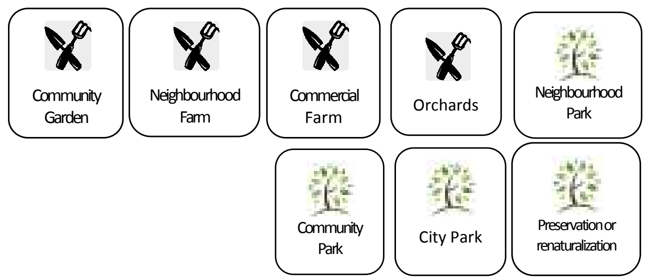
- Is there an unpleasant smell due to either an existing on-site or abutting land use?

Criteria 4. Developability of Site

Note: If there are many divided, sub-areas for potential reuse on a particular parcel of land, this section must be completed for each sub-area.

Access to water

1 point maximum
(Yes – 1, No – 0)

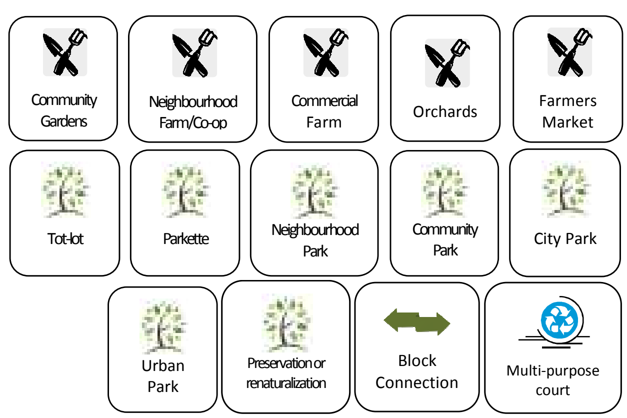


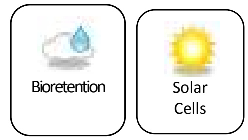
- Is there access to irrigation water?
    - Note: Irrigation water is accessible via an existing on-site water line, an abutting public housing complex, apartment building, commercial, institutional, or industrial structure, or a fire hydrant (same side of the road, <100 feet from parcel)

Access to irrigation is essential for urban food production uses as well as establishing plant material in parks and open space during the first several years after planting (KSU, 2008 or 2009). If access to water is not available, a water line may need to be connected to the site, at a cost of several thousand dollars.

Debris

1 point maximum
(Yes-0; No-1)

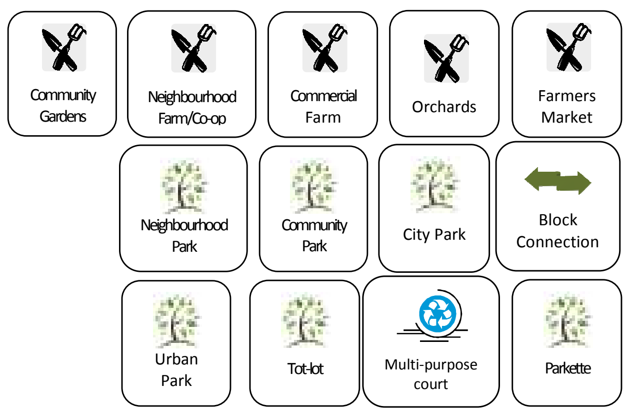




- Does any debris need to be removed from the potential area for reuse prior to development?
    - Items could include:
    - Building foundation(s)
    - Derelict structure (s)
    - Paving material
    - Dead or declining trees

  Note to user: if there are dead or declining trees, do not include these in the shadow-mapping tool

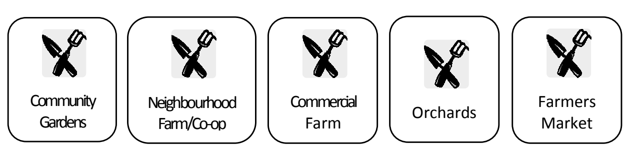
Site Access
1 point maximum
(Yes-1; No-0)



- Does the parcel have direct access from at least one public road (i.e. not “landlocked” or accessed via a private road)?

  Note: user to open City of Hamilton Private Roads Map

Exterior lighting or access to electricity
1 point maximum



(Yes-1; No-0)

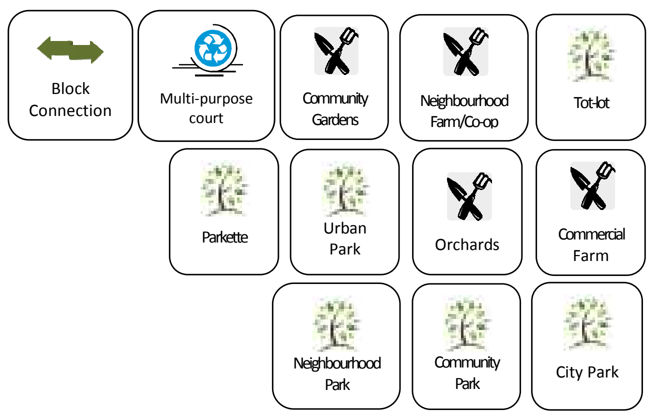
- There are existing light standards on or adjacent to the site that sufficiently illuminate the potential area for reuse after dusk, or there is access to electricity.

Urban parks require adequate lighting (KSU, 2008 or 2009)

Neighbourhood park lighting should be designed for safety and security, not for playfields (Hamilton Parks and Open Space Master Plan, 2002).

Eyes on the Parcel

1 point maximum (All strategies except orchards and commercial farms: Yes – 1; No – 0; Orchards and commercial farms: Yes – 0; No - 1)



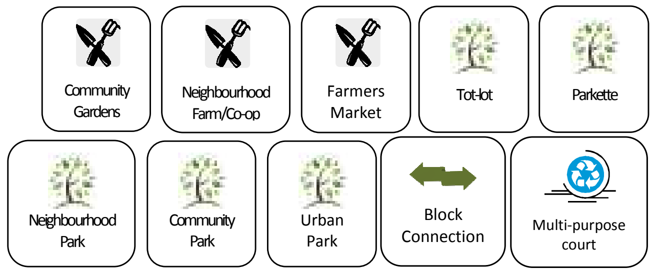
- Are there at least 5 residential structures (single family homes, multi-family homes, apartments) that have unobstructed windows that look onto the potential area for reuse?

  Note: consider only windows that are at-grade, abutting the potential area for reuse [and across the street], up to 3 storeys high, regardless of the total height of the building

A minimum distance separation from residential uses for commercial farms and orchards may be required to protect against noise, smell, light, dust, and any crop sprays (KSU, 2008)

Close proximity to downspouts in low and medium-density residential developments is ideal for rain gardens (KSU, 2008)

Site lines
1 point maximum
(Yes – 1; No – 0)

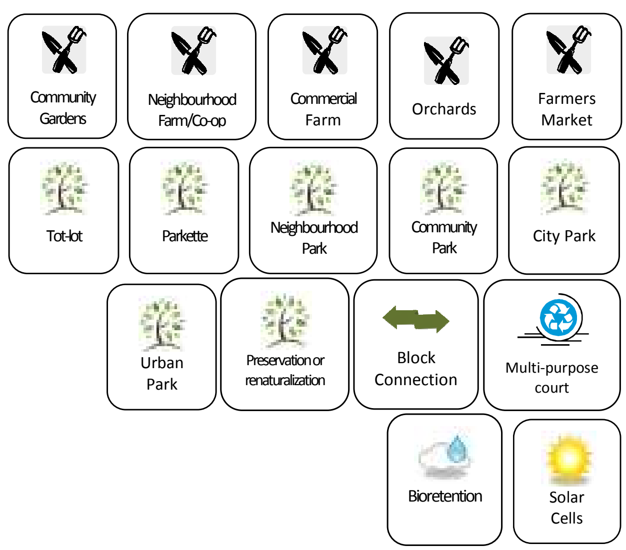


- Is the potential area for reuse clearly visible to a passerby, walking along the street edge?

Clear visual continuity from the street is important for urban parks – there is a need to be able to see into the square; major changes in street level can be harmful to a public square; maintaining visual contact with the street is important (Corbett, 2004)

Neighbourhood parks should have a maximum amount of street frontage to encourage access and use (Hamilton Parks and Open Space Master Plan, 2002)

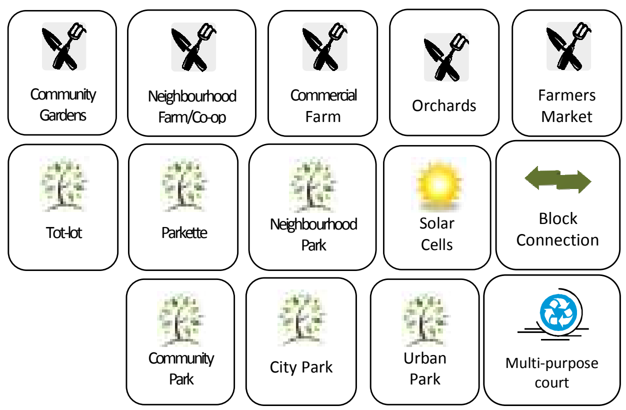
Groundcover
1 point maximum
(Grass – Score: 1 for rain garden, tot-lot, parkette, neighourhood, community or city park; Natural Foliage – Score: 1 for rain garden renaturalization; Asphalt/concrete – good condition – 1 for multi-use courts, urban park, and block connection; gravel or mixed – 0 for all uses)



- The potential area for reuse is covered predominantly by:
    - Soil

- Gravel
- Asphalt or concrete – good condition (smooth, even surface)
- Asphalt or concrete – poor condition (cracked, heaving, pot holes - tripping hazards)
- Grass
- Natural foliage
- Mixed

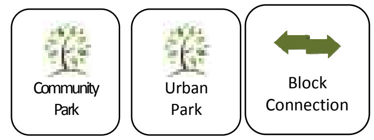
Buffering from adjacent land uses
1 point maximum
(Yes-0; No-1)



- Does it appear that a buffer (fencing or vegetative screening) will be required to screen the potential area for reuse from adjacent land uses?

Note: urban food production uses will likely require some form of screening to keep animals such as rabbits and deer from eating the produce. Commercial farms may require screening for noise and smells. Farmers' markets, and parkland may require screening related to noise and on-site human activity.

Grade changes
1 point maximum
(Yes-0; No-1)



- Are there significant grade changes between the street level and the parcel that contains the potential area for reuse that would require ramps to be installed to ensure equitable access for all users?

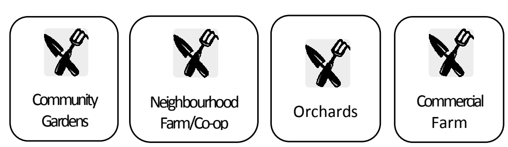
The Accessibility for Ontarians with Disabilities Act, 2005 makes Ontario the first jurisdiction in Canada to develop, implement and enforce mandatory accessibility standards, and applies to both the private and public sectors. The plan sets goals to make Ontario accessible by 2025. This includes access to parkland and green infrastructure.

Designated Parking
1 point maximum
(Yes-1; No-0)

- Is there designated parking (1 hour minimum) on streets that abut the potential area for reuse?

Criteria 5. Proximity to Complementary Uses

Existing access to healthy, affordable food
(see detailed scoring below)



- Is there access to healthy sources of food within an 800-metre radius from the potential area for reuse? (Database of access to food will be used for this question – no input required)

- Scoring for community gardens or neighbourhood farm: 2 points max – 1 point each if within 800-metres of a community kitchen or food bank
- Scoring for Farmers' Markets: points unlimited – 0.5 points assigned for every neighbourhood farm, orchard, or commercial farm located within a 3 mile radius
- Scoring for commercial farms and orchards: 7 points max - 1 point each if within 800-metres from a farmers' market, specialty grocer, produce market, small-scale grocer, supermarket, community kitchen, or food bank
- Double points are given if the area does not contain these food elements

When locating sites for urban food production purposes, it is important to consider proximity to other urban agriculture uses to facilitate combined efforts in distribution, marketing and sharing resources/tools (KSU 2008 and 2009; Hohenschau, 2005).

A weight has been assigned to the scoring such that areas that have fewer urban food production elements are deemed to be more vulnerable to food deserts and are therefore given a weight of 2x (Hohenschau, 2005).

The proximity of commercial farms to farmers' markets, specialty stores, and grocery stores is important (KSU 2008, 2009). This logic has also been extended to orchards.

Farmers' markets have a typical trade area of 3-7 miles (Hohenschau, 2005).

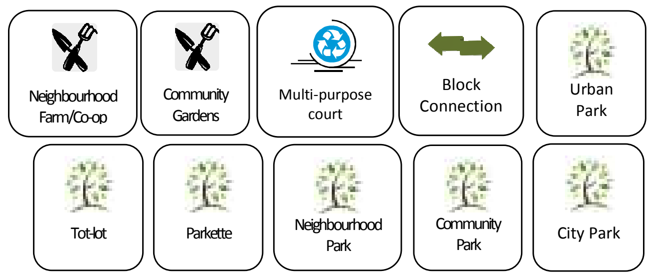
Urban Natural Heritage System
1 point maximum
(Yes -1; No-0)

- Is the potential area for reuse located within a 5-minute walk of a natural heritage system element

- Note: user to open Urban Natural Heritage System Map and identify "Core Areas". Core Areas include significant wetlands, rivers, and woodlands

Providing green infrastructure linkages and corridors that connect existing natural heritage areas is important in creating continuous productive urban landscapes. They also assist in migration patterns of animals.

Public housing
1 point maximum
(Yes – 1; No – 0)



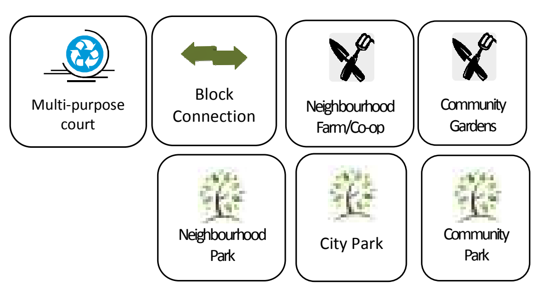
- Are there medium- to high-rise public (social) housing complexes located within a 400-metre radius from the potential area for reuse? (no input required – database of locations to be used)

Urban parks require well connected locations that can then encourage a lively mix of uses, but should be located in areas that contain supporting uses such as commercial and residential uses (Corbett, 2004)

Tot lots should only be developed in exceptional circumstances, as they accommodate only a very small portion of people's needs, and due to limited space, they often cater to very focused age groups.

It is important to target food production areas to low income neighbourhoods (Hohenschau, 2005).

Schools
1 point maximum
(Yes – 1; No – 0)



- Are there any elementary, middle, high schools, colleges, or universities located within a 400-metre radius from the potential area for reuse? (Database of schools will be used for this question – no input required)

Community gardens should be located in close proximity to schools (KSU, 2008 or 2009; Hohenschau, 2005; Hamilton Community Garden Network, 2008).

There is a policy direction to develop agreements with school boards for the construction/ maintenance of outdoor recreation facilities for community use on school property (Hamilton Parks and Open Space Master Plan, 2002).

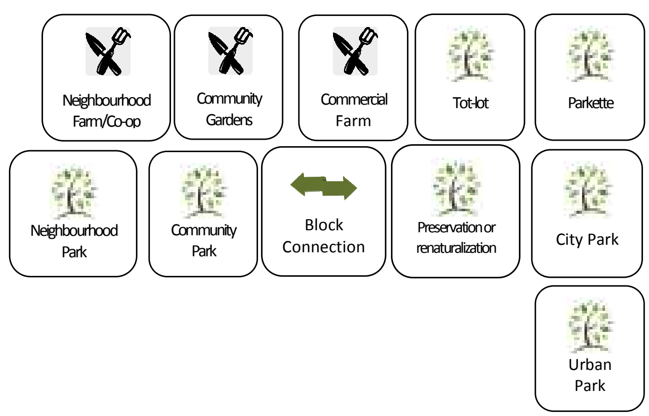
School-park combinations are an efficient way of providing parkland to neighbouring residents (and are a part of many municipal policies); block connections, located in close proximity to these institutions, aids in accessibility.

School facilities provide parking and facility support elements on these sites that will serve the community uses during out of school hours (Hamilton Parks and Open Space Master Plan, 2002)

The local school acts as a focal point of neighbourhood identity and activity, neighbourhood parks should be located adjacent to, and integrated with, the neighbourhood elementary school (City of Hamilton Parks and Open Space Master Plan, 2002)

Parkland

2 points maximum (Parkland uses: 1 point if a diverse mix of uses are not present e.g. <3 uses present; 1 point if park levels are not currently met; Food production uses: 2 points if located within 400-metres of either a neighbourhood, community, or city park)



- Are there any parks (active, passive, or naturalized open space) located within a 400-metre radius from the potential area for reuse? (Database of parks and neighbourhood deficiency rates related to parkland access will be used for this question – no input required)

Community gardens should be located such that they create a network of food spanning the urban fabric – located on vacant land, institutional lands, in parks, and private land (Hohenschau, 2005).

The most popular potential site identified for community gardens in the City of Hamilton (by gardeners) was in City parks (Hamilton Community Garden Network)

Commercial farms should be located in mixed-use, diverse urban areas with multiple land uses, where there is equal access by all community members (Grimm, 2009)

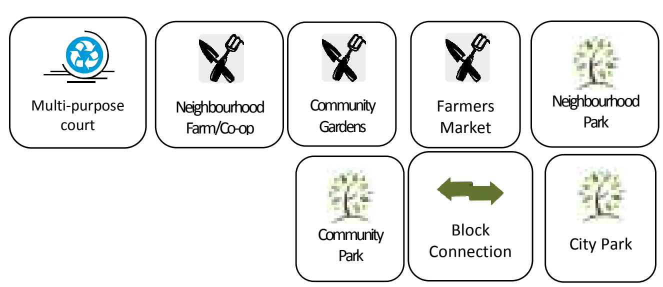
The proximity of block connections to parks further encourages pedestrian/cyclist activity in accessing these facilities

Potential areas for reuse that are in close proximity to other parks can assist in creating a continuous green infrastructure/productive urban landscape, which can provide linkages and facilitate habitat migration patterns (KSU, 2008 or 2009; CPULs, 2009)

The City of Hamilton Parks and Open Space Master Plan (2002) stresses the importance of increasing linear linkages between parks and cultural/recreational buildings. As such, having block connections in close proximity to parkland is beneficial.

Tot lots should only be developed in exceptional circumstances, as they accommodate only a very small portion of people's needs, and due to limited space, they often cater to very focused age groups.

Community Centres
1 points maximum
(Yes – 1; No – 0)



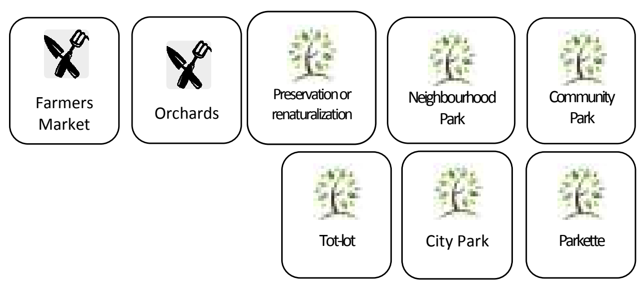
- Are there any community centres located within a 400-metre radius from the potential area for reuse? (Database of community centres will be used for this question – no input required)

Community gardens should be located such that they create a network of food spanning the urban fabric – located on vacant land, institutional lands, in parks, and on public and private land

Community centre, located across the street from farmers' markets, provides complementary programming – opportunities for cooking demonstrations and cafes (Hohenschau, 2005)

The City of Hamilton Parks and Open Space Master Plan (2002) stresses the importance of increasing linear linkages between parks and cultural/recreational buildings. As such, having block connections in close proximity to community centres is beneficial.

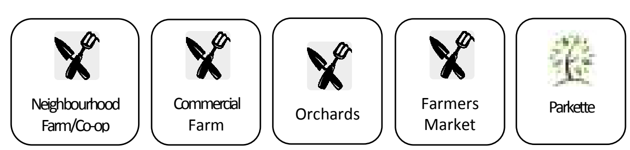
Hospitals
1 point maximum
(Yes – 1; No – 0)



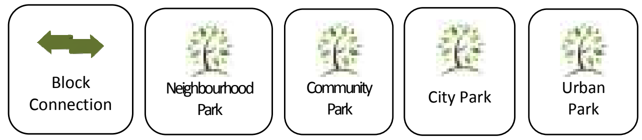
- Are there any hospitals located within a 400-metre radius from the potential area for reuse? (Database of hospitals will be used for this question – no input required)

Orchards and Farmers' Markets in close proximity to hospitals (or even on hospital lands) would promote healthy eating, provide a place for staff, visitors and patients to walk and pick a piece of fruit. Green spaces and vegetation also have psychological benefits when seen from a patient's room/bed (sources to be added later)

Mixed-use, pedestrian-oriented commercial areas
1 point maximum



(Yes – 1; No – 0)



- Are there any pedestrian-oriented, mixed use commercial areas located within a 400-metre radius from the potential area for reuse? (Database of mixed-use commercial areas will be used for this question – no input required)

Commercial farms should be located in mixed-use, diverse urban areas with multiple land uses, where there is equal access by all community members (Grimm, 2009)

Farmers' markets should be situated in close proximity to a mix of commercial uses (Hohenschau, 2005)

Urban parks require well connected locations that can then encourage a lively mix of uses, but should be located in areas that contain supporting uses such as commercial and residential uses (Corbett, 2004)

Proximity to mixed-use, pedestrian-oriented commercial space provides opportunities for the sale of locally-grown produce.

Homes for the aging
1 point maximum
(Yes – 1; No – 0)

- Are there any homes for the aging (e.g. seniors apartments, transitional homes, nursing homes) located within a 400-metre radius from the potential area for reuse? (Database of homes for the aging will be used for this question – no input required)

Commercial farms should be located in mixed-use, diverse urban areas with multiple land uses, where there is equal access by all community members (Grimm, 2009)

Places of worship
1 point maximum
(Yes – 1; No – 0)

- Are there any places of worship located within a 400-metre radius from the potential area for reuse? (Database of places of worship will be used for this question – no input required)

Potential sites for community gardens, identified by the Hamilton Community Garden Network, included church properties (Hamilton Community Garden Network).Church property was also identified as a prime location for Neighbourhood farms (KSU 2008 and 2009)

Proximity to public buildings (e.g. libraries, cathedrals, town halls) can help generate activity and be beneficial to urban parks (Corbett, 2004)

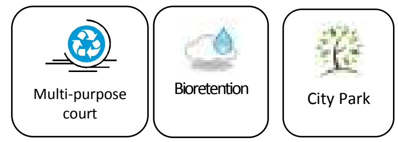
Places of worship typically facilitate a wide variety of services for the community at large (including growing Victory gardens for food banks and low income earners (personal communication, 2010).

Significant natural heritage features
1 point maximum
(Yes – 1; No – 0)

- Is the potential area for reuse within a 400-metre radius from a significant natural heritage feature?

Potential for Increased residential density in the Neighbourhood
1 point maximum
(Potential development or pending review – 0;

Draft Approved or
Registered - 1)



- Are any parcels of land within this Census Tract in the City's residential vacant land inventory? If so, at what stage in the development process is it?
    - Potential development
    - Pending review
    - Draft Approved
    - Registered

The user will open the vacant residential land inventory prepared by the City to answer this question.

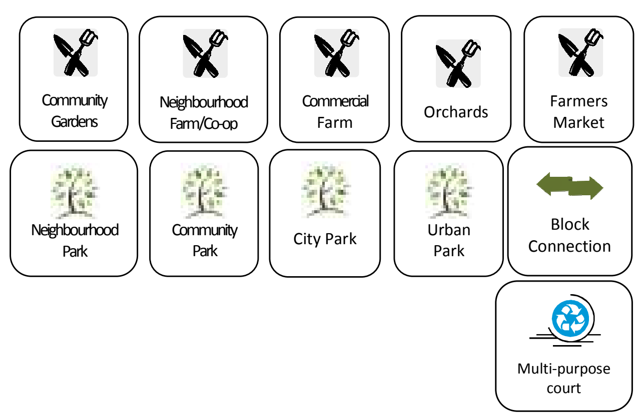
Priorities for parkland acquisition are often cited as areas with significant existing and/or proposed residential densities (City of London Official Plan, City of Hamilton Official Plan)

Neighbourhood tot lots and play areas act almost exclusively as a replacement for private open space in high-density neighbourhoods (City of Hamilton Parks and Open Space Master Plan, 2002)

Criteria 6. Transportation

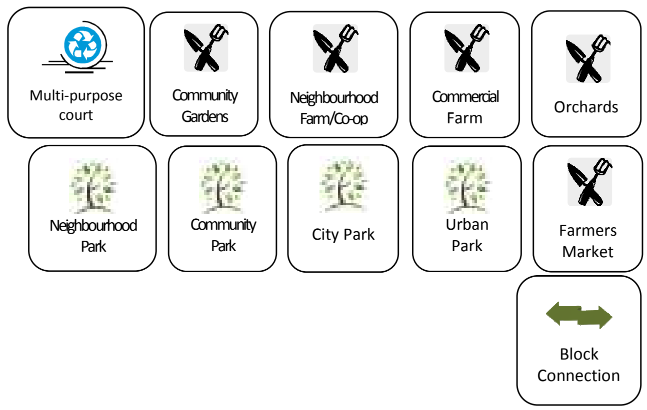
Public Transit - Bus

1 Point Maximum
(<= 15-minute headway = 1; all others =0)



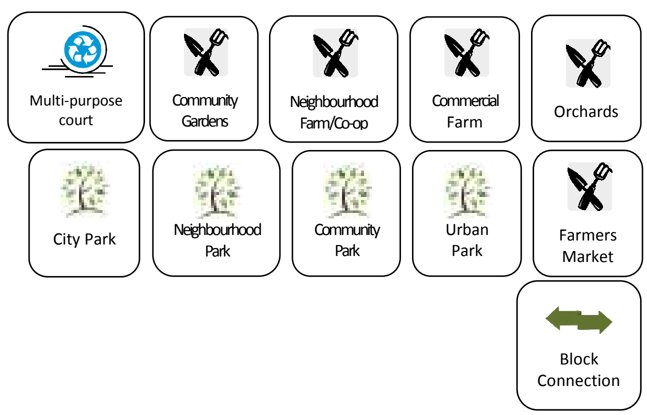
- The potential area for reuse is within 400-metres of:
    - A bus stop (user to enter bus # only)

Rapid Transit
1 Point Maximum
(Yes-1; No-0)



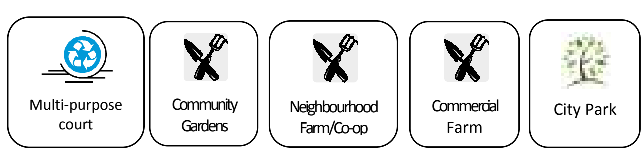
- The potential area for reuse has a proximity/density score of 6 or higher (note: the user is required to open the City of Hamilton's Rapid Transit Map to view the scoring).

On-Street Bike Paths
1 Point Maximum
(Yes-1; No-0)

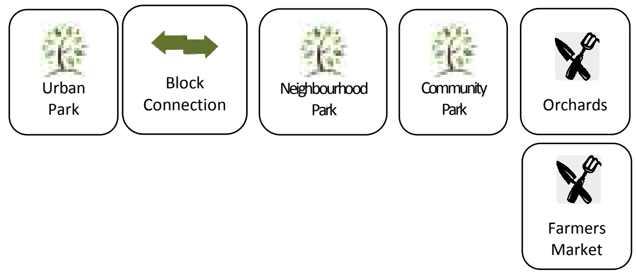


- The potential area for reuse is within 400-metres of an existing or future on-street bike path.

Recreational Trails
1 Point Maximum



(Yes-1; No-0)



- The potential area for reuse is within 400-metres of an existing or future recreational trail.

Bruce Trail
1 Point Maximum
(Yes-1; No-0)

- The potential area for reuse is within 400-metres of the Bruce trail.

Neighbourhood farms should be located in close proximity to good transit service (Hohenschau, 2005).

Community gardens should be located in close proximity to high-frequency bus service (KSU, 2008).

Commercial farms should be located in mixed-use, diverse urban areas with multiple land uses, where there is equal access by all community members (Grimm, 2009).

Commercial farms should be located in close proximity to high frequency transit (KSU, 2009).

Farmers' markets should be located in close proximity to high frequency transit (Hohenschau, 2005)

Acquisitions which will serve to create a more continuous or linked park system area priority (City of London Official Plan)

The reuse treatment will minimize the generation of traffic on local streets through residential areas by placing a heavier weight on its proximity to high-frequency public transit and accessible multi-purpose trails/bike paths (adapted from the City of London Official Plan)

There is currently a lack of public transportation to public facilities and special events (Hamilton Parks and Open Space Master Plan, 2002)

The proximity of block connections to trails and transit stops supports access to these transportation options (KSU, 2008; 2009)

Urban parks require well connected locations that can then encourage a lively mix of uses (Corbett, 2004)

Hamilton has an extensive network of trails available to residents, totaling 137 km. The most prominent is the Bruce Trail. The Hamilton to Brantford Rail Trail (32 km), the Lafarge 2000 Trail (22km) and the Dofasco 2000 (11.5 km) (Hamilton Parks and Open Space Master Plan)

References

Adams, C.D., Baum, A. E. and MacGregor, B.D. (1988). The availability of land for inner city development: A case study of Inner Manchester. Urban Studies. Vol. 25(1): 62-76.

Bowman, A. O'M. and Pagano, M. A.. (2004). Terra Incognita: Vacant Land and Urban Strategies. Washington, D.C.: Georgetown University Press.

Corbett, N. (2004). Transforming Cities, Revival in the Square. RIBA Enterprises Ltd., England.

Cutter, S.L., Mitchell, J.T. and Scott, M.S. (1997). Handbook for conducting a GIS-based hazards assessment at the county level, Hazards Research Lab, University of South Carolina.

Departments of the Army and Air Force. (1988). Technical Manual Headquarters No. 5-803-10. Washington, DC. [Design of Sports Facilities]

Duany Plater-Zyberk & Company, LLC. (2009). Agricultural Urbanism. Accessed via http://www.lindroth.cc/pdf/QuickReadAgf.pdf. Accessed on July 23, 2010. [Illustrating the first AU project in Canada]

Grimm, J. (2009). Food urbanism: A sustainable design option for urban communities.

Hamilton, City of. (2002). Hamilton Parks and Open Space Master Plan.

Hamilton, City of. (2007). Hamilton Recreational Trails Master Plan.

Hamilton Food Share. (2009). Hamilton Hunger Count 2009. *[Report]*

Hamilton Roundtable for Poverty Reduction. (2007). Making Hamilton the Best Place to Raise a Child.

Hohenschau, D. L. (2005). Community food security and the landscape of cities. (Master of Landscape Architecture, University of British Columbia). 1-84.

Kent State University (KSU). (2008). Re-imagining a more sustainable Cleveland. Citywide strategies for reuse of vacant land. Cleveland: Cleveland Land Lab at the Cleveland Urban Design Collaborative.

Kent State University. (2009). Re-imagining Cleveland. Vacant land re-use pattern book. Cleveland: Cleveland Land Lab at the Cleveland Urban Design Collaborative.

London, City of. (2009). Parks and Open Space Master Plan.

London, City of. (Current, 2010). Official Plan.

Maryland, University of (no date). Pedestrian Environment Data Scan (PEDS) Tool. Accessed via http://www.activelivingresearch.org/resourcesearch/toolsandmeasures. Accessed on May, 9, 2010.

Maryland, University of (no date). Measurement Instrument for Urban Design Quantities Related to Walkability. Accessed via http://www.activelivingresearch.org/resourcesearch/toolsandmeasures. Accessed on May, 9, 2010.

Mayo, J. (2008). Report for the Hamilton Community Garden Network.

Mendes, W., Balmer, K., Kaethler, T., & Rhoads, A. (2008). Using land inventories to plan for urban agriculture. Journal of the American Planning Association, 74(4), 435-449.

Ministry of Culture and Recreation. (1976). Guidelines for Developing Public Recreation Facilities.

Ontario Power Authority. (2010). Micro Feed-in Tariff Program: Program Overview.

Pagano, M. A. and Bowman, A. O'M. (2000). Vacant land in cities: An urban resource. Brookings Institution Survey Series, Centre on Urban and Metropolitan Policy.

Rosenberg, J.L. and Esnard, A. (2008). Applying a Hybrid Scoring Methodology to Transit Site Selection. Journal of Urban Planning and Development Vol. 134(4): 180-186.

San Diego State University, Cincinnati Children's Hospital Medical Center. (no date). Neighborhood Environment Walkability Survey – Abbreviated (NEWS-A). Accessed via http://www.activelivingresearch.org/resourcesearch/toolsandmeasures. Accessed on May, 9, 2010.

Statistics Canada (2006). Custom-built Dissemination Area tables for the City of Hamilton. Accessed via http://dc2.chass.utoronto.ca.libaccess.lib.mcmaster.ca/cgi-bin/census/2006/displayCensusDA.cgi?lang=&c=&p=&l=&dt=s&ct=c. Accessed on June, 16, 2010.

Van Herzele, A. and Wiedemann, T. (2003). A monitoring tool for the provision of accessible and attractive urban green spaces. Landscape and Urban Planning Vol. 63(1): 109-126.

Wisconsin Department of Natural Resources: UW-Extension. (2003). Rain Gardens: A how-to manual for homeowners.

Part 2: Final Community-based self-assessment planning tool (C-SAP)

for identifying reuse strategies for vacant and underutilized urban land

Document Finalized: January, 2011

Part 2 of Appendix A provides a summary of the vacant and underutilized land inventory (VULI) included in C-SAP (refined through consultation with experts in a variety of professional designations). VULI employs a hybrid, normalized, binary scoring methodology, as described in detail in Chapter 2 of this thesis (and accompanying appendix). Each question below is scored a "1" if "yes" is selected (favourable) and "0" if "no" is selected (less favourable). The user can set-up default "questions scenarios" for each reuse strategy in C-SAP.

General input for each potential area for reuse:

- Street Address
- Longitude/latitude of parcel
- Neighourhood, Census Tract, and Dissemination Area
- Reuse Treatments to be evaluated
- Size of potential area(s) for reuse
- Sunlight conditions

Criterion 1 - Neighbourhood Quality

Question 1. Are streets generally well-framed by buildings, creating a sense of enclosure?

Question 2. Do streets generally contain elements that are designed at a human scale?

Question 3. Are streets generally tree-lined, creating a continuous canopy over the street?

Question 4. Do buildings have ground-level windows that look onto the street?

Criterion 1 - Neighbourhood Quality

Question 5. Is the street network generally characterized by a grid network?

Question 6. Are any properties in the walkable catchment declining or abandoned?

Question 7. Do neighbourhood streets have sidewalks, typically on both sides of the street?

Criterion 2 – Developability Potential

Question 1. Is the site located in an area with an active neighbourhood association or group?

Question 2. Is the site owned by the City?

Question 3. Does the site have good soil drainage?

Question 4. Is there access to water (for irrigation) either on or adjacent to the site?

Question 5. Will structures, foundations, or large debris need to be removed prior to reuse?

Question 6. Does the site have access from a public road (i.e. not land-locked)?

Question 7. Is there potential to retain existing vegetation, if any?

Question 8. Does the site have a sense of enclosure?

Question 9. Will on-site lighting need to be installed (lighting after dark, for example)?

Question 10. Is the site currently covered in asphalt or concrete - e.g. parking lot?

Question 11. Will a fence/screening likely be required between the site and adjacent uses?

Question 12. Will special access provisions be required to provide access to the site?

Question 13. Does the site contain any active uses/is it partially occupied?

Criterion 2 – Developability Potential

Question 14. Given the abutting zoning, could the site potentially require soil remediation?

Question 15. Given the on-site zoning, could the site potentially require soil remediation?

Question 16. Will the site likely require grading to make the surface level for parks/gardens?

Criterion 3 – Visual Quality of Site

Question 1. Is there a pedestrian presence abutting the site throughout the day/evening?

Question 2. Is the site located on a street with 3 or more lanes for vehicles?

Question 3. Are there unobstructed sightlines from adjacent buildings and sidewalks?

Question 4. Is the site currently in a state of decline?

Question 5. Does the site support pleasant views (adjacent uses, natural elements, etc.)?

The user of C-SAP is required to select a distance that is deemed to be "walkable". The majority of the following questions can be set-up in C-SAP such that they are automated for the user (geodesic distances calculated between the area for reuse and abutting urban land uses)

Criterion 4 – Compatibility with Urban Environment

Question 1. Is the site located in a predominantly residential neighbourhood?

Question 2. Is the site within a walkable distance of a parcel in the vacant land inventory?

Question 3. Is the site within a walkable distance from healthy food sources?

Criterion 4 – Compatibility with Urban Environment

Question 4. Is the site within a walkable distance from social/subsidized housing?

Question 5. Is the site within a walkable distance from any educational institutions?

Question 6. Is the site within a walkable distance from any parks?

Question 7. Is the site located within a walkable distance from a community centre?

Question 8. Is the site located within a walkable distance of a hospital?

Question 9. Is the site located within a walkable distance from a mixed-use area?

Question 10. Is the site located within a walkable distance from a home for the aging?

Question 11. Is the site located within a walkable distance from a place of worship?

The following criteria are required prior to completing this section:

Criterion 5 – Transportation Options

Criterion 1. How many buses/hour represent sustainable bus service with respect to access to this site?

Criterion 2. Select the % of the daily bus service that must meet Criterion 1 to be considered sustainable (e.g. 80% of the daily bus service must meet Criteria 1)

Criterion 3. Select "1" to evaluate the bus schedule on weekdays. Select "2" to evaluate the bus schedule on weekdays and weekends

Criterion 4. Select "1" to evaluate the bus schedule during activity peak periods (6am-10am, and 3pm-8pm). Select "2" to evaluate the bus schedule all day.

Criterion 5. Select all bus stops within a walkable distance of the potential area for reuse.

Criterion 5 – Transportation Options

Criterion 6. Select the minimum percentage of city-wide bus routes that should be accessible to this site (e.g. "5% of all city routes should be within the walkable catchment").

The following questions need to be completed for this section:

Question 1. Question 1. Is there adequate neighbourhood bus service, currently servicing the site?

Question 2. Question 2. Is the site sufficiently connected to city-wide bus routes?

Question 3. Question 3. Does the site have access from an abutting sidewalk or a nearby linear trail?

Question 4. Question 4. Is the site located on a road that contains a designated bike route?

Question 5. Question 5. Is there potential for either on or off-street parking, adjacent to the site?

Criterion 6 – Vulnerable Populations

Step 1. Select a vulnerable population sub-group to evaluate and save the record (Census data are collected for the selected vulnerable population sub-group at the Census Tract level).

Appendix C. Decision Support Tool Help Files

A series of *.pdf help files were developed to assist the user in navigating the C-SAP interface and completing VULI, SSI, LOCAL and DECO. A brief description of the contents of each help file is provided below, along with the help file name in bolded text. All help files are located in Appendix D (located on the enclosed CD), and can be accessed via the C-SAP user interface, when additional explanations/assistance is required. Note: helpful hints and notes have also been included on the main C-SAP interface (in text format – no download required).

User Guide – this is the main help file for C-SAP. It provides an overview of the decision support tool, as well as the system requirements for the tool.

Resolving Missing References – if C-SAP does not run successfully, this file contains trouble-shooting information (note: C-SAP was developed using Windows XP, and Office 2007).

Reuse Strategies – this file contains short (< 5 years), medium (5+ years) and long-term (potentially permanent) reuse strategy timelines for vacant and underutilized urban land. This file assists users in identifying which reuse strategies to evaluate for each potential area for reuse (based on the potential lease length of the parcel).

Areas for Reuse – this file depicts two examples for identifying one, or multiple, areas for reuse for a particular municipal address/location.

Minimum Area Requirements – this file identifies the recommended minimum areas required for each reuse strategy in C-SAP. This file will assist the user in identifying which reuse strategies to evaluate (i.e. those that are feasible) for each potential area for reuse. The minimum dimensions help file (described below) will also be useful in determining feasible strategies for analysis.

Minimum Dimensions – this file is used in LOCAL (location-allocation model). These are the recommended minimum dimensions required for a strategy, prior to allocating it to a particular site.

AHP Technique – this is an excerpt from a textbook, explaining the basics of the Analytic Hierarchy Process (an example is included).

Approximation Method AHP – this file explains the differences between the approximation methods available in SSI: (i) the squaring method, (ii) the nth root method and (iii) the normalized relative weight method.

Census Tract/Dissemination Areas (CT1.01-CT303.02) – these files assist the user in identifying the corresponding CT and DA identification numbers for the geographic location under analysis (note: these files can be replaced and renumbered to correspond to the city under analysis – see CTDA_Helpfiles for instructions). This information is then used to in C-SAP to identify vulnerable populations in the area surrounding each potential area for reuse.

CTDA Help files – this file assists the user in customizing the above-noted help files for any city under analysis (note: the existing files in C-SAP correspond to CT's and DA's Hamilton, Ontario, Canada).

Developability Potential (DQ1-DQ8) – these files provide photographs to assist the user in completing the developability potential section of the vacant and underutilized land inventory (note: these are not city-specific; rather, they are general).

Visual Quality of Site (OQ1-OQ2, WQ1-WQ6, and WardTax1-WardTax15) – these files provide photographs/maps to assist the user in completing the visual quality of site section of the vacant and underutilized land inventory (note: OQ1-OQ2 and WQ1-WQ6 are not city-specific; rather, they are general, while WardTax1-WardTax15 are specific to the City of Hamilton; however, these can be replaced and renamed for the city under analysis).

Transportation Options (Ward 1 – Ward 15) – these files contain information that assists the user in completing the transportation options section of VULI (note: these files are specific to Hamilton, but can be replaced and renamed for the city under analysis).

Safety – this file contains information on street lighting/illumination values to assist the user in identifying the visibility of the area for reuse after dark.

Shade garden – this file contains a series of shade garden designs. The user can select a garden design in DECO, and the corresponding cost per square foot will be automatically assigned.

Sun garden – this file contains a series of sun garden designs.

INFO help files – these files contain information specific to the City of Hamilton, and assist the user in completing VULI. These files can be replaced with data for another City; however, the file names need to remain unchanged.

DECO – this is a comprehensive help file that assists the user in completing DECO.

Maintenance Modes – this file that assists the user in selecting a maintenance mode for analysis in DECO.

Location Factors – this file assists the user in selecting a multiplication factor (location factor) for application in DECO. The location factor converts the life cycle costs to Canadian or American dollars.

Appendix D. Decision Support Tool (CD)

C-SAP is a scientific software product, developed in Microsoft Excel®. Appendix D is an electronic appendix, and is located on the CD on the inside back-cover of the thesis document. If you are viewing an electronic version of this thesis document, the tool can be downloaded from McMaster University's Sustainable Communities Research Group website, located at: www.eng.mcmaster.ca/civil/sustain/downloads.html.

Appendix E. Supplementary Material Related to Chapter 2

Appendix E contains text detailing the procedure for calculating site suitabilty indices. This appendix also includes a set of two tables that provide supplementary detail to support the manuscript presented in Chapter 2. Table E.1 provides a summary of the judgment statements available to the user in C-SAP, while Table E.2 provides the corresponding scale (or, intensity of importance), for each statement.

Calculating Site Suitability Indices (SSIs)

The steps required for the calculation of the site suitability indices are shown in Figure 2.5. To calculate the site suitability indices, the binary scores are collected from the inventory process, tallied within each of the umbrella criteria and then normalized, based on the best performing site for each strategy. C-SAP uses the Analytic Hierarchy Process (AHP) to clarify the importance of each criterion using a set of fifteen judgment statements (shown in Table E.1). From these statements, the umbrella criteria weights are calculated and finally the scores are aggregated using the calculated weights. The output is a set of site suitability indices for individual strategies, relative to the inventoried sites.

Developed by Thomas Saaty, the Analytic Hierarchy Process is described in detail in many other written works (Saaty, 1977; Saaty, 1990), with applications in a broad range of disciplines, spanning several decades. In C-SAP, a unique set of judgment statements can be entered for each reuse strategy, or statements can be completed on a sub-set of strategies. The user repeats this process until judgment statements have been made for all strategies under analysis. The statements available in C-SAP are shown in Table E.1, while Saaty's corresponding scale is shown in Table E.2 (Saaty, 1977). These statements are then translated into a 6x6 matrix of judgment statements, **A**. The diagonal elements are assigned a value of "1", as each criterion is equally important when compared to itself. Next, the priority vector, $\boldsymbol{\omega}$ is calculated from the matrix of judgment statements. Three approximate methods are available in C-SAP for calculating the priority vector: nth root, squaring, and normalized relative weight, which provide good approximations of the priority vector (Palcic and Lalic, 2009). The nth root is calculated by taking the product of n values in each row of Matrix, **A**, calculating the nth root of that product (the geometric mean), and then normalizing the vector (the cells are divided by the sum of the product column). A priority vector can also be obtained by squaring the pair-wise comparison matrix, **A**, summing the rows and dividing each row element by the sum of the column. This process is iterative and will continue until the change in priority matrix values between the current and previous squared matrix is less than 0.0001. The normalized relative weight method is calculated by dividing all cells in an individual column of the Matrix, **A** with the sum of the cells of each given column, then all rows are summed and divided by n.

The next step in calculating the site suitability indices is to calculate estimates for λ_{max}. This is done by multiplying the judgment statement matrix, **A** by the priority vector, $\boldsymbol{\omega}$ and dividing by the corresponding priority vector element, $\boldsymbol{\omega}$ ($\mathbf{A}\boldsymbol{\omega}=\lambda_{max}\boldsymbol{\omega}$). The average is then calculated for the set of λ_{max} values. Next, a Consistency Index (CI) is calculated as follows: $(\lambda_{max}-n)/(n-1)$, where n is the number of criteria. The final step is to calculate the Consistency Ratio (CR) by dividing the CI by the index for the corresponding random matrix (1.24 for n=6) for random judgments (Saaty, 1990). A CR of zero means that the judgment statements are perfectly consistent, while a ratio that exceeds 0.1 may indicate that the judgments are too inconsistent to be reliable (Saaty, 1990). A warning is provided to the user if the CR is greater than 0.1, giving the user the option to re-enter the judgment statements.

The final step required in calculating the site suitability indices is to multiply the normalized matrix of scores, **B,** from the inventory process by the priority vector, $\boldsymbol{\omega}$. This results in Matrix, **C**, which consists of numeric values between 0 and 1 for each strategy at each site. This methodology allows the user to make statements about the suitability of a single strategy across all sites, but does not allow the user to make fair statements with respect to the suitability of one strategy over another at any given site.

Table E.1 Fifteen (15) judgment statements required to calculate the site suitability index for vacant and underutilized land

Neighbourhood Quality is	***Saaty* statement***	when compared to developability potential
		when compared to visual quality
		when compared to compatibility with urban environment
		when compared to modal options
		when compared to vulnerable populations
Developability potential is	***Saaty* statement***	when compared to visual quality
		when compared to proximity to compatibility with urban environment
		when compared to modal options
		when compared to vulnerable populations
Visual Quality of Site is	***Saaty* statement***	when compared to compatibility with urban environment
		when compared to modal options
		when compared to vulnerable populations
Compatibility with Urban Environment is	***Saaty* statement***	when compared to modal options
		when compared to vulnerable populations
Modal Options are	***Saaty* statement***	when compared to vulnerable populations

*For Saaty's statement descriptions, please see Table E.2 on opposite page

Table E.2 Analytic Hierarchy Process (AHP): Saaty's Scale

Saaty's Statement	Intensity of Importance
equally important (1)	1.00
very close, but slightly more important (1.5)	1.10-1.90 (C-SAP uses 1.5)
very close, but slightly less important (1/1.5)	0.67
slightly more important (2)	2.00
slightly less important (1/2)	0.50
moderately more important (3)	3.00
moderately less important (1/3)	0.33
moderately more important plus (4)	4.00
moderately less important plus (1/4)	0.25
strongly more important (5)	5.00
strongly less important (1/5)	0.20
strongly more important plus (6)	6.00
strongly less important (1/6)	0.17
very strongly more important (7)	7.00
very strongly less important (1/7)	0.14
very, very strongly more important (8)	8.00
very, very strongly less important (1/8)	0.12
extremely (ultimately) important (9)	9.00
extremely (ultimately) unimportant (1/9)	0.11

References

Palcic I, Lalic B, 2009, "Analytic Hierarchy Process as a Tool for Selecting and Evaluating Projects", *International Journal of Simulation Modelling* **8**(1) 16-26

Saaty T L, 1977, "A Scaling Method for Priorities in Hierarchical Structures" *Journal of Mathematical Psychology* **15** 234-281

Saaty T L, 1990, "How to make a decision: The Analytic Hierarchy Process" *European Journal of Operational Research* **48** 9-26

Appendix F. Supplementary Material Related to Chapter 3

Appendix F contains five tables and one figure that provide supplementary information related to the manuscript located in Chapter 3. Table F.1 provides a summary of the inventoried sites used in the prototype decision support system (PDSS) application described in Chapter 3 (VULI). Table F.2 contains a summary of the judgment statements applied in Applications 1 through 8 for the calculation of the site suitability indices (SSI). Table F.3 provides a summary of the constraints applied to the 8 applications, as part of the location-allocation model set-up (LOCAL). Table F.4 provides a summary of the location-allocation output and the corresponding area allocated to each reuse strategy. Table F.5 depicts the number of urban agricultural strategies that were assigned in each application. The highlighted text represents reuse strategies that fell short of the desired number of allocations for said strategy (e.g. in Application 1, four community gardens were desired, while only 3 were allocated, based on the user-specified constraints in the model). Figure F.1 depicts output from LOCAL. This picture depicts a keyhole markup language (.kml) file, opened and displayed in Google Maps. The selection of any of the inventoried sites will provide a high-level summary (via an on-screen call-out bubble) of the allocated uses, site location, and site dimensions.

Table F.1 Location and description of sites analyzed in Chapter 3

Site Number	Neighbourhood	Address	Areas for Reuse – Approximate	Description
1	Ainslie Wood East	201 Whitney Avenue	45mx65m	Alexander Park
2	Ainslie Wood East	200 Whitney Avenue	20mx10m, 15mx20m	St. Marys High School
3	Beasley	135 Barton Street East	30mx45m	Land behind Food Basics, off Mary Street
4	Cootes Paradise	1280 Main Street West	20mx25m, 20mx40m	McMaster University
5	Corktown	175 Ferguson Avenue South	5mx50m	Corktown Park
6	Crown Point West	181 Belmont Avenue	20mx20m, 30mx30m	Belmont Park and Holy Name of Jesus School
7	Durand	120 Bay Street South	35mx125m	Old St. Mark's church lot at Bay and Hunter
8	Kernighan	3 StonePine Crescent	25mx80m, 45mx170m	Open land behind houses on StonePine Crescent, north of Stone Church Road
9	Kirkendall North	247 Duke Street	15mx10m, 12mx12m	HAAA Park
10	Kirkendall South	59 Beulah Avenue	20mx30m	Beulah Park
11	Landsdale	166 West Avenue North	10mx10m	West Avenue Christian Church
12	McQueston West	70 Reid Avenue North	35mx15m	Near Roxborough Park
13	Mohawk	299 Fennell Avenue West	95mx65m, 30mx65m	Hillfield Strathalan School
14	North End East	57 Guise Street East	70mx85m, 35mx100m	Marina at Guise and Hughson
15	North End West	500 MacNab Street North	20mx20m, 10mx65m	Land beside apartment towers on south side of Guise and Bayview Park
16	North End West	38 Strachan Street West	30m x 10m	Simcoe Tot lot
17	North End West	344 Bay Street North	50mx40m	Bayfront Park
18	St. Clair	499 Charlton Ave East	10mx25m	Grassy area off of rail trail, east of Wentworth Street
19	Upper King's Forest	1100 Mohawk Road East	25mx50m	Edge of Mohawk Sports Park
20	Westdale North	85 Oak Knoll	35m x 55m	Cootes Paradise – RBG Lands
21	Westdale North	300 Longwood Road North	20mx20m, 10mx5m, 10mx35m, 20mx25m	Princess Point – Royal Botanical Garden Lands

Note: It was assumed that all parks and corresponding parking would maintain their existing functions and that urban food production would be a supplementary/complementary 'infill' use. All potential areas for reuse identified were located in full sun.

Table F.2 Judgment statements utilized in Applications 1-8

Left-hand side of statement	Community Gardens and Neighbourhood Farms CR=0.135	Commercial Farms and Orchards CR= 0.069	Farmers' Markets CR= 0.079	Right-hand side of statement
Neighbourhood Quality is	slightly less important (1/2)	strongly less important (1/5)	slightly less important (1/2)	when compared to developability potential
	slightly less important (1/2)	moderately less important (1/3)	moderately less important (1/3)	when compared to visual quality
	moderately less important (1/3)	moderately less important (1/3)	equally important (1)	when compared to compatibility with urban environment
	very close, but slightly more important (1.5)	slightly more important (2)	moderately less important (1/3)	when compared to modal options
	strongly less important (1/5)	slightly less important (1/2)	slightly more important (2)	when compared to vulnerable populations
Developability potential is	strongly more important (5)	very, very strongly more important (8)	moderately more important (3)	when compared to visual quality
	slightly more important (2)	moderately more important plus (4)	moderately more important (3)	when compared to proximity to compatibility with urban environment
	slightly more important (2)	moderately more important plus (4)	slightly more important (2)	when compared to modal options
	moderately more important (3)	moderately more important (3)	slightly more important (2)	when compared to vulnerable populations
Visual Quality of Site is	slightly more important (2)	equally important (1)	moderately more important (3)	when compared to compatibility with urban environment
	slightly more important (2)	moderately more important (3)	slightly less important (1/2)	when compared to modal options
	slightly more important (2)	slightly more important (2)	slightly more important (2)	when compared to vulnerable populations
Compatibility with Urban Environment is	strongly more important (5)	moderately more important (3)	equally important (1)	when compared to modal options
	equally important (1)	equally important (1)	slightly more important (2)	when compared to vulnerable populations
Modal Options are	slightly less important (1/2)	moderately less important (1/3)	moderately more important (3)	when compared to vulnerable populations

Table F.3 User-specified constraints applied to eight applications of LOCAL

Reuse Treatment	Application #	Minimum Area (m^2)[1]	Maximum Area (m^2)[2]	Maximum number of treatments[3]	Service radius for each reuse treatment (m)	Minimum population density (upa)[4]	Minimum separation distance (m)[5]	Is the area currently deficient ?(y/n)[6]	Minimum width (m)[7]	Minimum length (m)[7]	Sunlight conditions
Community Gardens	A1	300	2023	4	400	25	400	Y	10	30	Full Sun
	A2	300		4		0			10	30	
	A3	300		4		0			0	0	
	A4	200		4		0			0	0	
	A5	300		8		25			10	30	
	A6	300		8		0			10	30	
	A7	300		8		0			0	0	
	A8	200		8		0			0	0	
Neighbourhood Farm	A1	300	4046	4	800	50	800	Y	10	30	Full Sun
	A2	300		4		0			10	30	
	A3	300		4		0			0	0	
	A4	200		4		0			0	0	
	A5	300		5		50			10	30	
	A6	300		5		0			10	30	
	A7	300		5		0			0	0	
	A8	200		5		0			0	0	
Commercial Farm	A1	1200	4046	4	1000	50	1000	Y	10	120	Full Sun
	A2			4		0			10	120	
	A3			4		0			0	0	
	A4			4		0			0	0	
	A5			2		50			10	120	
	A6			2		0			10	120	
	A7			2		0			0	0	
	A8			2		0			0	0	
Orchards	A1	300	4046	4	1000	50	1000	Y	20	15	Full Sun
	A2	300		4		0			20	15	
	A3	300		4		0			0	0	
	A4	200		4		0			0	0	
	A5	300		2		50			20	15	
	A6	300		2		0			20	15	
	A7	300		2		0			0	0	
	A8	200		2		0			0	0	
Farmers' Markets	A1	300	2023	4	1000	50	1000	Y	5	60	Any
	A2	300		4		0			5	60	
	A3	300		4		0			0	0	
	A4	200		4		0			0	0	
	A5	300		4		50			5	60	
	A6	300		4		0			5	60	
	A7	300		4		0			0	0	
	A8	200		4		0			0	0	

[1] Minimum contiguous area required for each treatment at a given site
[2] Maximum area desired at a given site for each treatment
[3] Maximum number of treatments desired across the entire area under evaluation
[4] Minimum population density required within the service radius for each treatment to be considered viable (units/hectare)
[5] Minimum separation distance between treatments of the same type
[6] Is the area currently deficient in the corresponding treatment? If no, the treatment is not considered in the analysis.
[7] Minimum width and length of the site to make it useable for the corresponding reuse treatment

Table F.4 Output from LOCAL for eight applications (A1-A8)

Site #	**Reuse Treatments Allocated to Each Site**				
	Community Gardens (m^2)	Neighbourhood Farm (m^2)	Commercial Farm (m^2)	Orchards (m^2)	Farmers' Markets (m^2)
1	A2/A4/A6/A8 : 2023	A4/A6/A8: 902, A7: 2925	A3: 2925	A1/A5: 2925	
2					A4/A8:500
3	A3/A6/A8: 1350	A2/A3/A7: 1350			
4		A2/A6: 800			A3/A4/A7/A 8: 1300
5	A4/A8: 250				
6				A2/A3/A4/A6 /A7/A8:1300	
7	A3/A4/A6/A7 /A8: 2023	A3/A4/A7: 2352	A1/A5: 4046, A2: 2352		A2/A6: 2023
8	A1/A5: 2000, A3/A7: 1558, A8: 2023	A1/A5: 3604, A3/A4/A7: 4046	A1/A2/A3/A4/A 5/A6/A7/A8: 4046		A2/A6: 2000
9					
10	A1/A2/A4/A5 /A6/A7/A8: 600	A3: 600			
11					
12	A2/A6/A7: 525	A8: 525		A1/A3/A4: 525	
13	A3/A7: 2023	A6: 4046	A3/A4/A7: 3046, A8: 4046		A2/A6: 1950
14	A2/A3/A6/A7 : 2023	A6/A7/A8: 4046		A2/A3/A4: 4046	
15				A1/A5: 400	A2/A6: 650, A3/A4/A7/A 8: 1050
16		A4/A8: 300			
17	A6: 2000	A2/A8: 2000			A3/A4/A7: 2000
18	A8: 250				
19	A1/A5: 1250		A3/A4: 1250	A2/A6/A7/A8: 1250	
20	A6: 1925		A4: 1925	A1/A2: 1925	A3/A7/A8: 1925
21	A7/A8: 1250	A2/A6: 350		A3/A4: 1250	

Table F.5 Allocation results for urban agricultural reuse treatments across the entire area under analysis

Application #	Community Gardens	Neighbourhood Farm	Commercial Farm	Orchards	Farmers' Markets
1	3	1	2	4	0
2	4	4	1	4	4
3	4	4	3	4	4
4	4	4	4	4	4
5	3	1	2	2	0
6	8	5	1	2	4
7	7	5	2	2	4
8	8	5	2	2	4

Note: The desired outcome was the allocation of 4 of each use for applications 1 through 4, and 8 community gardens, 5 neighbourhood farms, 2 commercial farms, 2 orchards, and 4 farmers' markets for applications 5 through 8. Scenarios that did not meet the desired outcome are shaded in grey.

Figure F.1 Sample Output from LOCAL (.kml)

Appendix G. Supplementary Material Related to Chapter 4

Appendix G contains three tables and two figures that provide supplementary detail for the manuscript presented in Chapter 4. Tables G.1 and G.2 present the capital and maintenance items selected for analyses in both Scenario 1 and 2. Table G.1 also shows the service life of each capital cost item, or alternatively, the replacement year for each item. Table G.2 depicts the maintenance frequency, or schedule, for each maintenance item. This is based on annual maintenance cycles (e.g. planting beds will be weeded sixteen times in the first and second growing years after planting and then sixteen times per year for Maintenance Mode I, and one time per year for Maintenance Mode IV, thereafter. Table G.3 presents the multiplication factors utilized in each application (1-9). Figure G.1 provides a snapshot of the main graphical user interface for DECO, where the user selects a scale for their design drawing and amends capital and maintenance costing data, as required. Figure G.2 provides a screenshot of the design drawing page and associated design layer input prompt. The user can add, size, position and rotate existing layers to their design drawing, or create and add new layers to the design page, as desired.

Table G.1 Capital Costs included in Applications

Capital Cost Items	Scenarios									Service Life
	S1					S2				
Capital Costs: Common to Designs A and B	1	2	3	4	5	6	7	8	9	
Dirt path, 3' wide						1				0
Woodchips, 4" deep, hand spread	1	1	1	1	1					2
Crushed stone, 1" thick							1			5
Stone mulch, Pea gravel								1		5
Stone mulch, ceramic chips, economy									1	2
Trees, deciduous, large	1	1	1	1	1	1	1	1	1	35
Trees, coniferous , medium	1	1	1	1	1	1	1	1	1	35
Trees, Apple	1	1	1	1	1	1	1	1	1	35
Trees, Apricot	1	1	1	1	1	1	1	1	1	15
Trees, Cherry	1	1	1	1	1	1	1	1	1	15
Trees, Pear	1	1	1	1	1	1	1	1	1	35
Raspberry	1	1	1	1	1	1	1	1	1	10
Perennial Garden Bed	1	1	1	1	1	1	1	1	1	0
Garden/storage shed, 32 to 200 S.F.	1	1	1	1	1	1	1	1	1	15
Cast iron bench, 8' long	1	1	1	1	1	1	1	1	1	15
Picnic Table, Yellow Pine	1	1	1	1	1	1	1	1	1	10
Garbage receptacles, galvanized steel, 40 gal. capacity	1	1	1	1	1	1	1	1	1	20
Recycling receptacles, galvanized steel, 40 gal. capacity	1	1	1	1	1	1	1	1	1	20
Wooden compost bins, 3' x 3' x 3' (Redwood)	1	1	1	1	1	1	1	1	1	10
Bike rack, 10' long	1	1	1	1	1	1	1	1	1	10
Design A: Cultivate new vegetable garden (no mulch, in-ground)	1	1	1	1	1	1	1	1	1	0
Design B: Raised planting beds, wood, 2' x 5' x 10’	1	1	1	1	1	1	1	1	1	10

Table G.2 Maintenance Modes

Maintenance Cost Items	Maintenance Modes (# times/year) e.g. 1 = one time/year; 0.33 = once every 3 years							
	Special maintenance frequency considerations for plant establishment period (yrs 1-5), if applicable					Frequency after establishment period		Reduc-ed Maint-enance
	1st year	2nd year	3rd year	4th year	5th year	Mode I	Mode IV	%
Planting beds - Weed mulched bed	16	16				16	1	94
Planting beds - Spring prepare, flower bed						1	1	0
Planting beds - Fall clean-up, pick up mulch for reuse						1	1	0
Planting beds - Separating perennials						0.33	0.33	0
Planting beds - Water planting bed, 1" water, manual	16	8				0	0	0
Mowing, riding mower, 36"-44"						40	9	78
Woodchips, rake						40	9	78
Crushed Stone - Spread sand and salt mix						40	9	78
Crushed Stone - Snow removal, plow						40	9	78
Dirt path, preventive maintenance (per week)						20	10	50
Pruning: Trees, deciduous, large	1	1				1	0.33	67
Pruning: Trees, coniferous, medium	1	1				1	0.33	67
Pruning: Fruit trees	1	1	1	1	1	1	0.33	67
Garbage Can - Empty						52	26	50
Recycling Can - Empty						52	26	50
Garden shed, preventive maintenance						1	0.5	50
Bench - Metal: preventive maintenance						1	0.5	50
Picnic table, preventive maintenance						1	0.5	50
Bike rack, preventive maintenance						1	0.5	50
Water food production areas, 1”						24	24	0

Table G.3 Multiplication Factor Scenarios Analyzed

Description of Life Cycle Multiplication Factor	Scenarios								
	S1					S2			
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Labour, Capital	1	1	0	1	0	1	1	1	1
Materials, Capital	1	1	0	1	0	1	1	1	1
Equipment, Capital	1	1	0	1	0	1	1	1	1
Labour, Maintenance	1	0	1	1	1	1	1	1	1
Materials, Maintenance	1	0	1	1	1	1	1	1	1
Equipment, Maintenance	1	0	1	1	1	1	1	1	1
Rubbish handling (%)	1	1	1	1	1	1	1	1	1
Discount Rate (%)	3	3	3	3	3	3	3	3	3
City Location Factor (varies)	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Sales Tax (%)	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
Contingency (%Capital Costs)	5	5	5	5	5	5	5	5	5
Maintenance Frequency (Multiplication factor = frequency in Table G.2)									
Mode/Frequency	1	1	1	4	4	4	4	4	4

Figure G.1 Customized Graphical User Interface (GUI) for DECO

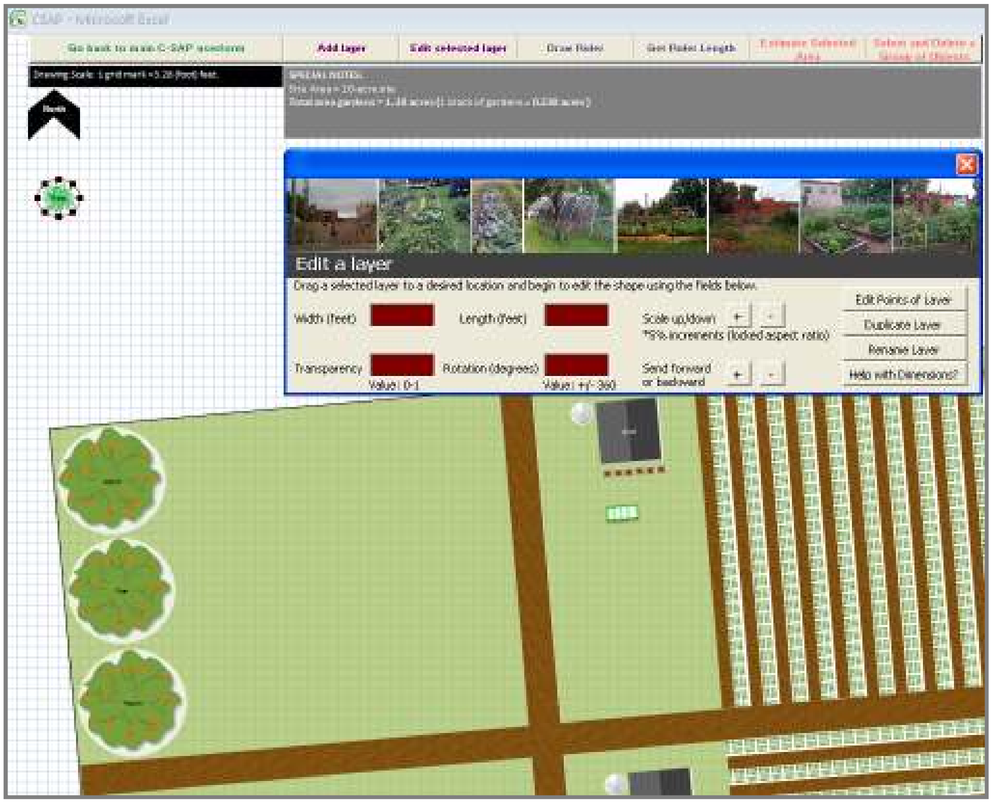


Figure G.2 Screenshot of Scaled Design Drawing

Appendix H. Supplementary Material Related to Chapter 5

Appendix H contains forty tables (H.1-H.40) that provide a concise summary of the tree growth and water balance modeling that was completed for the manuscript presented in Chapter 5. Tables H.1-H.4 present a summary of the total historical rainfall amounts for seven years of data, canopy interception, evaporation, throughfall, and site runoff for the four tree species modeled. Tables H.5-H.8, H.9-H.12, H.13-H.16, H.17-H.20, H.21-H.24, H.25-H.28, and H.29-H.32 present a summary in the same format as Tables H.1-H.4 for each tree species; however, these tables represent the results from a sensitivity analysis whereby the total historical rainfall amounts were increased by 5%, 10%, 15%, 20%, 25%, 30%, and 35%, respectively. Tables H.33-H.36 present a summary of the total canopy evaporation potential for the four tree species evaluated, when total historical rainfall amounts are increased from 5% to 35% by increments of 5%. Lastly, Tables H.37-H.40 present a summary of the results of the sensitivity analysis on total site runoff for the four species.

Water Balance Summary: Historical Data

Table H.1 *Ginkgo biloba* Water Balance – Historical Data: Christie Dam Station

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	3119 20611	9	12285	675	7650	19935	701	3	3
2002	378 2495	11	2203	28	264	2467	43	1	2
2003	482 3185	9	2594	48	543	3137	79	2	2
2004	396 2616	10	1909	64	643	2552	82	2	3
2005	534 3528	7	2227	83	1217	3445	137	2	4
2006	452 2985	7	1553	99	1333	2886	114	3	4
2007	286 1890	11	753	117	1021	1773	22	6	1
2008	592 3912	9	1045	236	2630	3676	225	6	6

Table H.2 *Platanus x acerifolia* Water Balance – Historical Data: Christie Dam Station

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	3119 20611	9	11199	743	8668	19868	697	4	3
2002	378 2495	10	2133	31	331	2463	43	1	2
2003	482 3185	8	2357	59	768	3125	78	2	2
2004	396 2616	9	1656	80	880	2536	82	3	3
2005	534 3528	7	1889	101	1539	3427	135	3	4
2006	452 2985	7	1333	113	1539	2872	112	4	4
2007	286 1890	12	691	124	1075	1766	22	7	1
2008	592 3912	9	1140	234	2538	3678	225	6	6

Table H.3 *Liquidambar styraciflua* Tree Water Balance – Historical Data: Christie Dam Station

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	3119 20611	18	12199	1280	7132	19331	684	6	3
2002	378 2495	27	2242	54	199	2441	42	2	2
2003	482 3185	20	2632	92	461	3093	78	3	2
2004	396 2616	21	1926	120	570	2496	81	5	3
2005	534 3528	15	2222	166	1139	3362	132	5	4
2006	452 2985	15	1524	192	1270	2793	111	6	4
2007	286 1890	24	717	225	948	1665	20	12	1
2008	592 3912	17	935	431	2545	3480	219	11	6

Table H.4 *Acer saccharinum* Tree Water Balance – Historical Data: Christie Dam Station

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	3119 20611	9	13456	565	6589	20046	704	3	3
2002	378 2495	12	2325	18	152	2477	43	1	2
2003	482 3185	9	2748	36	401	3149	79	1	2
2004	396 2616	10	2031	52	533	2564	82	2	3
2005	534 3528	7	2394	71	1063	3457	138	2	4
2006	452 2985	7	1711	82	1192	2903	114	3	4
2007	286 1890	11	875	101	913	1789	23	5	1
2008	592 4107	9	1372	205	2335	3707	225	5	6

Water Balance: Sensitivity Analysis

Table H.5 *Ginkgo biloba* Water Balance – Sensitivity Analysis: Increased Precipitation Values 5%

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	3275 21641	8	12899	678	8064	20963	821	3	4
2002	396 2620	10	2313	28	278	2591	52	1	2
2003	506 3344	8	2723	48	573	3296	95	1	3
2004	416 2747	9	2005	64	678	2682	94	2	3
2005	560 3704	7	2339	84	1282	3621	163	2	4
2006	474 3135	7	1631	96	1408	3039	134	3	4
2007	300 1985	11	791	118	1076	1867	28	6	1
2008	622 4107	9	1098	240	2770	3867	256	6	6

Table H.6 *Platanus x acerifolia* Water Balance – Sensitivity Analysis: Increased Precipitation Values 5%

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	3275 21641	8	11759	747	9135	20894	813	3	4
2002	396 2620	9	2239	32	348	2588	51	1	2
2003	506 3344	7	2475	60	809	3284	93	2	3
2004	416 2747	9	1739	81	927	2666	94	3	3
2005	560 3704	6	1983	101	1620	3603	160	3	4
2006	474 3135	7	1400	109	1625	3025	134	3	4
2007	300 1985	11	726	126	1133	1859	28	6	1
2008	622 4107	9	1197	238	2672	3869	254	6	6

Table H.7 *Liquidambar styraciflua* Water Balance – Sensitivity Analysis: Increased Precipitation Values 5%

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	3275 21641	17	12809	1293	7540	20348	801	6	4
2002	396 2620	25	2354	54	212	2566	52	2	2
2003	506 3344	19	2764	93	487	3251	93	3	3
2004	416 2747	20	2022	121	603	2625	93	4	3
2005	560 3704	14	2334	167	1204	3538	157	5	4
2006	474 3135	15	1600	194	1340	2940	132	6	4
2007	300 1985	23	753	226	1005	1758	26	11	1
2008	622 4107	16	982	438	2688	3670	249	11	6

Table H.8 *Acer saccharinum* Water Balance – Sensitivity Analysis: Increased Precipitation Values 5%

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	3275 21641	8	14129	570	6942	21071	824	3	4
2002	396 2620	11	2441	18	160	2602	53	1	2
2003	506 3344	8	2885	36	423	3308	94	1	3
2004	416 2747	9	2133	52	562	2695	94	2	3
2005	560 3704	6	2514	71	1120	3633	164	2	4
2006	474 3135	7	1797	83	1255	3052	134	3	4
2007	300 1985	11	919	103	963	1882	28	5	1
2008	622 4107	8	1440	208	2459	3899	257	5	6

Table H.9 *Ginkgo biloba* Water Balance – Sensitivity Analysis: Increased Precipitation Values 10%

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	3430 22672	8	13514	687	8472	21985	949	3	4
2002	415 2744	10	2424	28	292	2716	62	1	2
2003	530 3503	8	2853	48	602	3455	111	1	3
2004	435 2877	9	2100	65	712	2813	106	2	4
2005	587 3881	6	2450	85	1346	3796	191	2	5
2006	497 3284	7	1708	97	1479	3187	157	3	5
2007	315 2079	11	828	120	1131	1959	34	6	2
2008	651 4303	8	1150	244	2909	4059	288	6	7

Table H.10 *Platanus x acerifolia* Water Balance – Sensitivity Analysis: Increased Precipitation Values 10%

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	3430 22672	8	12319	755	9598	21917	943	3	4
2002	415 2744	9	2346	32	367	2713	62	1	2
2003	530 3503	7	2593	61	849	3443	109	2	3
2004	435 2877	8	1822	82	974	2796	106	3	4
2005	587 3881	6	2078	102	1701	3779	188	2	5
2006	497 3284	6	1467	110	1707	3174	155	3	5
2007	315 2079	11	760	127	1192	1952	34	6	2
2008	651 4303	9	1254	241	2808	4062	288	5	7

Table H.11 *Liquidambar styraciflua* Water Balance – Sensitivity Analysis: Increased Precipitation Values 10%

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	3430 22672	16	13419	1304	7949	21368	927	6	4
2002	415 2744	24	2466	54	224	2690	61	2	2
2003	530 3503	18	2896	94	514	3410	110	3	3
2004	435 2877	19	2118	123	636	2754	105	4	4
2005	587 3881	13	2445	167	1269	3714	184	4	5
2006	497 3284	14	1676	194	1414	3090	153	6	5
2007	315 2079	22	789	230	1061	1850	32	11	2
2008	651 4303	16	1029	442	2832	3861	281	10	7

Table H.12 *Acer saccharinum* Water Balance – Sensitivity Analysis: Increased Precipitation Values 10%

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	3430 22672	8	14802	577	7293	22095	951	3	4
2002	415 2744	11	2558	18	169	2726	62	1	2
2003	530 3503	8	3023	36	444	3467	111	1	3
2004	435 2877	9	2234	53	590	2825	106	2	4
2005	587 3881	6	2633	71	1176	3809	192	2	5
2006	497 3284	6	1882	84	1318	3200	156	3	5
2007	315 2079	10	963	104	1012	1975	35	5	2
2008	651 4303	8	1509	211	2584	4092	289	5	7

Table H.13 *Ginkgo biloba* Water Balance – Sensitivity Analysis: Increased Precipitation Values 15%

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	3586 23702	8	14128	693	8882	23010	1088	3	5
2002	434 2869	9	2534	29	307	2840	72	1	3
2003	554 3663	8	2983	49	631	3614	129	1	4
2004	455 3008	9	2196	66	747	2943	121	2	4
2005	614 4057	6	2561	85	1411	3973	223	2	5
2006	519 3433	6	1786	97	1550	3336	180	3	5
2007	329 2174	10	866	121	1187	2053	41	6	2
2008	681 4499	8	1202	246	3050	4252	322	5	7

Table H.14 ***Platanus x acerifolia*** **Water Balance – Sensitivity Analysis: Increased Precipitation Values 15%**

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	3586 23702	8	12879	761	10062	22941	1079	3	5
2002	434 2869	8	2453	32	385	2837	72	1	3
2003	554 3663	7	2711	61	890	3601	128	2	4
2004	455 3008	8	1904	82	1022	2926	119	3	4
2005	614 4057	6	2172	101	1784	3956	218	2	5
2006	519 3433	6	1533	111	1789	3322	179	3	5
2007	329 2174	10	795	129	1250	2045	41	6	2
2008	681 4499	8	1311	245	2943	4254	322	5	7

Table H.15 *Liquidambar styraciflua* Water Balance – Sensitivity Analysis: Increased Precipitation Values 15%

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	3586 23702	16	14028	1318	8356	22385	1064	6	4
2002	434 2869	23	2579	55	236	2815	71	2	2
2003	554 3663	18	3027	95	540	3568	127	3	3
2004	455 3008	19	2215	125	669	2883	120	4	4
2005	614 4057	13	2556	168	1333	3889	215	4	5
2006	519 3433	13	1752	194	1487	3239	178	6	5
2007	329 2174	21	825	232	1117	1942	39	11	2
2008	681 4499	15	1076	449	2974	4050	314	10	7

Table H.16 *Acer saccharinum* Water Balance – Sensitivity Analysis: Increased Precipitation Values 15%

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	3586 23702	8	15475	583	7645	23120	1091	2	5
2002	434 2869	10	2674	18	177	2851	73	1	3
2003	554 3663	8	3160	36	466	3626	129	1	4
2004	455 3008	9	2336	53	619	2955	121	2	4
2005	614 4057	6	2753	71	1233	3986	223	2	6
2006	519 3433	6	1968	84	1381	3349	181	2	5
2007	329 2174	10	1007	105	1062	2068	42	5	2
2008	681 4499	8	1577	214	2708	4285	322	5	7

Table H.17 *Ginkgo biloba* Water Balance – Sensitivity Analysis: Increased Precipitation Values 20%

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	3742 24733	8	14742	699	9292	24034	1238	3	5
2002	453 2994	9	2644	29	321	2965	83	1	3
2003	578 3822	7	3113	49	660	3772	150	1	4
2004	475 3139	8	2291	66	781	3073	137	2	4
2005	641 4233	6	2673	84	1477	4150	256	2	6
2006	542 3582	6	1864	98	1621	3484	206	3	6
2007	343 2268	10	904	122	1242	2146	50	5	2
2008	710 4694	8	1254	250	3190	4444	357	5	8

Table H.18 *Platanus x acerifolia* Water Balance – Sensitivity Analysis: Increased Precipitation Values 20%

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	3742 24733	7	13439	767	10527	23966	1229	3	5
2002	453 2994	8	2559	32	403	2962	83	1	3
2003	578 3822	7	2829	62	931	3760	147	2	4
2004	475 3139	8	1987	83	1069	3056	135	3	4
2005	641 4233	5	2267	101	1866	4132	253	2	6
2006	542 3582	6	1600	112	1870	3471	205	3	6
2007	343 2268	10	829	130	1309	2138	49	6	2
2008	710 4694	8	1368	247	3079	4447	357	5	8

Table H.19 *Liquidambar styraciflua* Water Balance – Sensitivity Analysis: Increased Precipitation Values 20%

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	3742 24733	15	14638	1326	8768	23407	1211	5	5
2002	453 2994	22	2691	55	249	2939	83	2	3
2003	578 3822	17	3159	96	567	3726	147	3	4
2004	475 3139	18	2311	126	702	3013	134	4	4
2005	641 4233	12	2667	168	1399	4066	248	4	6
2006	542 3582	12	1828	194	1560	3388	203	5	6
2007	343 2268	20	861	232	1176	2036	46	10	2
2008	710 4694	15	1122	455	3117	4239	349	10	7

Table H.20 *Acer saccharinum* Water Balance – Sensitivity Analysis: Increased Precipitation Values 20%

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	3742 24733	7	16148	588	7997	24145	1240	2	5
2002	453 2994	10	2790	18	185	2976	84	1	3
2003	578 3822	8	3298	37	487	3785	149	1	4
2004	475 3139	8	2438	53	648	3086	137	2	4
2005	641 4233	6	2873	71	1290	4163	257	2	6
2006	542 3582	6	2053	85	1444	3498	206	2	6
2007	343 2268	10	1051	107	1111	2162	49	5	2
2008	710 4694	8	1646	217	2832	4478	358	5	8

Table H.21 *Ginkgo biloba* Water Balance – Sensitivity Analysis: Increased Precipitation Values 25%

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	3898 25763	7	15356	705	9702	25058	1396	3	5
2002	472 3119	9	2754	29	336	3090	96	1	3
2003	602 3981	7	3242	50	689	3931	171	1	4
2004	495 3270	8	2387	66	817	3203	153	2	5
2005	667 4410	5	2784	84	1542	4326	291	2	7
2006	565 3732	6	1941	99	1691	3633	233	3	6
2007	358 2363	10	941	124	1298	2239	59	5	3
2008	740 4890	8	1307	253	3330	4636	393	5	8

Table H.22 *Platanus x acerifolia* Water Balance – Sensitivity Analysis: Increased Precipitation Values 25%

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	3898 25763	7	13999	775	10989	24988	1387	3	5
2002	472 3119	8	2666	32	421	3087	95	1	3
2003	602 3981	6	2947	62	972	3919	169	2	4
2004	495 3270	8	2070	84	1115	3185	152	3	5
2005	667 4410	5	2361	101	1948	4309	289	2	7
2006	565 3732	6	1667	113	1952	3619	232	3	6
2007	358 2363	10	864	131	1367	2231	57	6	2
2008	740 4890	8	1425	251	3214	4639	393	5	8

Table H.23 *Liquidambar styraciflua* Water Balance – Sensitivity Analysis: Increased Precipitation Values 25%

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	3898 25763	15	15248	1340	9176	24424	1368	5	5
2002	472 3119	21	2803	55	261	3064	94	2	3
2003	602 3981	16	3290	97	593	3884	169	2	4
2004	495 3270	17	2407	127	735	3142	151	4	5
2005	667 4410	12	2778	169	1463	4241	283	4	6
2006	565 3732	12	1904	196	1631	3535	230	5	6
2007	358 2363	19	896	236	1231	2127	56	10	2
2008	740 4890	14	1169	460	3261	4430	385	9	8

Table H.24 *Acer saccharinum* Water Balance – Sensitivity Analysis: Increased Precipitation Values 25%

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	3898 25763	7	16821	594	8349	25170	1400	2	5
2002	472 3119	10	2906	19	194	3100	95	1	3
2003	602 3981	7	3435	37	509	3944	172	1	4
2004	495 3270	8	2539	54	676	3216	153	2	5
2005	667 4410	5	2993	71	1346	4339	292	2	7
2006	565 3732	6	2139	86	1507	3646	233	2	6
2007	358 2363	9	1094	108	1161	2255	59	5	3
2008	740 4890	7	1715	220	2956	4670	394	4	8

Table H.25 *Ginkgo biloba* Water Balance – Sensitivity Analysis: Increased Precipitation Values 30%

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	4054 26794	7	15971	710	10114	26084	1565	3	6
2002	491 3243	8	2864	29	350	3215	110	1	3
2003	626 4140	7	3372	50	718	4090	195	1	5
2004	515 3401	8	2482	67	851	3333	170	2	5
2005	694 4586	5	2895	84	1607	4502	328	2	7
2006	587 3881	6	2019	99	1763	3782	262	3	7
2007	372 2457	9	979	125	1354	2332	69	5	3
2008	769 5085	7	1359	255	3471	4830	431	5	8

Table H.26 *Platanus x acerifolia* Water Balance – Sensitivity Analysis: Increased Precipitation Values 30%

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	4054 26794	7	14559	782	11453	26012	1557	3	6
2002	491 3243	7	2773	32	438	3211	108	1	3
2003	626 4140	6	3065	63	1013	4077	194	2	5
2004	515 3401	7	2153	85	1163	3315	169	3	5
2005	694 4586	5	2456	102	2029	4485	326	2	7
2006	587 3881	6	1733	113	2035	3768	261	3	7
2007	372 2457	9	899	133	1426	2324	68	5	3
2008	769 5085	8	1482	254	3350	4832	431	5	8

Table H.27 *Liquidambar styraciflua* Water Balance – Sensitivity Analysis: Increased Precipitation Values 30%

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	4054 26794	14	15858	1346	9590	25448	1535	5	6
2002	491 3243	20	2915	55	273	3188	108	2	3
2003	626 4140	16	3422	98	620	4042	193	2	5
2004	515 3401	17	2503	127	770	3273	168	4	5
2005	694 4586	11	2889	168	1529	4418	320	4	7
2006	587 3881	12	1981	197	1704	3684	259	5	7
2007	372 2457	18	932	238	1287	2220	65	10	3
2008	769 5085	14	1216	463	3407	4623	423	9	8

Table H.28 *Acer saccharinum* Water Balance – Sensitivity Analysis: Increased Precipitation Values 30%

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	4054 26794	7	17493	598	8702	26196	1569	2	6
2002	491 3243	9	3023	19	202	3225	110	1	3
2003	626 4140	7	3572	37	531	4103	196	1	5
2004	515 3401	8	2641	55	705	3346	170	2	5
2005	694 4586	5	3112	71	1403	4515	329	2	7
2006	587 3881	5	2224	86	1571	3795	263	2	7
2007	372 2457	9	1138	108	1211	2349	69	4	3
2008	769 5085	7	1783	222	3080	4863	433	4	9

Table H.29 *Ginkgo biloba* Water Balance – Sensitivity Analysis: Increased Precipitation Values 35%

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	4210 27825	7	16585	714	10526	27111	1744	3	6
2002	510 3368	8	2974	29	365	3339	124	1	4
2003	651 4299	7	3502	51	747	4249	220	1	5
2004	534 3531	8	2578	68	886	3463	188	2	5
2005	721 4763	5	3007	85	1671	4678	368	2	8
2006	610 4030	5	2097	99	1834	3931	292	2	7
2007	386 2552	9	1016	123	1412	2428	80	5	3
2008	799 5281	7	1411	259	3611	5022	471	5	9

Table H.30 ***Platanus x acerifolia*** **Water Balance – Sensitivity Analysis: Increased Precipitation Values 35%**

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	4210 27825	7	15119	784	11921	27040	1735	3	6
2002	510 3368	7	2879	32	457	3336	123	1	4
2003	651 4299	6	3183	63	1054	4236	218	1	5
2004	534 3531	7	2235	86	1210	3445	187	2	5
2005	721 4763	5	2550	102	2111	4661	365	2	8
2006	610 4030	5	1800	113	2117	3917	292	3	7
2007	386 2552	9	933	132	1487	2420	79	5	3
2008	799 5281	7	1539	256	3487	5025	471	5	9

Table H.31 *Liquidambar styraciflua* Water Balance – Sensitivity Analysis: Increased Precipitation Values 35%

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	4210 27825	14	16468	1357	9999	26468	1710	5	6
2002	510 3368	20	3027	56	285	3312	122	2	4
2003	651 4299	15	3554	99	647	4201	218	2	5
2004	534 3531	16	2600	129	803	3403	186	4	5
2005	721 4763	11	3000	168	1595	4595	359	4	8
2006	610 4030	11	2057	198	1776	3832	289	5	7
2007	386 2552	18	968	240	1343	2312	75	9	3
2008	799 5281	13	1263	468	3551	4813	461	9	9

Table H.32 *Acer saccharinum* Water Balance – Sensitivity Analysis: Increased Precipitation Values 35%

Date	Total Rainfall (mm and m^3)	% Canopy evaporation (based on total rainfall falling directly on canopy)	Direct Throughfall onto grass layer (without canopy contact) (m^3)	Canopy Evaporation (m^3)	Canopy Throughfall (m^3)	Total Throughfall (m^3)	Parcel Runoff (m^3) with trees and grass layer	% Canopy Evaporation (based on total rainfall across the entire parcel)	% Runoff with trees and grass layer
2002-2008	4210 27825	7	18166	599	9059	27225	1748	2	6
2002	510 3368	9	3139	19	211	3349	124	1	4
2003	651 4299	7	3710	38	552	4262	221	1	5
2004	534 3531	8	2742	55	734	3476	188	2	5
2005	721 4763	5	3232	72	1459	4691	370	2	8
2006	610 4030	5	2310	86	1634	3944	293	2	7
2007	386 2552	8	1182	106	1264	2446	79	4	3
2008	799 5281	7	1852	224	3205	5057	473	4	9

Canopy Evaporation: Sensitivity Analysis

Table H.33 Sensitivity Analysis: *Ginkgo biloba* Canopy Evaporation

Year	Evaporation – Historical (m^3)	Evaporation - 5% increase in rainfall (m^3)	Actual % increase in canopy evaporation	Evaporation - 10% increase in rainfall (m^3)	Actual % increase in canopy evaporation	Evaporation - 15% increase in rainfall (m^3)	Actual % increase in canopy evaporation	Evaporation - 20% increase in rainfall (m^3)	Actual % increase in canopy evaporation	Evaporation - 25% increase in rainfall (m^3)	Actual % increase in canopy evaporation	Evaporation - 30% increase in rainfall (m^3)	Actual % increase in canopy evaporation	Evaporation - 35% increase in rainfall (m^3)	Actual % increase in canopy evaporation
2002-2008	675	678	0	687	2	693	3	699	3	705	4	710	5	714	6
2002	28	28	1	28	2	29	3	29	3	29	3	29	3	29	4
2003	48	48	0	48	1	49	2	49	3	50	4	50	5	51	6
2004	64	64	1	65	2	66	3	66	4	66	4	67	6	68	7
2005	83	84	0	85	1	85	1	84	0	84	1	84	1	85	2
2006	99	96	-3	97	-3	97	-2	98	-1	99	0	99	0	99	0
2007	117	118	1	120	3	121	4	122	5	124	6	125	7	123	6
2008	236	240	2	244	3	246	4	250	6	253	7	255	8	259	9

Table H.34 Sensitivity Analysis: *Platanus x acerifolia* Canopy Evaporation

Year	Evaporation – Historical (m^3)	Evaporation - 5% increase in rainfall (m^3)	Actual % increase in canopy evaporation	Evaporation - 10% increase in rainfall (m^3)	Actual % increase in canopy evaporation	Evaporation - 15% increase in rainfall (m^3)	Actual % increase in canopy evaporation	Evaporation - 20% increase in rainfall (m^3)	Actual % increase in canopy evaporation	Evaporation - 25% increase in rainfall (m^3)	Actual % increase in canopy evaporation	Evaporation - 30% increase in rainfall (m^3)	Actual % increase in canopy evaporation	Evaporation - 35% increase in rainfall (m^3)	Actual % increase in canopy evaporation
2002-2008	743	747	1	755	2	761	2	767	3	775	4	782	5	784	6
2002	31	32	1	32	0	32	1	32	1	32	2	32	3	32	3
2003	59	60	1	61	2	61	3	62	5	62	5	63	6	63	7
2004	80	81	1	82	3	82	3	83	4	84	6	85	7	86	8
2005	101	101	1	102	1	101	0	101	1	101	1	102	1	102	1
2006	113	109	-4	110	-3	111	-2	112	-1	113	0	113	0	113	0
2007	124	126	1	127	2	129	4	130	5	131	6	133	7	132	6
2008	234	238	2	241	3	245	5	247	6	251	7	254	8	256	9

Table H.35 Sensitivity Analysis: *Liquidambar styraciflua* Canopy Evaporation

Year	Evaporation – Historical (m^3)	Evaporation - 5% increase in rainfall (m^3)	Actual % increase in canopy evaporation	Evaporation - 10% increase in rainfall (m^3)	Actual % increase in canopy evaporation	Evaporation - 15% increase in rainfall (m^3)	Actual % increase in canopy evaporation	Evaporation - 20% increase in rainfall (m^3)	Actual % increase in canopy evaporation	Evaporation - 25% increase in rainfall (m^3)	Actual % increase in canopy evaporation	Evaporation - 30% increase in rainfall (m^3)	Actual % increase in canopy evaporation	Evaporation - 35% increase in rainfall (m^3)	Actual % increase in canopy evaporation
2002-2008	1280	1293	1	1304	2	1318	3	1326	4	1340	5	1346	5	1357	6
2002	54	54	0	54	1	55	2	55	2	55	3	55	3	56	4
2003	92	93	1	94	2	95	3	96	5	97	6	98	7	99	8
2004	120	121	1	123	2	125	4	126	5	127	6	127	6	129	7
2005	166	167	0	167	1	168	1	168	1	169	1	168	1	168	1
2006	192	194	1	194	1	194	1	194	1	196	2	197	2	198	3
2007	225	226	1	230	2	232	3	232	3	236	5	238	6	240	7
2008	431	438	1	442	3	449	4	455	5	460	7	463	7	468	8

Table H.36 Sensitivity Analysis: *Acer saccharinum* Canopy Evaporation

Year	Evaporation – Historical (m^3)	Evaporation - 5% increase in rainfall (m^3)	Actual % increase in canopy evaporation	Evaporation - 10% increase in rainfall (m^3)	Actual % increase in canopy evaporation	Evaporation - 15% increase in rainfall (m^3)	Actual % increase in canopy evaporation	Evaporation - 20% increase in rainfall (m^3)	Actual % increase in canopy evaporation	Evaporation - 25% increase in rainfall (m^3)	Actual % increase in canopy evaporation	Evaporation - 30% increase in rainfall (m^3)	Actual % increase in canopy evaporation	Evaporation - 35% increase in rainfall (m^3)	Actual % increase in canopy evaporation
2002-2008	565	570	1	577	2	583	3	588	4	594	5	598	6	599	6
2002	18	18	1	18	1	18	2	18	3	19	4	19	4	19	5
2003	36	36	0	36	1	36	1	37	2	37	3	37	4	38	5
2004	52	52	0	53	2	53	3	53	3	54	4	55	5	55	7
2005	71	71	1	71	1	71	1	71	1	71	1	71	1	72	2
2006	82	83	1	84	1	84	2	85	3	86	4	86	4	86	4
2007	101	103	1	104	3	105	4	107	5	108	6	108	7	106	5
2008	205	208	1	211	3	214	4	217	6	220	7	222	8	224	9

Runoff: Sensitivity Analysis

Table H.37 Sensitivity Analysis: *Ginkgo biloba* Runoff

Year	Runoff - Historical (m^3)	Runoff - 5% increase in rainfall (m^3)	Actual % increase in runoff	Runoff - 10% increase in rainfall (m^3)	Actual % increase in runoff	Runoff - 15% increase in rainfall (m^3)	Actual % increase in runoff	Runoff - 20% increase in rainfall (m^3)	Actual % increase in runoff	Runoff - 25% increase in rainfall (m^3)	Actual % increase in runoff	Runoff - 30% increase in rainfall (m^3)	Actual % increase in runoff	Runoff - 35% increase in rainfall (m^3)	Actual % increase in runoff
2002-2008	701	821	17	949	35	1088	55	1238	77	1396	99	1565	123	1744	149
2002	43	52	22	62	45	72	69	83	95	96	124	110	156	124	190
2003	79	95	20	111	41	129	64	150	91	171	118	195	148	220	180
2004	82	94	14	106	29	121	47	137	66	153	85	170	107	188	129
2005	137	163	19	191	39	223	63	256	87	291	112	328	140	368	169
2006	114	134	18	157	38	180	59	206	81	233	105	262	131	292	157
2007	22	28	26	34	54	41	86	50	125	59	165	69	208	80	257
2008	225	256	14	288	28	322	43	357	59	393	75	431	92	471	110

Table H.38 Sensitivity Analysis: *Platanus x acerifolia* Runoff

Year	Runoff - Historical (m^3)	Runoff - 5% increase in rainfall (m^3)	Actual % increase in runoff	Runoff - 10% increase in rainfall (m^3)	Actual % increase in runoff	Runoff - 15% increase in rainfall (m^3)	Actual % increase in runoff	Runoff - 20% increase in rainfall (m^3)	Actual % increase in runoff	Runoff - 25% increase in rainfall (m^3)	Actual % increase in runoff	Runoff - 30% increase in rainfall (m^3)	Actual % increase in runoff	Runoff - 35% increase in rainfall (m^3)	Actual % increase in runoff
2002-2008	697	813	17	943	35	1079	55	1229	76	1387	99	1557	123	1735	149
2002	43	51	19	62	45	72	69	83	95	95	122	108	151	123	188
2003	78	93	18	109	40	128	64	147	88	169	115	194	148	218	179
2004	82	94	14	106	29	119	45	135	64	152	85	169	106	187	127
2005	135	160	19	188	40	218	62	253	87	289	114	326	142	365	171
2006	112	134	19	155	38	179	59	205	83	232	107	261	132	292	160
2007	22	28	26	34	55	41	86	49	120	57	156	68	209	79	255
2008	225	254	13	288	28	322	43	357	59	393	75	431	92	471	109

Table H.39 Sensitivity Analysis: *Liquidambar styraciflua* Runoff

Year	Runoff - Historical (m^3)	Runoff - 5% increase in rainfall (m^3)	Actual % increase in runoff	Runoff - 10% increase in rainfall (m^3)	Actual % increase in runoff	Runoff - 15% increase in rainfall (m^3)	Actual % increase in runoff	Runoff - 20% increase in rainfall (m^3)	Actual % increase in runoff	Runoff - 25% increase in rainfall (m^3)	Actual % increase in runoff	Runoff - 30% increase in rainfall (m^3)	Actual % increase in runoff	Runoff - 35% increase in rainfall (m^3)	Actual % increase in runoff
2002-2008	684	801	17	927	36	1064	56	1211	77	1368	100	1535	124	1710	150
2002	42	52	22	61	44	71	69	83	95	94	122	108	156	122	188
2003	78	93	19	110	41	127	64	147	90	169	118	193	148	218	180
2004	81	93	14	105	29	120	47	134	65	151	85	168	106	186	129
2005	132	157	19	184	40	215	63	248	88	283	115	320	142	359	172
2006	111	132	19	153	38	178	60	203	83	230	107	259	133	289	160
2007	20	26	27	32	57	39	90	46	126	56	171	65	217	75	266
2008	219	249	14	281	28	314	43	349	59	385	76	423	93	461	110

Table H.40 Sensitivity Analysis: *Acer saccharinum* Runoff

Year	Runoff - Historical (m^3)	Runoff - 5% increase in rainfall (m^3)	Actual % increase in runoff	Runoff - 10% increase in rainfall (m^3)	Actual % increase in runoff	Runoff - 15% increase in rainfall (m^3)	Actual % increase in runoff	Runoff - 20% increase in rainfall (m^3)	Actual % increase in runoff	Runoff - 25% increase in rainfall (m^3)	Actual % increase in runoff	Runoff - 30% increase in rainfall (m^3)	Actual % increase in runoff	Runoff - 35% increase in rainfall (m^3)	Actual % increase in runoff
2002-2008	704	824	17	951	35	1091	55	1240	76	1400	99	1569	123	1748	148
2002	43	53	22	62	45	73	69	84	95	95	122	110	156	124	189
2003	79	94	19	111	41	129	64	149	89	172	118	196	148	221	179
2004	82	94	14	106	29	121	47	137	66	153	86	170	106	188	129
2005	138	164	19	192	39	223	62	257	86	292	112	329	139	370	168
2006	114	134	18	156	37	181	59	206	81	233	105	263	131	293	157
2007	23	28	26	35	54	42	85	49	118	59	164	69	207	79	253
2008	225	257	14	289	28	322	43	358	59	394	75	433	92	473	110