Generating a New Evaluating System for Regional Scale Redevelopment Effectiveness of Brownfields in Waterloo Region Using a Multi-Criteria Analysis Mechanism

by

Jialei Pan

A thesis

presented to the University of Waterloo

in fulfilment of the

thesis requirement for the degree of

Master of Environmental Studies

in

Planning

Waterloo, Ontario, Canada, 2017

Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Brownfield redevelopment has been a popular topic as part of the contemporary planning literature. Encouraging brownfields' redevelopment and improving the redevelopment effectiveness and efficiency have been two of the top concerns for planners. Redevelopments with various purposes can benefit the region in different ways. It is not necessary that redeveloping into the most common purpose would make the greatest contribution to the region. A region-wide redevelopment projects' effectiveness evaluation will help planners have a better understanding of the region's current situation in terms of brownfield redevelopment. This research aims to integrate a multi-criteria analysis method with brownfield redevelopment effectiveness evaluation, with the intention of suggesting improvements to brownfield redevelopment resource allocation and enlightening regional land use efficiency. During the first phase of this study, a database was generated for previously redeveloped brownfields within Waterloo Region to fill in the informational gap of region-wide redevelopment projects. During the second phase, criteria were selected that can represent redevelopments' influences, and a multi-criteria analysis technique was used to generate a region-wide effectiveness evaluation model. The redevelopment projects in Waterloo Region have been assessed by this evaluation model.

This study not only creates an information database for redeveloped brownfields in Waterloo Region, but also provides an effectiveness ranking for previous redevelopment projects and identifies the best and worst performing projects. Based on the effectiveness evaluation, the region's performance in terms of brownfield redevelopment can also be analyzed. Waterloo Region has planning tools and policies available to provide legal and technical advice for potential developers of brownfield sites. At the same time, different levels of financial supports, such as grants and tax incentive programs, are also available in Waterloo Region. However, a lack of monitoring and evaluation of programs after redevelopments is Waterloo Region's shortcoming. In terms of brownfield redevelopment, efficiently allocating supportive resources would be the key for the region's next step. The region-wide brownfield repurposing activities' effectiveness evaluation could be a start that draws attention to development of efficient brownfield redevelopment resources allocation tools in the future.

Acknowledgements

First and foremost, I would like to thank my advisor, Prof Michael Drescher, for the guidance and insights to all aspects of this research. I also owe gratitude to Prof Markus Moos for his thoughts and suggestions. I am grateful for all the valuable feedbacks provided by my friends: Aysha Edathodu, Katie Newton, Siqi Wang, and Qing Lu. I really appreciate the supportive living environment generated by my roommates, Siyuan Li, Xinyue Pi, and Weikai Tan. I would also like to thank my parents for their love and support. I could not be able to finish this research without their financial and spiritual supports. Finally, I would like to thank all my friends and colleagues from University of Waterloo, who provided a supportive and stimulating research environment for my research.

Table of Content

List of Figures

List of Tables

Chapter 1. Introduction

1.1 Background

1.1.1 Brownfield Definition

Contemporary urban development has led to an increasing demand for land. As population size increases, land for various purposes such as residences, green space, and office buildings is urgently needed - especially within large urban centres. Given this demand for developable land, the reuse of previously developed but now vacant land has become more and more appealing to developers. Given the current attention to redeveloping vacant sites, it is important to formulate a nationwide agreed-upon and accepted definition of brownfields that will hopefully help prevent misunderstanding and confusion about urban redevelopment among the various stakeholders (Alker, Joy, Roberts, & Smith, 2000). Due to the involvement of various stakeholder groups during different stages of the land redevelopment process (Table 1), forming a definition of brownfield has been a complex problem in several countries, including the United States, the United Kingdom, and Canada.

Development Interests	Professional Interest	Regulatory Interests	Other Interests
Land and property developers	Lawyers	Central government departments	Academics
Institutional investors and banks	Planners	Environmental agencies	Community groups
Landowners	Civil and environmental engineers	Local authorities	Environmental and conservation groups
Industrial and commercial enterprises	Surveyor	Health and safety executives	Data management organizations
Public sector development organization	Insurers	---	Concerned citizens
Utilities	Environmental consultants	---	---

Table 1. Stakeholders involved with brownfield redevelopment. Adapted from Alker, Joy, Roberts, and Smiths (2000, p. 51)

In 2002, the United States passed the Small Business Liability Relief and Brownfields Revitalization Act (Pub.L.No. 107-118, 115 stat. 2356, "the Brownfields Law"), which aimed to help cleaning up environmental crisis sites by providing financial funds and liability protection (US Environmental Protection Agency, 2012). To identify all sites that would be eligible for these redevelopment grants, a formal definition of brownfield and a series of assessment acts, were developed to help assess site conditions. Following the definition formulated by the U.S. Environmental Protection Agency, brownfields were defined as sites that were "real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant" (U.S. Environmental Protection Agency, 2011).

The British government implemented a similar act in the early 1990s. Due to the rapid urban sprawl in London during the 1980s, not enough land remained available for future development. As a solution, policies that could provide feasible and acceptable development options were established (Breheny, 1997). The British government formed a perspective according to which a brownfield could be identified using three key factors, namely "contaminated", "derelict", and "vacant" (Department of the Environment, Transport, and the Regions, 2014). Through the assessment of the correlation between these three factors, a redevelopment project's cost and benefit could be determined.

In the context of Canadian cities, environmental impacts of previously contaminated sites were taken into consideration as well. Following discussions in the context of the Canadian National Round Table on the Environment and Economy (NRTEE), brownfields were defined as "abandoned, idle, or underutilized commercial or industrial properties where past actions have

caused known or suspected environmental contamination, but where there is an active potential for redevelopment" (OCETA, 2008). The Canadian brownfield definition reflected the public's fundamental view that these sites had potential development value despite possible environmental contamination.

In 2009, of an estimated 30,000 brownfield sites across Canada, most of the brownfield redevelopment projects were driven by financial profit (Government of Ontario, 2009). The sites with higher potential property value have higher redevelopment potential than the sites with lower potential property value. The redevelopment of a brownfield site could be expensive due to the unknown cost of the remediation processes. Therefore, developers have chosen to redevelop the sites where profitability following completion of redevelopment appears very certain. Consequently, less contaminated sites and sites located within urban cores have had a greater likelihood of redevelopment. Currently, brownfields in Canada can be categorized into three groups: 1) for 15%-20% of sites, expected market value after remediation is much higher than the expected cost of remediation; 2) for 60%-70% of sites, expected cost for cleanup is approximately equal to the expected market value after remediation; and 3) for the remaining 15%-20% of heavily contaminated sites, expected market value after remediation is very low (Canadian Real Estate Association , 2015). The top tier of brownfields has been the most popular sites for developers, whereas the middle and bottom tier sites have not been as attractive as "virgin" lands. However, besides the financial profitability of brownfield redevelopment for the developer, the environmental and social impacts for society at large of brownfield redevelopment should also be taken into consideration during the decision-making progress about brownfield redevelopment. Planners should not only consider the economic benefits for the current generation, but should also consider future generations' welfare.

In addition to economic profit for developers, it is important to realize that brownfields can bring much more value to a region. For example, the environmental value of brownfield redevelopment can be significant. Brownfields in urban areas are often viewed as one of the most serious urban environmental challenges to their neighbourhood communities (Bjelland, 2004). Proven or potential contamination by toxins could have negative impacts on groundwater and ecological systems, as well as serious impacts on the health conditions of the people who live in the surrounding area. In the Kitchener-Waterloo area, the main source of drinking water is the Grand River water system which could be easily affected by toxins leaking from historically contaminated brownfield sites (City of Kitchener, 2015). Thus, even though some heavily contaminated brownfield sites may not be financially profitable for redevelopment, their cleanup should still be attempted because of the environmental benefits. Moreover, these vacant sites in urban areas could be well-suited candidates for generating urban green spaces. In addition, some ecological experts hold the opinion that certain not heavily contaminated brownfields might have even greater ecological value than various greenfields because certain brownfields have been found to provide habitats for endangered and rare species (Hunter, 2014). Thus, brownfields' ecological value should be studied well before a redevelopment decision is made.

Brownfield redevelopment projects might not only increase environmental values in a community but may also have social benefits for the surrounding neighbourhood. For example, the remediation of brownfields can improve quality of life. Overall, green coverage of large urban centres is relatively low because of the land cover transformations involved in urbanization and intensification; therefore, cleaning up brownfields and transforming them into green spaces could be a socially and environmentally beneficial approach (Duarte, Gonçalves, & Monteiro, 2006). For instance, the successful conversion of the High Line in New York City

from a railway infrastructure brownfield to a green space was followed by increases in property values and employment density and decreases in crime rate in surrounding neighbourhoods (Green & Letsch, 2014). Even though the abandoned High Line was not developed into a directly profitable source for the city's revenue, its redevelopment triggered socio-economic improvements in the community. What is more, according to Howland (2007) there has been an internal relationship between brownfield redevelopment and employment density within the area. Successful remediation and redevelopment has been linked to job creation for the local residents. Clearly, the overall value of brownfields is far more than just the financial profit they can generate for the immediate brownfield site and for local developers. It is therefore important to develop a fuller understanding of the value characteristics belonging to successfully redeveloped brownfields and to prioritize brownfield redevelopment projects based on such a general value assessment.

1.1.2 Context for Brownfield Redevelopment in Ontario, Canada

Despite the complexity of brownfield redevelopment, brownfields often exist in strategic and desirable locations. As a result, the Government of Ontario encourages owners, developers, and environmentalists to remediate brownfield sites so that the surrounding areas can benefit in terms of "urban intensification, community revitalization, economic development and jobs, and/or new housing to take the pressure off greenfield" (Government of Ontario, 2006). In 2004, the Brownfield Statute Law Amendment Act and its companion regulation was put in use so that barriers against redevelopment regarding regulatory liability, financing, and planning could be eliminated (Government of Ontario, 2001). Moreover, the Provincial Land Use Planning Framework includes new policies, which create a supportive environment for brownfield redevelopment:

> "Identifying brownfield sites as opportunities for redevelopment; recognizing the important role that intensification and redevelopment play in meeting land-use requirements; requiring upper-tier municipalities to set targets for intensification and redevelopment, as well as targets for minimum densities along important transit and other corridors; and linking the achievement of intensification and redevelopment targets to urban boundary expansions."
>
> (Government of Ontario, 2014)

In Ontario, there are two phases of Environmental Site Assessment during the brownfield redevelopment processes. Phase one of this assessment requires environmental experts' professional opinion in determining whether a site is contaminated, whereas phase two covers further surveying, remediation, and monitoring if the site is indeed found to be polluted (Government of Ontario, 2009). According to Wang (2011), the environmental assessment stage can be problematic due to the fact that it requires subjective judgments at several important stages before decisions are made. For example, during the survey stage, it is likely that community members will be more of the opinion that a site needs remediation in comparison to the opinion of developers. These differences in opinion are driven by varying perspectives on environmental or financial benefits from brownfield redevelopment. To address these differences in opinion, the decision-making process can be approached as a multi-criteria aggregation where all interested parties can be involved and express their preferences (Wang, 2011).

The value of brownfields has drawn attention from multiple stakeholders. Neighbourhood residents benefit from the cleanup of the environment, whereas developers benefit from the potential tax incentive programs. Since brownfield redevelopment was initiated later in Canada than it was in the United States and in the United Kingdom, some of the strategies that encourage brownfield redevelopment in these countries might be helpful references for the Canadian context. First, the United States generated a superfund for cleaning up brownfield sites nationwide, which provided solid financial support for the cities that were in most urgent need of

cleaning up their brownfields (Whitney, 2003). Superfund was initiated by the comprehensive environmental response, compensation and liability act of 1980, and it gives rights to federal natural resource agencies to compel other parties to clean up the brownfields or conduct the cleanup process by themselves using the superfund (The U.S. Congress, 1980). This superfund reduced the developers' risk of dealing with the contaminated sites' environmental impacts, and thereby enhanced the economic competitiveness of brownfield redevelopment compared to greenfield development. With the encouragement of the superfund, a nationwide brownfield database was established which also made the environmental characteristics of all brownfield sites available for further study. Capitalizing on this financial support, brownfield redevelopment projects have been viewed as an option for cities' smart growth plans (Alberini, Longo, Tonin, Trombetta, & Turvani, 2005; Greenberg, Lowrie, Mayer, Miller, & Solitare, 2001).

Unlike this radical government support in the United States, the British government used public-private partnership programs to encourage urban redevelopment projects, most of which were converting brownfields into residences (Dair & Williams, 2006). Canadian brownfield redevelopments are currently encouraged by federal tax incentive programs and environmental protection funds, although these are not available nationwide (Government of Ontario, 2009). The Government of Canada offers public consultation regarding brownfield redevelopment projects at the federal level. Programs such as "aboutREMEDIATION" and organizations like "Canadian Brownfield Network" are the sources that provide policy and strategic supports for parties interested in brownfield redevelopment activities (Lomas-Jylha, 2004). The Canadian Environmental Protection Act, Fisheries Act, and Clean Air Act also provide legislation and regulation guidelines for brownfield redevelopment projects (Tiedemann, Beriatos, & Brebbia, 2008). The federal government is fully responsible for reported federal contaminated sites.

Another type of brownfield is shared liability site. During the cleanup process of shared liability sites, the government is only responsible for consulting and advising whereas the private sector is held financially and legally responsible. According to the 2004 Canadian Federal Budget, $3.5 billion was allocated to the clean-up of federal brownfield sites; $500 million was assigned to shared liability sites; and $250 million was assigned to Green Municipal programs (Tiedemann, Beriatos, & Brebbia, 2008). While these are large sums of money, they are insufficient to finance the clean up of all of the approximately 30,000 brownfield sites across the country. Therefore, how to allocate the funding efficiently among these brownfield sites has become a very important question.

1.2 Research Motivations and Research Questions

After forming an understanding of brownfield definition, brownfield potential value, and brownfield redevelopment context in Canada, the study of brownfield redevelopment evaluation could be initiated. Recycling brownfield sites not only generates profits for developers, but also benefits many aspects of livability in the surrounding neighbourhoods. There might be impacts on the people that live and work in the surrounding neighbourhoods. Depending on the purposes of redevelopment, jobs might be created, population might be increased, and public infrastructure might be enhanced. These benefits should be considered while talking about the effectiveness of redevelopments. Therefore, for the purposes of the current study, brownfield redevelopment effectiveness is defined as the amount of positive impacts this redevelopment has at the site level and on the surrounding neighbourhoods. The greater the contributions are that redevelopments provide to the area, the more effective the redevelopments are. Therefore, to evaluate the effectiveness of redevelopments, it is necessary to consider a variety of aspects being affected by the land remediation and repurposing. First of all, there are many more

brownfields than available cleanup grants and funds in Canada. Assigning limited resources to the brownfields with the most urgent need for remediation should be a priority task for any government. However, these might not be the sites redeveloped first. Identifying the effectiveness of previously redeveloped brownfield sites and their characteristics could help identify actual, underlying drivers of brownfield redevelopment resource allocation, which may be different from the previously described environmental and socio-economic considerations. Secondly, according to the redevelopment project effectiveness evaluation, all previous redevelopments could be assessed based on certain standards. Not only redevelopments' environmental benefits, but also economic and social contributions could be assessed at the same time. Distinguishing the most effective redevelopments and the least effective redevelopments could contribute to better decision-making for future cases in similar situations. Valuable lessons could be learned from previous brownfield redevelopment projects that were more or less effective. Finally yet importantly, building up an information system regarding brownfield-related activities could improve the efficiency of future developments and ultimately help in reaching the region's sustainable development goals.

According to the Growth Plan for the Greater Golden Horseshoe (2013), the Region of Waterloo as a metropolitan area should keep its population and employment opportunities increasing at a steady pace - especially for the urban growth centres such as Downtown Kitchener and Uptown Waterloo, which will have a minimum gross density target of 200 residents and jobs combined per hectare by 2031 (Ontario Ministry of Infrastructure, 2013). Repurposing the brownfields within these areas could not only help the regional municipality to reach its growth target, but could also lead to more revenue for the Region after redevelopment. Dealing with the contaminated sites is not only economically beneficial to all levels of municipal

government, but it is also a movement towards local sustainability. The following Waterloo Region's Official planning goals of creating a sustainable urban area could be achieved through encouraging effective brownfield redevelopments: "building a vibrant place, fostering a strong economy, enhancing natural environment, and ensuring coordination and communication" (Region of Waterloo, 2015). Exploring the contaminated sites' conditions and possibilities could help provide guidance on building a sustainable land use system.

Based on curiosity of exploring Canadian cities' brownfield redevelopment situation and the effectiveness of each repurposing project, the following research questions of this study will be investigated: How has Waterloo Region's brownfield redevelopment performed over the past thirty years? Has the previous brownfield redevelopment resource allocation been an efficient arrangement?

1.3 Thesis Structure

Over the last thirty years, the Planning field has given increasing attention to brownfield repurposing in the context of sustainable urban land use. Finding efficient ways to assist and encourage brownfield redevelopment activities while ensuring the effectiveness of each redevelopment project should be primary planning goals of every municipality. This paper is organized as follows: Chapter 1 of this thesis provides the necessary background knowledge of brownfield redevelopment and specifically illustrates various brownfield-related policies in Ontario, Canada. This chapter also states the research motivations and questions. The motives for this research are to improve the availability of information regarding brownfield redevelopment activities in Canada and to enable large-scale brownfield redevelopment evaluations. Chapter 2 presents an overview of brownfield redevelopment-related research. The purpose of this review is to understand the current body of knowledge about brownfield redevelopment and to identify

remaining knowledge gaps. This leads to the research statement of purpose and identification of objectives. Chapter 3 explains the methodological progress of this study. This chapter is divided into five distinct steps: introducing the study area, making the necessary assumptions, collecting the data, building the evaluation model, and analyzing the evaluation's sensitivity and uncertainty. Chapter 4 presents the results from the redevelopment projects' assessment, and distinguishes the most effective redevelopment projects from the least effective projects. Chapter 5 further illuminates the meaning of the assessment results. While comparing the real world redevelopment priorities and the assessed effectiveness of the brownfield redevelopment project, it is more thoroughly discussed how brownfield redevelopment efficiency could be improved. Finally, Chapter 6 assesses how well the study has answered the research questions and offers ideas for future development of the brownfield redevelopment project evaluation model.

Chapter 2. Literature Review

2.1 Previous Brownfield Redevelopment-Related Literature

2.1.1 What Makes Brownfield Redevelopment So Difficult?

The strong increase in the number of brownfield sites is the result of the country's rapid structural change from a manufacturing-based economy in the 1980s to a service-based economy in the 1990s. Switching of the main economic model led to the abandoning of various industrial sites or the need for their repurposing. In order to study the impacts that prevent investors from redeveloping brownfields, Alberini, Longo, Tonin, Trombetta, and Turvani (2005) conducted a survey of developers on the effectiveness of the incentives that aimed to promote the redevelopment of brownfields. These incentives include relief from cleanup liability, reduction of regulatory charges, and government subsidies. The study found that the cleanup liability was a significant driver for keeping developers from initial brownfield redevelopment, whereas developers with prior remediation experiences were responsive to the relief from cleanup liability (Alberini, Longo, Tonin, Trombetta, & Turvani, 2005). Other work has found that cost of remediation, potential risk during the entire process, and slow investment return might be major barriers against brownfield redevelopment (McCarthy, 2002).

2.1.2 What are the Risks of Brownfield Redevelopment?

In order to remediate brownfields, it is necessary first to gain a full understanding of the reuse of contaminated lands. Every successfully redeveloped brownfield has its risks during the entire redeveloping process. The risks related to brownfield redevelopment could be categorized into three groups, namely environmental risk, technical risk, and financial risk. From a municipality's perspective, the basic risk before remediation is the environmental risk, where contamination could affect air, water, ecology, land, and public health (Greenberg, Lowrie,

Mayer, Miller, & Solitare, 2001). The encouragement of remediation processes aims to minimize this environmental risk. Various techniques based on the contamination type are applied to minimize this risk. For example, Hamby (1996) conducted a thorough review of the purposes and costs of remediation techniques that could be applied to resolve risks of soil and water pollution. Either through chemical, physical, or biological remediation, methods to clean up brownfields can be used to reduce the sites' contamination to an acceptable level for redevelopment (Hamby, 1996). From a developer's perspective, technical risks and financial risks are two major challenges during the redevelopment activity. Technical risk refers to the challenges that may occur at the clean-up stage. Generally, the less contaminated the site, the less costly the remediation. If the original cleanup plan cannot achieve the redevelopment's cleanup target, more funds would be required for the land recovery in terms of cleanup technology investments. Therefore, financial risks is involved as well because another round of remediation might cause the project to go over budget. There is an interrelationship between the three types of risks from the planning stage to the brownfield redeveloping stage. Therefore, risk management is a significant component for government to consider during the remediation plans generating progress.

2.1.3 What is the Potential for Brownfields?

2.1.3.1 Redevelopment

Theoretically, brownfield sites could be developed for any purposes with the approval of zoning change. However, one of the biggest challenges for remediation is that brownfields tend to vary in conditions in relation to cleanup stage. Page and Rabinowitz (1994) identified a relationship between redevelopment priority and contamination level through a study of several brownfield redevelopment projects. The heavier the contamination, the less redevelopment

potential the sites would have - although the sites could be less costly to purchase due to the contamination (Page & Rabinowitz, 1994). Brownfields could be a suitable site for affordable housing (Greenberg, Craighill, Mayer, Zukin, & Wells, 2001), green spaces (De Sousa, 2004; Siikamäki & Wernstedt, 2008), and office use (Rall & Haase, 2011). Despite the fact that contemporary urban development projects are mostly oriented to satisfy developers' economic profit requirements, Schädler, Morio, Bartke, Rohr-Zaenker, and Finkel (2011) developed an integrated assessment model, which could provide decision-making supports for choosing brownfield revitalization options that would provide more benefits for society at large, now and into the future.

2.1.3.2 Keep the Sites as Brownfield

In addition, ecological researchers have proposed following the "let it be" approach as another option (Harrison & Davies, 2002). Certain disturbance-sensitive species have inhabited brownfield sites because of the low volume of human activities in these locations. Some rare species have even been attracted by the heavy metal that sometimes is contained in the soil; therefore, brownfields could continue to exist as habitats for various species. For instance, brownfields in the United Kingdom have been identified as supportive habitats for a number of protected species, including "Great crested newts, Slow worms, Common lizards, and the Black redstart, a rare bird associated with brownfield sites in towns and cities" (Buglife, 2009). Some European countries have policies that require a time buffer before the brownfield is redeveloped so that the potentially bio-diverse habitats could be protected (Strauss & Biedermann, 2006). Instead of cleaning up the contaminants, a temporary conservation area could be created to keep the urban biodiversity intact (Kattwinkel, Biedermann, & Kleyer, 2011). Thus, redevelopment is not the only option for brownfields.

2.1.4 How could Government Assist Developers during the Brownfield Redevelopment Process?

One important reason for why developers have preferred to develop virgin land is to avoid risks in the pursuit of profits. If more benefits for developing brownfields could be identified, there might be increased interest in creating remediation plans and take on some risk. To help developers realize the benefits from brownfield redevelopment, several mechanisms could be supportive during the decision-making stage such as: identifying the financial supports (Bartsch, 2002); minimizing the risks and costs (De Sousa, 2000); and choosing the most suitable development options (Greenberg, Lowrie, Mayer, Miller, & Solitare, 2001). For the government, in order to provide financial supports or tax incentives for redeveloping brownfield sites, a database must be generated for all the brownfields within the region with a thorough environmental assessment for each site so that the priorities for brownfield redevelopment based on their environmental impacts could be determined (Hayek, Novak, Arku, & Gilliland, 2010). For example, in 2007 the City of Hamilton's Planning and Economic Development Department requested proposals that could help assess and rank the redevelopment opportunities to determine priorities for the city-wide collection of brownfield sites in order to distribute three million dollars in provincial funds (Planning and Economic Development Department, City of Hamilton, 2007). Beyond external financial supports, Wang (2011) established a fuzzy real option model in which risks caused by subjective judgments could be diminished and a reliable evaluation of the potential for success of a redevelopment plan could be concluded. There is an increasing interest in decision-making instruments that could support fund distribution as well as risk management during the remediation planning process at a regional municipal level.

2.1.5 Changes in the Methods for Assessment of Brownfield Redevelopment Projects

Previous industrial sites within a city's central districts have already started being redeveloped because of the rapidly increasing urban property values in the 20th century. Nevertheless, have these remediation plans been sustainable enough to fit into cities' future development? At first, recycling brownfields has been considered an efficient usage of urban land (Force, Britain, & Rogers, 1999). Since brownfields have become a popular topic in urban development, studies of various aspects of brownfields have been conducted by scholars all across the world. One question that has been frequently raised is how to determine whether a redevelopment project is successful. Bacot and O'Dell (2006) conducted a thorough study to determine the indicators for evaluating brownfield redevelopment projects in terms of their economic and environmental aspects through analyzing brownfield policy performances. The indicators of this study included "property value, tax relief, parcel size, private investment, market condition, end use of the site, return on investment, and cleanup cost" (Bacot & O'Dell, 2006). The evaluation was based on cost-benefit analysis, in which almost every indicator had an impact on the land's economic value. Moreover, the surrounding property values were affected positively by most of the redevelopment projects, especially in the case of projects that converted the sites into residential areas or green spaces (De Sousa, Wu, & Westphal, 2009). On the other hand, in spite of the assessment from the private sector, the evaluation from the government sector has hardly covered the redevelopments' effects on the surrounding neighbourhoods. According to the U.S. EPA (2012), the brownfield redevelopment evaluating program is intended to ensure that the brownfield grant is used properly at every step of the redeveloping progress. Nevertheless, the U.S. EPA also refers to the redevelopment's impacts on its surrounding neighbourhoods as its performance.

2.2 The Use of Multi-Criteria Analysis Mechanism in Brownfield Redevelopment Field

2.2.1 General Multi-Criteria Evaluation Progress

Decisions about simple problems can be made through cost-benefit analysis or cost-effectiveness analysis. However, while dealing with large amounts of complex information, these two types of techniques are not likely to provide all of the assessment possibilities in a consistent way. For instance, complexity of data types and involvement of multiple stakeholders could make the decision-making progress impossible to complete with cost-benefit analysis or cost-effectiveness analysis. In comparison, multi-criteria analysis has numerous advantages. For example, the overall modelling structures are easy to adapt, and the choice of alternatives and criteria can be open and explicit. What is more, a weighted scoring system is often used to build the performance matrix, which makes the output results easy to compare and helps to identify the most advantageous decision. In this way, various criteria from different perspectives could be easily combined for assessment.

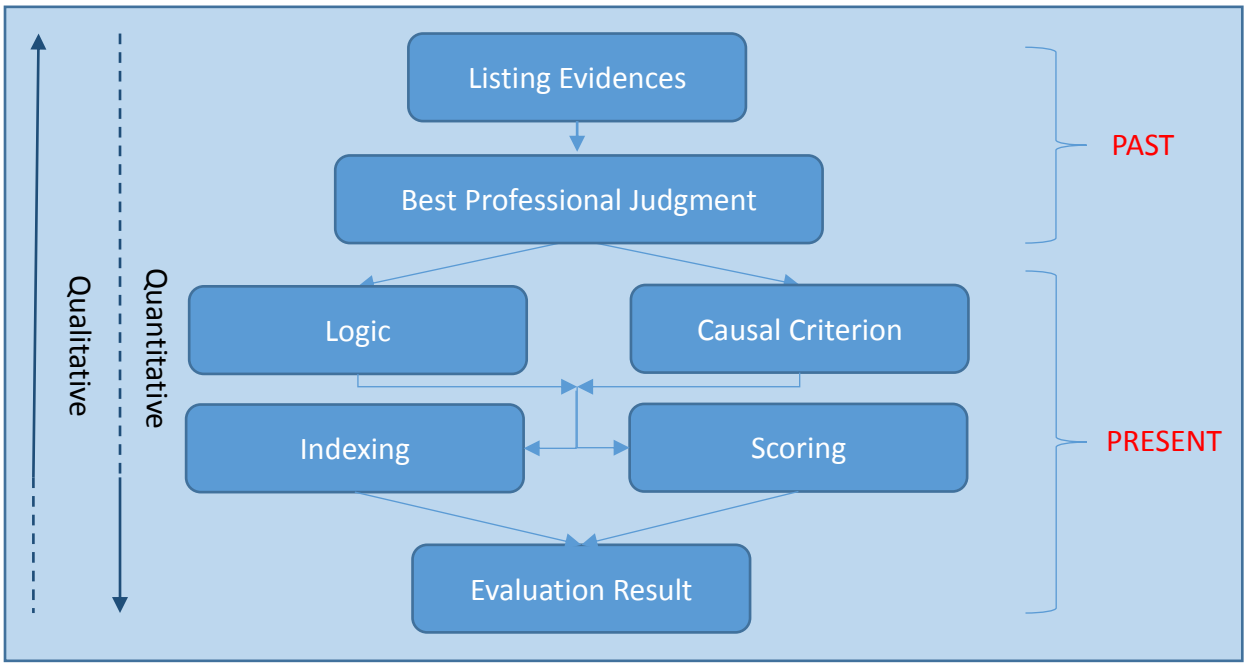


Figure 1. Multi-Criteria Analysis Process (Linkov, et al., 2011)

Figure 1 shows the usual progress for performing a multi-criteria analysis. The first step is to choose the relevant criteria through judging a list of possible indicators based on evidence and previous experiences. The second step is to try out various weight distributions based on the analysis of past trends so that a logical model can be created. The multi-criteria analysis model is a combination of logic and numeric analysis of the problem. In the third step, a reasonable evaluation can be made based on the multi-criteria analysis model. In conclusion, a multi-criteria evaluation model is a blend of qualitative analysis and quantitative analysis, which tries to simulate real life situations. Carefully identifying the criteria and distributing the weights are key stages for decision-makers to perform a multi-criteria analysis.

2.2.2 What Methodologies are Available for Evaluating Brownfield Redevelopment Projects?

Rational decisions regarding any problems are made based on one or more criteria which can be combined and assessed through certain decision-making rules (Eastman, 1999). The more complex the problem, the more difficult the assessing process will be. There is a large amount of strategic multi-criteria decision-making tools available for supporting decision-making problems that occur during the brownfield redevelopment processes, such as: "case-based reasoning (CBR), mathematical programming, data envelopment analysis (DEA), simple multi-attribute rating technique (SMART), fuzzy set theory, analytic hierarchy process (AHP), analytic network process (ANP), and their hybrids" (Ho, Xu, & Dey, 2010). All of these tools belong to a large category called multi-criteria analysis process (Table 2). However, not all of these tools are suitable for making decisions about prioritizing brownfield repurposing projects.

MCA Type	Typical Applied Situation
Case-Based Reasoning	Regression and Classification Processes
Mathematical Programming	Linear/ Multiple Regression in transportation, Scheduling, and Resource Allocation
Data Envelopment Analysis	Production Performance Evaluation
Simple Multi- Attribute Rating Technique (SMART)	Present numeric evaluation for a set of alternatives
Fuzzy Set Theory	Case-based Modelling Program which could be suitable for resoling complex problems
Analytic Hierarchy Process (AHP)	Translate hieratical none numeric opinions into weights
Analytic Network Process	Translate large cluster of non-numeric opinions into weights

Table 2. MCA types and characteristics summarization. MCA types highlighted in red are selected for this study.

A Case-based reasoning method is usually understood as a type of artificial intelligence technique which teaches the machine previous cases as knowledge to form a prediction for future, similar cases (Poole & Mackworth, 2010). While this method is suitable for regression and classification processes, the number of previous cases can have a direct impact on the accuracy of the model. Mathematical programming is a very broad topic, which contains linear regression, multiple regression, and many other mathematical models. These techniques could be applied, along with certain assumptions about the input variables, to solve problems of production, transportation, scheduling, and resource allocation (Hansen & Jaumard, 1997). DEA is a programming-based linear analyzing technique in which a mathematical scoring system is presented to assess all the input criteria (Molinero & Woracker, 1996). DEA is often used by economists to establish production performance numeric evaluation of various targets. It is assumed that all variables should be free of measurement errors, and there should be no inner relationships between independents (Poole & O'Farrel, 1971).

In order to form a reasonable representation of a real situation, there should be an acceptable tolerance of error. With fuzzy set theory, different degrees of fuzzy functions could be established based on one classic function, which is to say that the system is no longer binary (Zimmermann, 2010). The fuzzy set theory stands for a black box, which contains the problem solving expert system (Figure 2). The users only need to provide the basic information that is requested by the system, and the experts adjust the analyzing process so that a desired result can be provided to the users. Therefore, involving the fuzzification programming into a decision-making process could enhance the robustness of the entire modelling progress. Integrating fuzzy set theory could minimize uncertainty during the communication process; however, this technique requires the development of a case-based modelling program and may be very time consuming when dealing with a complex problem.

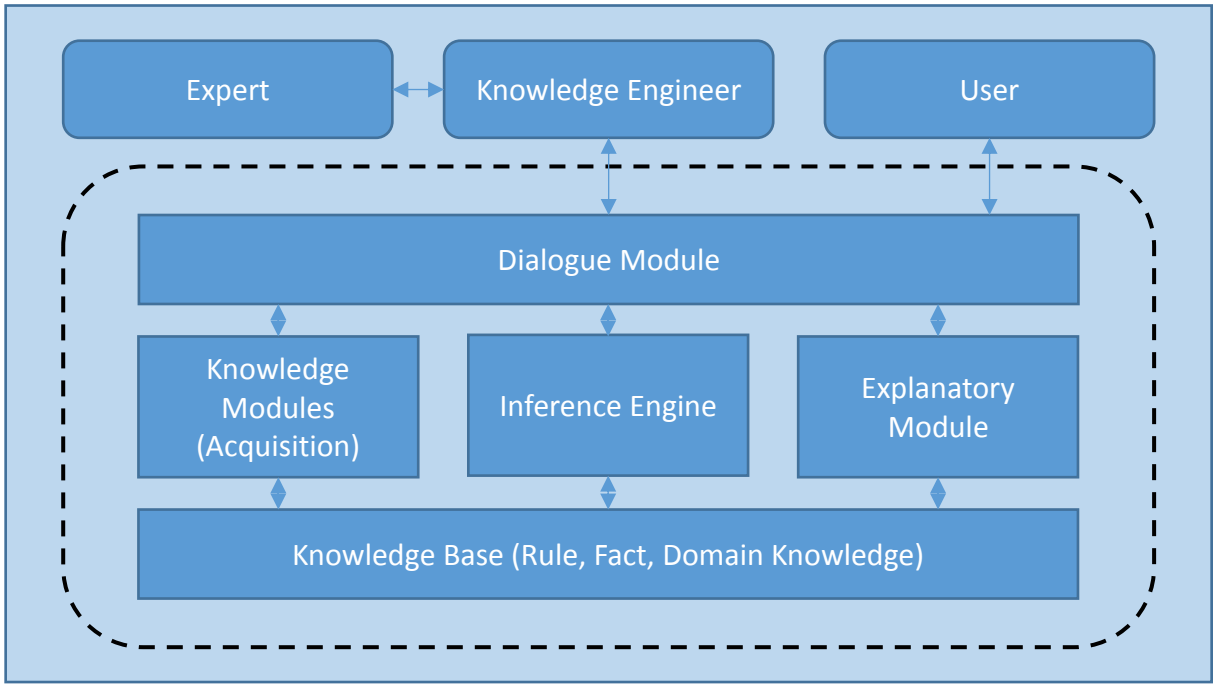


Figure 2. Expert System in Fuzzy Set Theory (Zimmermann, 2010)

The simple multi-attribute rating technique (SMART) is a widely used method for solving complex problems that require consideration of multiple aspects. The SMART is a decision-making technique in which all of the alternatives are assessed by numeric values through simple, usually linear calculations (Ho, Xu, & Dey, 2010). Because selecting a weight distribution may be difficult, decision-makers may find it easier to evaluate all of the influential criteria by their significance. The SMART can translate the importance of the criteria into weights based on the decision-maker's preferences, such as an equal distribution. The advantage of SMART is that it is easy to understand and it present the ranking results as explicit, simple values. As the complexity of a set of criteria increases, the weight distribution method's difficulty increases as well. In order to evaluate the brownfields' redeveloping potential, SMART could be used as a base analysis model.

AHP, an evaluation process which incorporates mathematics and psychology, was one of the most popular methodologies for resolving problems following a multiple criteria approach (Saaty, 1987). The AHP can function as very good system providing feedback to decision-makers to form a better understanding of the entire evaluation process (Ho, Xu, & Dey, 2010). Through comparing and contrasting the impacts from different measurements, analysts can determine a numerical weight for each element in the analysis. Although AHP has been used frequently during complex decision-making processes because of its pairwise comparison technique, one challenge for this method is that all of the criteria at the same level should be independent of each other (Liu, Hsu, Yeh, & Chen, 2011). As an improved version of AHP, the Analytic Network Process (ANP) forms interrelated criteria into iterated clusters so that the inner influences among these criteria can be reduced (Saaty, 2004). Instead of grouping criteria into various levels, ANP groups interrelated criteria into clusters (Figure 3). Pairwise comparisons

within all the clusters can be assigned weights according to each criterion's significance. Each cluster can have a control criterion after pairwise comparison. After comparing the criteria within each cluster, an ideal solution can be formed by combining the results from all clusters. The approach usually requires an evaluation of four dimensions: benefits (B), opportunities (O), costs (C), and risks (R). Therefore, the overall most suitable alternative might be determined by the B,O/C,R ratio.

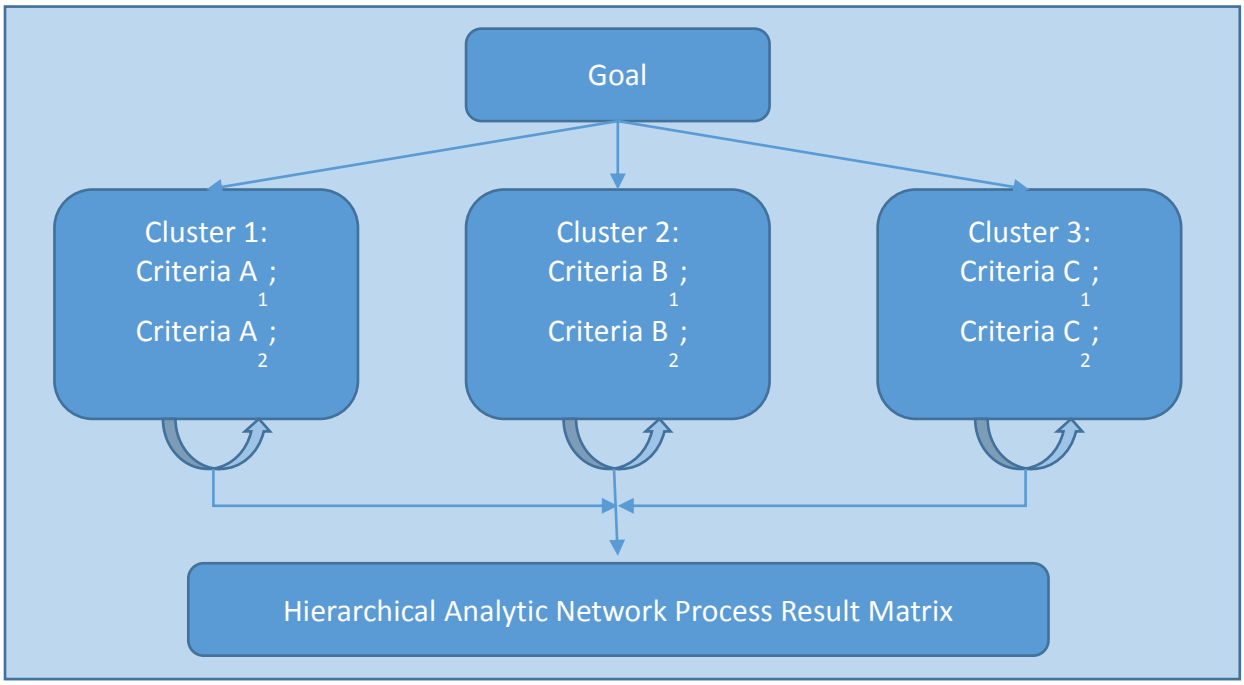


Figure 3. A Hierarchical Analytic Network Analysis Framework (Saaty, 2004)

2.2.3 What Methodologies are Available for Large-scale Brownfield Redevelopment Evaluation?

Brownfield redevelopment is a very complex process, which can involve many stakeholders. Thus, the indicators that impact brownfield repurposing activities should involve many perspectives. Through analyzing the characteristics of a brownfield site's redevelopment project assessment, a suitable modeling process may be formed based on a basic multi-criteria analysis approach. According to its features, ANP is suitable for resolving complex problems with a large number of criteria. For instance, ANP may be suitable for thorough investigation of

a small number of target sites and a large set of evaluation criteria. On the other hand, AHP's clear and easy structure of listing all criteria makes it a better candidate approach for large-scale brownfield redevelopment evaluation. AHP may be able to accurately delineate the significance of all input criteria in relation to all involved aspects such as economic, environment, and social. At the same time, pairwise comparison to enable criteria weight determination may provide reasonable significance estimates for each criterion that could be adapted for further analysis.

In conclusion, SMART and AHP may be two suitable methods for producing a regional brownfield repurposing priority assessment. AHP may be a suitable method for assigning weights to all relevant criteria when the involved evaluating parties do not have a clear understanding of how the criteria should be evaluated. SMART could be used for combining all of the criteria in situations where the involved evaluators are clear and in agreement about their preferences.

In addition to multi-criteria modelling, several sensitivity and uncertainty mechanisms are available to test the relevance and robustness of the chosen criteria. Specifically, there are two types of sensitivity analysis regarding multi-criteria modelling: local sensitivity analysis and global sensitivity analysis (Figure 4). Local sensitivity analysis relates to point estimates of parameter values, whereas global sensitivity analysis indicates sensitivity regarding the entire parameter distribution. The rationale behind sensitivity testing is to understand the degree of influence of all variables to ensure the effectiveness and efficiency of the model. Also, the variation of weight distribution might cause significant changes in the results. Assessing whether the scoring differences and aggregation methods are reasonable can be another purpose of sensitivity analysis.

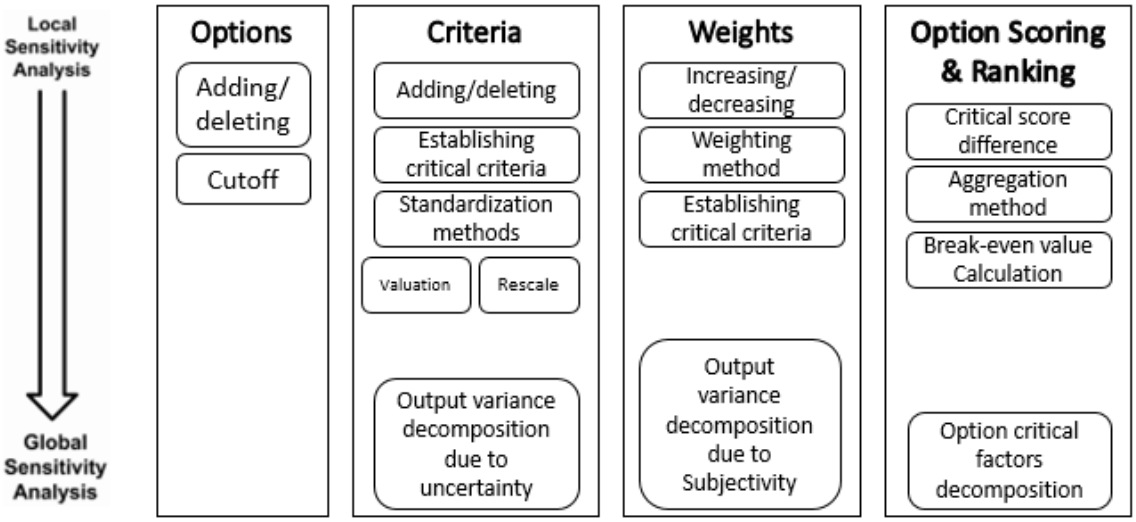


Figure 4. Multi-Criteria Evaluation's Sensitivity Analysis Methods and Their Scope (Ligmann-Zielinska & Jankowski, 2008)

Another important type of analysis associated with the multi-criteria analysis process is uncertainty analysis. Uncertainties exist throughout the entire modelling process. Understanding these uncertainties will help the model to perform under its best conditions. Developing an uncertainty analysis framework for a multi-criteria analysis model can help avoid unreasonable assumptions, as well as point toward future improvements of the modelling process. The purpose of uncertainty analysis is to quantify the risk to the evaluation process. The risk of the multi-criteria model is mainly due to uncertainty in the input criteria. Therefore, the uncertainty of the model may be represented by changes in the difference between the top two ranked alternatives' values while adjusting one specific input (Chen, Wood, Linstead, & Maltby, 2011). This approach entails the possibility of evaluators facing a reversal of rankings. The closer the top two alternatives are, the greater the likelihood that decision-makers will face a ranking reversal. This measurement is similar to sensitivity analysis yet mainly tests the robustness of the model's output results.

2.3 Knowledge Gap

After reviewing previous studies in brownfield redevelopment field, this chapter points out some missing pieces in the overall picture. First of all, researchers in the U.S. and the U.K. have had greater access to site-related data in comparison to the studies conducted in Canada. Lack of accessible information in Canada has become a barrier for large-scale brownfield redevelopment studies. Furthermore, many studies have been comprised of site-specific analysis, in which the number of involved sites is one or two per study. Although brownfield redevelopment projects differ from site to site, large-scale analysis may be able to create an overall picture of brownfield redevelopment activities within the region. In turn, such analysis may be useful in terms of supporting efficient redevelopment resource allocation.

2.3.1 Information Availability Comparison

The literature regarding brownfield redevelopment studies is highly concentrated in the U.S. and the U.K. These two countries both have government-led programs which gathered brownfield information and helped decision-makers to make better decisions in terms of assigning redevelopment funds. For example, the US Environmental Protection Agency generated a program called “Cleanups in my community” (CIMC), which used an interactive web map to collect and share information about contaminated sites (US EPA, 2016). The goal of this program is to summarize the assessment information of various cleanup programs across all states and territorial partners so that cleanup progress of contaminated sites across the country could be monitored (US EPA, 2016). Currently, this program contains site information about brownfield properties that have received all types of grants (US EPA, 2016). The dataset includes property information (land size, property location, and census block data around the site); property background information (previous usage and contamination type); and

environmental assessment information (US EPA, 2012). For instance, Figure 5 shows a map resulting from the informational database for the U.S. Northeast, which contains brownfield redevelopment projects in different stages. This kind of information supports the efficient allocation of brownfield redevelopment. Similarly, the U.K. government has considered brownfields to be one type of land use; thus, current and previous brownfield sites' basic information has been made available through the government's open data catalogue (UK Government, 2013).

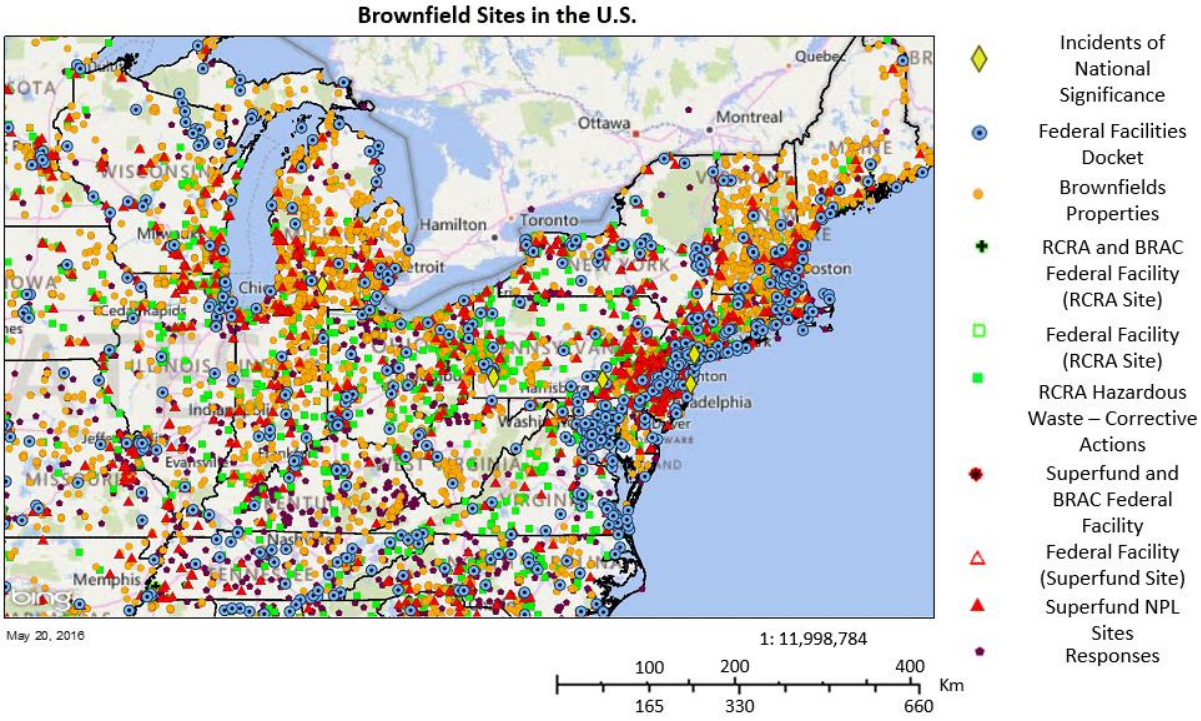


Figure 5. Map of Brownfield Database in the United States (US EPA, 2012)

Compared with the US and the UK, there is a lack of recorded information about brownfields in Canada. A Federal Contaminated Sites Inventory is available for recording information on known contaminated sites all across the country (Treasury Board of Canada Secretariat, 2016). However, only two sites within the Waterloo-Kitchener-Cambridge census

metropolitan area have been recorded by this inventory, indicating the underperformance of this inventory.

There are differences between Canada and the US and the UK in terms of land availability, government financial support, and public awareness of negative impacts from contaminated sites. What is more, Canadian cities are at different stages of understanding the concept of brownfield sites. Some large cities have included brownfield redevelopment as part of their sustainable planning goals, whereas other cities have not yet critically challenged by the existence of brownfields (Lomas-Jylha, 2004). It would be useful to not only have a universal policy structure to help more people understand the brownfield field redevelopment procedures, but to also keep documenting all information about brownfields so that redevelopment efficiency can be monitored. Also, assessing the effectiveness of previous redevelopment projects could help municipalities understand at which stage they currently are in terms of facilitating brownfield redevelopment projects.

2.3.2 Lessons Learned from Previous Studies

The scope of redevelopment-related studies is usually small. Due to limited access to information, most previous studies have focused on single site analysis. Some of these case-based studies provide information about the characteristics that could be used to evaluate the effectiveness of brownfield redevelopments. For instance, three Michigan sites were analyzed for their environmental justice achievement during the brownfield redevelopment process (Davies, 1999). Brownfield redevelopment projects are intended to improve the overall living quality within neighbourhoods. Thus, there could be improved public satisfaction through sufficient public engagement during the decision-making process. Case studies have also been conducted based on publicly and privately initiated brownfield redevelopment projects (Howland, 2003).

For privately initiated projects, land market demand could have a direct impact on a project's success. If the land market is weak, the economic risk from redevelopment is increased (Howland, 2003). What is more, brownfield redevelopment projects have been found to enable new job opportunities during the remediation, construction, and operation processes. Better policy construction and public support could further facilitate brownfield site redevelopment activities (Howland, 2007). Therefore, the effectiveness of brownfield redevelopments may be assessed by how the redevelopment affects a neighbourhood's quality of life, economic profitability, and socio-economic dimensions.

Brownfield policies in the U.S. encourage a large-scale analysis of the effectiveness of brownfield redevelopment projects. Lange and McNeil (2004) conducted an analysis of the factors, which could evaluate the success of brownfield redevelopment based on the results from national surveys. Based on the U.S. brownfield database and national surveys regarding brownfield redevelopments, the researchers concluded that citizen's satisfaction with brownfield redevelopment projects was not only dependent on solving environmental issues (Lange & McNeil, 2004). Yet very few studies have taken a large-scale perspective at the brownfield sites in Canada. For most of the brownfield redevelopment projects the government has focused more on monitoring the redevelopment process, whereas developers have evaluated redevelopment based on its economic profitability. A "value-for-money" culture, which focuses more on output (i.e., tangible elements such as the number of housing units created) than outcome (e.g., a neighbourhood's quality of life improvement) has existed among developers (Pediaditi, Doick, & Moffat, 2010). Also, the lack of measurable benchmarks has been identified as a problem for creating a rationale for a large-scale assessment of brownfield redevelopment projects (Yount & Meyer, 1999; Meyer & Lyons, 2000; De Sousa, 2006). A general evaluation of region-wide

brownfield redevelopments' effectiveness could help the government and concerned citizens to have a better understanding of the overall performance of redevelopment projects.

2.4 Research Purpose Statement

This study develops an evaluation matrix based on the characteristics of redeveloped brownfields within Waterloo Region, assesses the redevelopment effectiveness of these brownfield sites, and analyzes the contribution of redevelopment toward benefiting the surrounding neighbourhoods and achieving government development goals. Increasing the accessibility of brownfield information regarding public goals, environmental concerns, development motivations, and land capacity may be useful in the future for decision-makers when evaluating land use options (Thomas, 2002). Therefore, gathering all relevant information together into one dataset may help both the government and the private sector to form a better idea of brownfield redevelopment effectiveness. The effectiveness of brownfield redevelopment includes the land area it impacts, the size of population it affects, the natural environment it improves, and the economic profits that can be generated. While comparing brownfield redevelopment effectiveness and real-world redevelopment resource allocation, a discussion about actual drivers of brownfield redevelopment resource allocation is possible.

This research aims to integrate a multi-criteria analysis method with brownfield redevelopment effectiveness evaluation with the intention of improving brownfield redevelopment resource allocation and enlightening regional land use efficiency.

2.5 Research Objectives

Establishing research objectives helps break down the study's purpose into sections. To form an understanding of how Waterloo Region's brownfield redevelopment projects have

performed and whether previous brownfield redevelopment resources have been distributed effectively, the following four objectives have been established:

a. To fill the information gap regarding brownfield redevelopment within Waterloo Region;

b. To develop an assessment model for evaluating brownfield redevelopment effectiveness;

c. To evaluate the redeveloped brownfield effectiveness within Waterloo Region with the assessment model; and

d. To determine potential causes of resource allocation differences between the model and reality.

Chapter 3. Methods

3.1 Description of Methodological Steps

Over the past few decades, worldwide brownfield redevelopment has become a popular topic for researchers from various disciplines. Studies were first defining the term of brownfield, and then moved into brownfield redevelopment evaluation and future brownfield redevelopment strategic planning. A formally formed information platform could encourage large-scale brownfield redevelopment analysis, which could in turn benefit future brownfield redevelopment strategic planning. For instance, according to the United States Environment Protection Agency, all the listed brownfield sites of which information was available for public access were in the process of some form of cleanup (US EPA, 2016).

In contrast to the situations in the U.S. and the U.K., Canada has limited information about either current or previous brownfield sites. Therefore, the first step of conducting a performance analysis of previous brownfield redevelopment projects is to build a database with information about such projects. At the same time, criteria that may be useful for evaluating brownfield redevelopment performance could be chosen according to previous brownfield redevelopment research. After understanding the aspects each criterion represents, a model could be developed to assess the effectiveness of previous redevelopment projects. Furthermore, a comparison between effectiveness evaluation outcomes and real world redevelopment priorities could draw more attention toward creating an efficient brownfield redevelopment resource allocation system for future use.

In order to achieve all of the research objectives, this study follows seven stages in total (Figure 6): 1) build a dataset; 2) choose evaluation criteria; 3) make necessary modelling assumptions; 4) apply reasonable weight distribution techniques; 5) create the multi-criteria

analysis model and perform sensitivity and uncertainty test; 6) analyze the final evaluation results; and 7) discuss the modelling results' implications, limitations, and possible improvements.

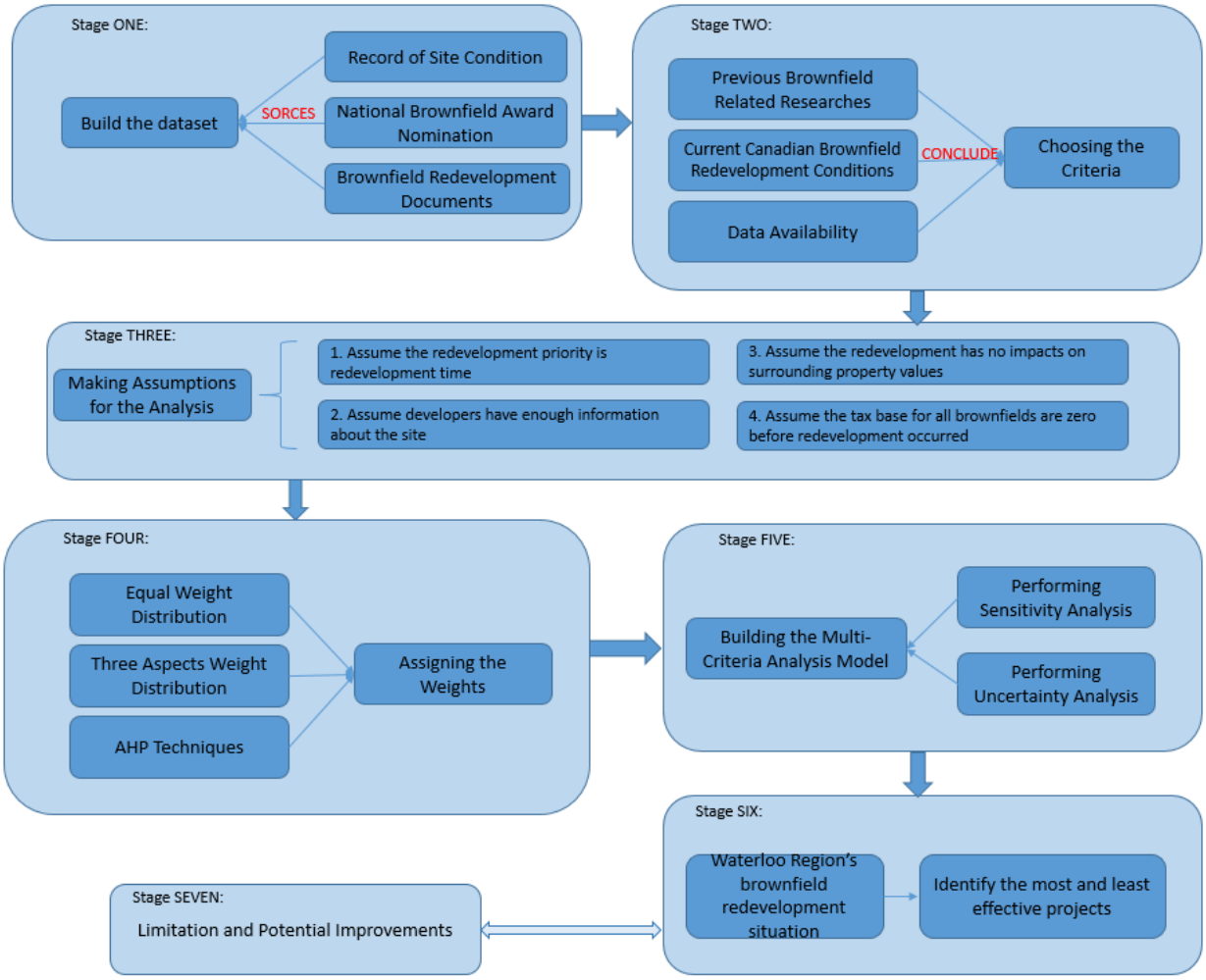


Figure 6. Methodological Steps Description

3.2 Study Area

Waterloo Region is one of the largest metropolitan area in Canada, and it is one of the fastest growing regions in Southwestern Ontario. According to the Growth Plan of the Greater Golden Horseshoe (Government of Ontario, 2006), Waterloo Region is the fourth largest urban area in the province and the tenth largest urban area in the country. The population of Waterloo

Region is expected to grow to 729,000 by 2031 (Government of Ontario, 2006). Although the region is composed of multiple lower-tier municipalities, the major urban areas of the City of Waterloo, the City of Kitchener, and the City of Cambridge are continuous. For instance, Downtown Kitchener and Uptown Waterloo are only three kilometres apart. In addition, many public facilities are shared among these separate municipalities. Therefore, it is useful to consider all of these separate municipalities as a single entity while planning for the region's sustainable development future.

Population and Employment Growth Plan Targets Region of Waterloo					
	2011	2031	2041	% Growth 2011-2031	% Growth 2011-2041
Population	528,000	729,000	835,000	41%	58%
Employment	269,000	366,000	404,000	36%	50%

Table 3. Population and Employment Growth Plan (Government of Ontario, 2006)

According to the Waterloo Region Population and Employment Growth Plan (2006), the regional population will increase from 528,000 in 2011 to 729,000 in 2031, and by 2041 the regional population is expected to exceed 835,000. In other words, a 41% increase for a 20-year population forecast and a 58% increase for a 30-year population forecast are expected (Table 3). The employment population is expected to increase from 269,000 in 2011 to 366,000 in 2031, and by 2041 the employed population is expected to exceed 404,000. The employed population is expected to increase by 36% according to a 20-year forecast and by 50% according to a 30-year forecast. With this potential population increase and growth pressure, a smart development strategy is needed for the region. According to the Region of Waterloo (2015), four important regional development goals for the region have been identified: 1) to form a long-term environmental plan; 2) to establish smart urbanization; 3) to perform quality of life initiatives; and 4) to create alternative transportation choices. As an urban metropolitan, many industries and

factories, which were developed during industrialization are now facing renovation. Thus, studying the brownfield sites' redevelopment situation for the Region of Waterloo and developing a brownfield redevelopment ranking system could help the region in reaching its development goals.

Unlike other large urban areas such as Toronto (De Sousa, 2000), Hamilton (Wang et al., 2008), and Montreal (Bliek & Gauthier, 2007), the Region of Waterloo has not yet been chosen by researchers as a brownfield redevelopment target study area. Yet the Region of Waterloo has several brownfield financial incentive programs. According to a 2016 summary of regional brownfield-related financial support, 11 regional development charge exemptions have been approved which have a value of approximate $14,448,277 (Region of Waterloo, 2015). At the same time, nine joint tax incentive grants with a value of $16,529,620; 22 phase II ESA grants with a value of $574,053; and 42 grant applications of miscellaneous kinds have been approved by the region since 2007. In total, 31,551,951 million dollars have been approved by the region to incentivize brownfield redevelopment (Region of Waterloo, 2016). The efficient allocation of various types of supports among all the brownfield sites should be a very important decision for municipal level decision-makers. Given the large amount of funds, it is important to examine whether the supporting funds were spent wisely. Thus, the current lack of brownfield records and the increasing resources for supporting brownfield redevelopment make the Region of Waterloo a good case study area for analyzing the performance of previously redeveloped brownfield sites.

3.3 Assumptions

With brownfields located all across the region, different sites have various redeveloping contexts. For example, the surrounding natural environment, neighbourhood, traffic accessibility, and available land area for each site likely differ. Therefore, several assumptions are necessary to

enable creation of an overall evaluation model for regional-scale brownfield redevelopment effectiveness:

a. The timing of redevelopment projects reflects the priority of brownfield sites' resource allocation. Brownfields, which were redeveloped at an earlier phase, were considered in this study as sites that had higher redevelopment priority and were thus allocated brownfield redevelopment resources at an earlier time.

b. There was enough information available for developers regarding cleanup fees, preparation cost, and social factor forecasts before the redevelopment decision was made.

c. The tax base for all the brownfield sites was zero before redevelopment.

d. The impacts of the redevelopment projects on residential properties within the neighbourhood were considered a major impact.

e. The impacts on the entire surrounding natural environment will be considered as the same and will not be quantified.

3.4 Selection of Evaluation Criteria

3.4.1 Criteria Used in Previous Studies

An examination of brownfield redevelopment evaluation criteria in the literature reveals that land market conditions, supporting policies, and property values are three frequently mentioned aspects. The redevelopment of brownfield sites in Toronto started in the 1990s when the infrastructure of industries and manufacturers became outdated and the service industry started to become a major part of the economy. Three key factors that have impacts on launching brownfield redevelopment projects were identified: 1) government supporting policies; 2) land market conditions; and 3) a desire to improve the city's overall urban condition (De Sousa, 2002). Basically, a lack of government support from finance and policy perspectives can make

developers focus more on the land market conditions. Sites, which are located in zones with higher property value, are likely to be redeveloped earlier than their counterparts. Despite that the strong influence that the land market has on brownfield redevelopment could lead to productive brownfield repurposing, it may not lead to the redevelopment of all brownfield sites. It may be better to seek a balance between using redeveloping policies and redeveloping profits to encourage redevelopment of all brownfield sites.

In addition, new purposes of redevelopments could lead to different evaluation standards. Whether a redevelopment project might benefit the surrounding neighbourhood is another component for brownfield redevelopment evaluation. Turning brownfield sites into green spaces could be another alternative for brownfield redevelopment projects. Since 2001, reducing the costs and risks while repurposing brownfield sites has become a provision in the Ontario Brownfields Statute Law Amendment Act, Chapter 17, Bill 56 (Government of Ontario, 2001). While economic factors have strong impacts on brownfield repurposing, brownfields spatial relations with large-scale green space patterns should not be ignored. It might be useful to develop brownfield sites that fall within greenbelts or flood plains as green spaces in order to create habitat areas within the greater urban pattern. However, this type of redevelopment is challenged by the significant cost of the cleanup process (De Sousa, 2003). In addition, a survey on brownfield repurposing preferences shows that community members preferred that new residential areas or community facilities replace the previous brownfield sites rather than commercial or industrial area replacement (Greenberg & Lewis, 2000). Redevelopments, which create new job opportunities, could be also considered as an alternative. Ignoring public opinions during the decision-making progress is not wise; therefore, social factors could prove to be very important while assessing the redevelopment of brownfield sites (Greenberg & Lewis, 2000).

Two U.S. nationwide brownfield surveys identified factors other than environmental factors. The analysis showed that "time to occupancy, total development cost, community support, proposed land use, condition of the local infrastructure, willingness of lending institutions to participate in the financing, support of local politicians, availability of financial incentives, and number of jobs to be created" have had equally significant impacts on the success of the brownfield redevelopment as addressing the environmental issues (Lange & McNeil, 2004).

In terms of brownfield redevelopment, Wedding and Crawford-Brown (2007) conducted a survey among professionals and experts on four indicators that they believed could measure the redevelopment projects' success. According to this study, successful redevelopment has three key characteristics: "(1) eradicating poverty, (2) protecting natural resources, and (3) changing unsustainable production and consumption patterns" (Wedding & Crawford-Brown, 2007). In order to translate this high-level definition into specific indicators, four aspects of criteria were created: environment-health, finance, livability, and socio-economic. What is more, indicators were identified including: probability of health risks; limitation of future environmental risks; percentage of site as green space; reduction in financial liability; investor satisfaction; internal rate of return; private funds leveraged; net jobs created per acre; increase in tax revenue; improved quality of life within the community; reduction in crimes rate; and increase in renovation and beautification projects in surrounding area (Table 4).

Aspects	Environment-health	Finance	Livability	Social-economic
Result of each aspect's importance to the success of redevelopment	30.2%	29.6%	21.6%	18.6%
Top 3 indicators in the survey	Probability of health risks	Reduction in liability	Private funds leveraged	Improved community
	Limitation of future risks	Investor satisfaction	Net jobs created per acre	Reduction in crime rates
	Percentage of site as green space	Internal rate of return	Increase in tax revenue	Increase in renovation and beautification projects in surrounding area

Table 4. Brownfield redevelopment evaluating aspects and Indicators from Wedding and Crawford-Brown's survey (Wedding & Crawford-Brown, 2007)

In conclusion, it may be possible to evaluate brownfield redevelopment projects based on the three following high-level criteria: social, environmental, and economic. Based on previous surveys and research, the brownfield reuse process should be evaluated based on full coverage of these three aspects. Social aspect variables represent the brownfield redeveloping activities' impacts on the welfare of surrounding neighbourhoods. Environmental aspect variables reflect the success of the cleanup process, which also has impacts on the quality of life in surrounding neighbourhoods. Economic aspect variables include the benefit from the redevelopment projects to the local municipal revenue. Inner-relationships also exist between these three perspectives. For instance, converting an abandoned site to a green space could benefit the neighbourhood from social and environmental perspectives; however, the municipal revenue may not directly benefit from this activity. Therefore, including all three aspects in the assessment model could help determine the overall effectiveness of the redevelopment projects and reflect the efficiency of the allocation of brownfield redevelopment supportive resources.

3.4.2 Criteria for Evaluating Large-scale Brownfield Redevelopment Projects

Out of all the criteria that have been used for evaluating brownfield redevelopments' impacts, not all could be used for region-wide brownfield redevelopment evaluation in this study. For instance, case-specific criteria, such as types of remediation and cleanup methods, would not be suitable for large-scale brownfield effectiveness assessment because they cannot be easily quantified or compared. In order to perform a rational evaluation of all brownfields, the criteria selected should be representative and accessible. This section lists some of the criteria used by certain municipalities in the US while assessing their redevelopment projects' effectiveness. Through identifying the current stage of Canadian cities brownfield redevelopment, criteria that could reflect the effectiveness in this context could be selected.

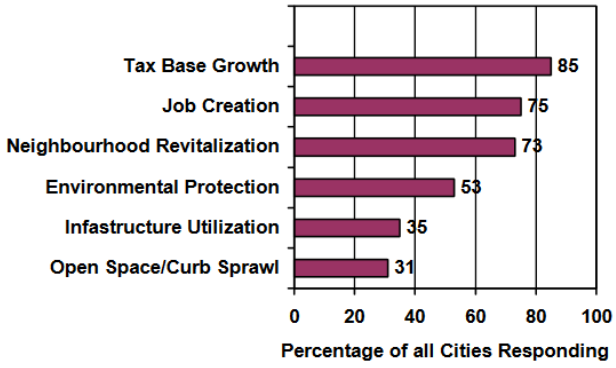


Figure 7. U.S. cities' responses to a survey on the most important benefits from brownfield redevelopments (The U.S. Conference of Mayors, 2000)

In 2000, The U.S. Conference of Mayors conducted a survey among 232 cities all across the U.S. regarding the benefits of brownfield redevelopment projects to cities (The U.S. Conference of Mayors, 2000). As shown in Figure 7, the most important benefit from redevelopment projects identified by the survey responses is tax base growth, whereas job creation and neighbourhood revitalization are identified as second and third factors of greatest importance. The next important factor is environmental protection, followed by infrastructure utilization and open space/curb sprawl (Regional Analytics Inc., 2002).

Researchers from George Washington University reviewed case studies of brownfield redevelopment projects and found that the most frequently reported benefit of redevelopment

projects was job creation followed by area improvements, surface clean-ups, increased property values, and local tax revenue (Deason, Sherk, & Carroll, 2001). Several municipalities in the United States utilize lists of criteria while evaluating the effectiveness of redevelopment. For example, Massachusetts uses pre- and post-redevelopment evaluation criteria to measure whether the redevelopment was necessary and effective. During the pre-redevelopment stage, the considered criteria include acquiring title, size, transportation access, historical districts/empowerment zone, public benefits, cost, contamination, and cleanup liability (State of Massachusetts, 2011). In the post-redevelopment inventory, the information that is kept on record includes site location, known environmental assessment, size of the parcel, ownership, zoning change, site condition updates, and tax base rise (State of Massachusetts, 2011). To summarize, the criteria chosen for large-scale brownfield redevelopment evaluations should include aspects of the neighbourhood instead of only the brownfield itself.

Canadian cities are still at an early stage of brownfield redevelopment, whereas the United States already has a specific structure for evaluating and monitoring redevelopment. Increasing public awareness, coordinating national interests, and guiding municipalities in developing effective strategies are three main goals for Canadian the brownfield redevelopment industry. Large-scale brownfield evaluation could support a comprehensive assessment of the brownfield redevelopment situation Canadian cities currently are facing.

3.4.3 Criteria Selection for this Study

The purpose of this study is to evaluate the effectiveness of previous redevelopments within Waterloo Region. As Canadian cities are still developing their methods of redeveloping brownfield lands, the selected criteria should be able to represent the impacts of brownfield redevelopment on broader aspects than site details. From all the criteria used in previous

brownfield redevelopment studies, the criteria that could be used for evaluating the redevelopments' effectiveness can be categorized into three aspects: criteria that represent the impacts on people (i.e., social), criteria that represent the impacts on the environment, and criteria that represent the impacts on the economy. Additionally, the criteria selection should not only base their relevance upon these three aspects but also upon data availability within the study area. Table 5 shows the evaluation criteria selected for this study.

Category	Criteria	Data Source	Used in previous Studies
Social factors	Population Density	National Census Survey and Cities' Zoning Bylaws	(Greenberg & Issa, 2005)
	Employment Density		(Doick, Sellers, Castan-Broto, & Silverthorne, 2009) (Greenberg & Issa, 2005) (Lange & McNeil, 2004)
	Unit Density		(Doick, Sellers, Castan-Broto, & Silverthorne, 2009) (Sun & Jones, 2013)
Environmental factors	Water body	Regional Open Data Catalogue	(Doick, Sellers, Castan-Broto, & Silverthorne, 2009) (Lesage, Deschênes, & Samson, 2007) (Sun & Jones, 2013) (Thomas, 2002)
	Greenfields		(De Sousa C. , 2000) (Lesage, Deschênes, & Samson, 2007)
	Number of Encouraged New Redevelopments	The Brownfield database	(Lange & McNeil, 2004)
Economic factors	Municipal Tax Base Rise	Estimation based on the market property values	(Doick, Sellers, Castan-Broto, & Silverthorne, 2009) (Thomas, 2002)

Table 5. Criteria and data sources used in this study

Social factors are the factors that reflect the impacts on society. First, density analysis is a popular topic of contemporary urban development-related studies. Density can be expressed as a numeric ratio which quantitatively reflects human activities within a given land base (Taylor & Nostrand, 2008). Different density analysis methods reflect various aspects of the region's urban

form such as population, employment, and built-up areas. Population density is useful for people-oriented studies in which impacts on people are a primary concern of researchers. Redevelopment in a neighbourhood with high population density would have larger impacts in terms of people's health and welfare than redevelopment in a neighbourhood with low population density. Employment density is frequently used as a supportive indicator for population density, because the two major compositions of an area's human activities are living and working. Besides people who live in the neighbourhood, the working population is also an important portion, which is influenced by the redevelopment project. Unit density does not usually follow the same trend as population density, because household size has spatial variation (Taylor & Nostrand, 2008). Therefore, the impacts on the density of a built-up area could be reflected through the unit density of the redevelopment's surrounding neighbourhood. The impacts from redevelopment on the property values within the surrounding neighbourhood are difficult to estimate quantitatively. Nevertheless, the impacts could be reflected by the unit density within the neighbourhood. A higher unit density could reflect a larger impact from the land repurposing process on a more intensely used urban area.

In addition, the most direct impact from recycling of brownfields is the rehabilitation of the natural environment. The clean-up process mostly focuses on reducing the impacts of contamination on the groundwater and surface water systems and the soil of the site. The potential impacts on the surface water system might be estimable through distance to the closest body of water. Additionally, the cleanup of contaminated sites could save existing greenfields from new development and reduce the speed of urban sprawl. Therefore, a larger amount of nearby greenfield is expected to reflect a larger positive environmental impact of brownfield redevelopment. Additionally, the initiation of brownfield redevelopment clusters should not be

ignored while evaluating the impacts from brownfield redevelopments. It is interesting to consider that a successful redevelopment may encourage more brownfield remediation activities in its surrounding, which may benefit the area's overall environmental condition (Lange & McNeil, 2004). This effect may not only encourage new redevelopments within the area, but may also strengthen the contribution of previously redeveloped sites. For instance, different repurposing projects can offer various kinds of contributions to the surrounding neighbourhoods, which may complement each other. The benefits achieved by a redevelopment cluster are therefore not simply the sum of each redevelopment's contribution. For the purposes of this study, the potential ability of reinforcing other brownfield redevelopments within the surrounding areas is categorized as part of environmental improvements.

Economic benefit has always been an important purpose of brownfield redevelopment. Not only can developers benefit from brownfield repurposing, but the government may also have a dramatic, local tax base rise following redevelopment projects. Since this study considers the effectiveness of redevelopment projects from a systemic, large-scale perspective, the tax base rise from the recycling of brownfield sites could be a significant indicator to represent the effectiveness of the redevelopment.

3.5 Building the Dataset

3.5.1 Identifying Redeveloped Brownfields within Waterloo Region

Since the Region of Waterloo does not currently have a brownfield site database, the establishment of a brownfield dataset was one of the major tasks for this research. Several resources were used for building the Waterloo Region brownfield database including records of site conditions, national brownfield awards, and redevelopment projects' records from planning firms. The first source used was the record of site condition. This record is meant to include the

environmental condition information for all of the sites that have changed their property usage. This registry only enforced Site Condition Records for properties whose purpose changed since July 1, 2011 (Government of Ontario, 2011). Therefore, this data source only covers brownfield sites, which were intended to be redeveloped after 2011. The Ontario Records of Site Condition Registration Program, which is intended for informational purposes only, contains environmental site assessments, property value, and site contamination conditions on record. This program could be an optimal source to identify all of the brownfield sites within Waterloo Region and to obtain basic information about these sites. Most of the records from this source are of the brownfields currently in the process of repurposing.

The second source for building the dataset comprised the sites that have won national brownfield awards (Canadian Brownfields Network, 2016). The Canadian Brownfields Network was officially launched in 2004 by the Ontario Centre for Environmental Technology Advancement (OCETA) and the Canadian Urban Institute (CUI) in order to respond to the recommendations in the National Roundtable on the Environment and the Economy's National Brownfield Redevelopment Strategy for Canada (Canadian Brownfields Network, 2016). The purpose for the Canadian Brownfield Network is to create bridges between practitioners and stakeholders to encourage facilitation of the brownfield redevelopment. Therefore, the brownfield redevelopment awards issued by the Canadian Brownfield Network were intended to encourage achievements from all perspectives regarding the brownfield redevelopment topic. The brownfield awards include: "CBN Heroes Underpinning Brownfield Awards; CUI Brownie Awards; Real property Institute of Canada Federal Contaminated Sites Awards; Brownfield Briefing Remediation Awards; the GLOBE Awards for Environmental Excellence; and Brownfield Renewal Awards" (Canadian Brownfields Network, 2016). These awards reveal

information about successfully redeveloped projects since 2001. Therefore, these awards could be a good data source that covers successfully redeveloped projects within the region. Since these projects have won national awards, information about these brownfield sites is mostly available on planning firms' websites and local news reports. Compared to the Site Condition Records, the sites' information from national brownfield award records require more organizational effort.

The third type of information source is the most difficult type to organize, as it includes the redevelopment projects' documents from planning and engineering firms. Searching through all brownfield redevelopment projects within the region and planning firm records can help locate detailed information about previous repurposed brownfield sites.

Using the data sources above, a dataset that contains 24 previous brownfield sites, redeveloped between 2000 and 2016 within the Waterloo Region, has been built. Because the Canadian census cycle is five years, all the previous redevelopment projects can be grouped into one of five census cycles: prior to 2000, 2001-2005, 2006-2010, 2011-2015, 2016 and beyond. Different colours are used for representing census cycles (Table 6). Table 7 shows the redevelopment project name, full address, redevelopment time, and the assumed redevelopment priority. Some examples of the sites' information source reports are included in Appendix B. According to the prior assumptions for this study, the redevelopment completion time (i.e., the year when redevelopment was completed) represents the projects' redevelopment priority. Table 7 also shows all previous redeveloped brownfield sites, which have been color-coded by the census cycle they belong

Color	Group
Blue	Before 2001
Red	2001-2005
Grey	2006-2010
Green	2011-2015
Yellow	2016 and after

Table 6. Color-coding based on which census cycle their redevelopment time belong.

to.

Two sites were redeveloped before 2001; seven sites were redeveloped between 2001 and 2005; three sites were redeveloped between 2006 and 2010; nine sites were redeveloped between 2011 and 2015; four sites were redeveloped starting 2016; and more brownfields are expected to be redeveloped in the future.

Name	Full Address	Redevelopment Time	Priority Assumption
McLennan Park	901 Ottawa Street South, Kitchener, N2E 0A5	1980	1
Alexandra Lofts	35 Alexander Avenue, Waterloo, ON N2L 1L4	2000	2
Seagram lofts	3 Father David Bauer Dr., Waterloo, ON N2L 6M1	2001	3
Spadina Apartments	301 Spadina Road East, Kitchener, N2M 3X9	2001	4
The Heartwood place	19-21 Gaukel st, Kitchener, N2G 1Y6	2001	5
Cambridge Transfer Station	201 Savage Dr, Cambridge, N1T 1S8	2003	6
University of Waterloo School of Architecture	7 Melville St S, Cambridge, ON N1S 2H4	2003	7
The Kaufman Lofts	410 King St W, Kitchener, ON N2G 1C3	2004	8
The Millcreek by the Grand townhouse	250 Ainslie St S, Cambridge, N1R 2G9	2005	9
Gaukel & Joseph	44 Gaukel St, Kitchener, N2G 4P3	2007	10
Elmira core Shoppers Drug Market	15 Arthur St N, Elmira, N3B 1Z4	2008	11
The Bauer buildings	187 King St S, Waterloo, ON N2J 1R1	2009	12
Savic Homes Ltd.	55 Mooregate Crescent, Kitchener, N2M 2E9	2011	13
The Corporation of the City of Cambridge	185 King Street E, Cambridge, N3H 3M5	2012	14
The Tannery District	151 Charles St W, Kitchener, ON N2G 1H6	2012	15
Northfield Equities Inc.	580 & 590 Weber Street North, Waterloo, N2V 1K4	2013	16
2371632 Ontario Inc.	300 Phillip Street, Waterloo, N2L 3W9	2013	17
MennoHomes Inc.	7 Memorial Avenue, Elmira, N3B 2P8	2014	18
Gautam Growth Properties Inc.	1126 Swan Street, North Dumfries, N0B 1E0	2014	19
One 55 Mady Limited	145 Caroline Street South, Waterloo, N2L 5T1	2014	20
The Breithaupt Block Project	51 Breithaupt St, Kitchener, ON N2H 5G5	2014	21
1841362 Ontario Inc.	340 Louisa Street, Kitchener, N2H 5N2	2016	22
445 King St	445 King Street West, Kitchener, N2G 1C2	2016	23
Regional Municipality of Waterloo	100 St. George Street, Kitchener, N2G 2S9	2016	24
83 Elmsdale	83 Elmsdale Dr, Kitchener, N2E 1H7	2016	25

Table 7. Brownfield Dataset Basic Information Template

3.5.2 Gathering Site-related Information Based on Chosen Criteria

By knowing the locations of brownfields and engaging assessment criteria as a basic framework, one objective of this study was to fill the information gap regarding previously redeveloped brownfield sites. The first task is to unify the spatial scale of the impacts of all redevelopment projects. Statistics Canada make available information about all levels of required social factors for Waterloo Region. This study chooses to use census tract data to represent characteristics of neighbourhoods.

Census Tracts, as defined by Statistics Canada, are small and stable geographic areas located within a metropolitan area that usually contains 2,500 to 8,000 residents (Statistics Canada, 2015). As required by census survey operators, the census tract establishment follows four characteristics: permanent and easily recognizable physical features; 4,000 persons on average; low internal variation in socioeconomic characteristics; and boundaries which respect the census metropolitan area. Thus, census tracts' geographic boundaries rarely change between census years. The most common change occurs when the census tract's population exceeds 8000. In such a case, a census tract could be split into two new census tracts, which would allow for re-aggregation to support historical comparison.

Since the study area of Region of Waterloo is a census metropolitan area, census tracts are considered a relatively reasonable geographic tool to represent the social indicators. Census tracts can represent the social changes that have been caused by brownfield redevelopment within this area. At the same time, using the social factors at a homogeneous level of geographic division can reduce the number of uncertainties caused by activities other than brownfield redevelopment. This study uses spatial information to identify which census tract the redevelopments belong to so that uncertainties caused by potential census tracts changes can be

reduced. Figure 8 below shows the process of combining multiple years' social characteristics. Spatial join allows the join feature to match the target features with relative spatial locations. Further analysis can be performed after placing the information from all five census years together with each redevelopment project.

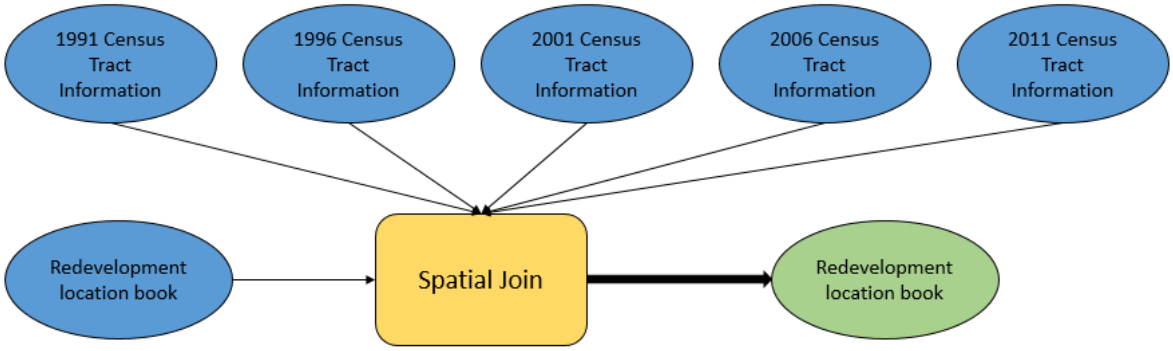


Figure 8. The Model for Gathering Redevelopment Sites' Multiple Year Census Information

3.5.2.1 Population Density

Population density is used as an indicator to assess the impacts of redevelopment projects on neighbourhood residents. A higher neighbourhood population density represents a potentially more effective land redevelopment project.

Census data are assessed every five years; however, redevelopments can take place at any time. In order to improve the representation of the population density impacted by redevelopment projects, a non-census year population density estimation is often necessary. The population density variation between census years is complex for each census tract. This study uses a simple linear function to make statistical inferences for each redevelopment year.

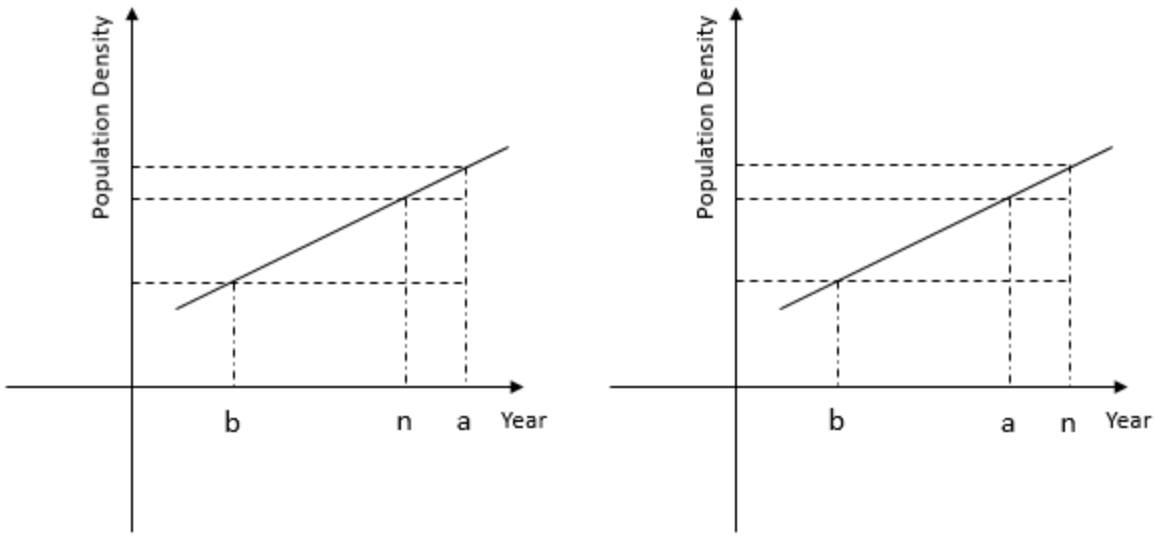


Figure 9. Estimation of Population Density at the Redevelopment Year

Figure 9 shows how population density for each redevelopment year was calculated. Population density represents the impact of the redevelopment project on human beings. The following equation [1] provides a general estimation function for population density between census years: n is the year of redevelopment; a and b are census years; P_{yn} represents the population density in year n; and P_{ya} and P_{yb} represent the population density in census years a and b.

$$Pyn = \frac{|n-b|}{|a-b|} \times (Pya - Pyb) + Pyb \text{ [1]}$$

According to data derived from Statistics Canada and the linear function above, it can be estimated what the impact is of brownfields on resident neighbourhood population. Table 8 presents some estimated population densities. For the entire dataset within the Waterloo Region, the largest impacted population density is 5,050 people/km^2, whereas the minimum value of redevelopment impacted population density is 144 people/km^2. Redevelopment of brownfields could impact the quality of life within surrounding neighbourhoods. The larger the population, the greater the potential impact of redevelopment.

Project Name	Alexandra Lofts	The Heartwood place	The Kaufman Lofts	The Bauer buildings	The Breithaupt Block Project	83 Elmsdale
Redevelopment Time	2000	2001	2004	2009	2014	2016
Population Density (per km^2)	2,151	3,994	2,606	2,369	2,943	3,032

Table 8. Examples of Redevelopment Projects' Impacted Population Density Estimation

3.5.2.2 Employment Density

The redevelopment may not only affect the people who live in the neighbourhood, but also affects the working population. Therefore, employment density can be a suitable indicator to reflect the brownfield redevelopment projects' impacts on the working population. A higher working population means a larger potential impact from the land repurposing progress.

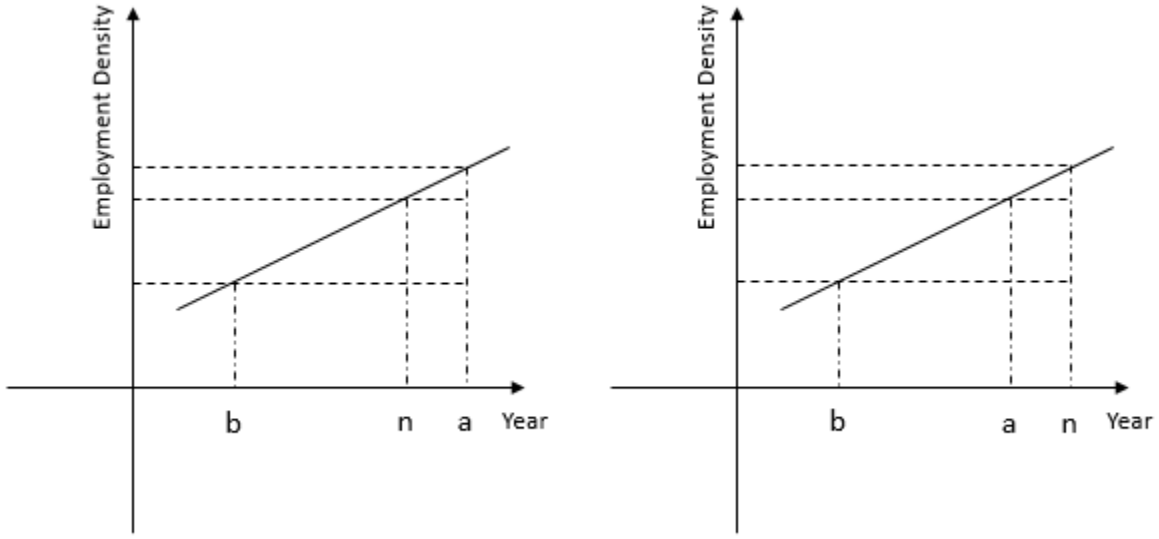


Figure 10. Estimation Employment Density at the Redevelopment Year

Similar to population density, the data source for employment density is the National Census Survey. The distribution of employed labour force within each census tract is used for

calculating the employment density for each census tract. The information of jobs can be derived from the "Place of work" portion of the Census Survey. This variable was used in the Growth Plan for Greater Golden Horseshoe area as a representation of development intensity, which provides the activity frequency in a defined area (Ontario Ministry of Infrastructure, 2013). Figure 10 shows the process used for approximating the employment density of each redevelopment year. In equation [2], n is the year of redevelopment. a, b are census years. E_{yn} stands for the employment density in year n. E_{ya} and E_{yb} stand for the employment density in census years a and b.

$$Eyn = \frac{|n-b|}{|a-b|} \times (Eya - Eyb) + Eyb \text{ [2]}$$

Based on this linear function and each site's census tract information, the employment density of the brownfields in its redevelopment year was estimated. Table 9 provides some examples of the employment density estimation. For the entire study area, the largest impacted employment density is 163, whereas the minimum value of redevelopment impacted employment density is 10. The larger employment density reflects higher potential impacts from redevelopment projects on the working population in the surrounding neighbourhood.

Project Name	Alexandra Lofts	The Heartwood place	The Kaufman Lofts	The Bauer buildings	The Breithaupt Block Project	83 Elmsdale
Redevelopment Time	2000	2001	2004	2009	2014	2016
Employment density (per km^2)	115	163	53	120	63	54

Table 9. Examples of Redevelopment Projects' Impacted Employment Density Estimation

3.5.2.3 Unit Density

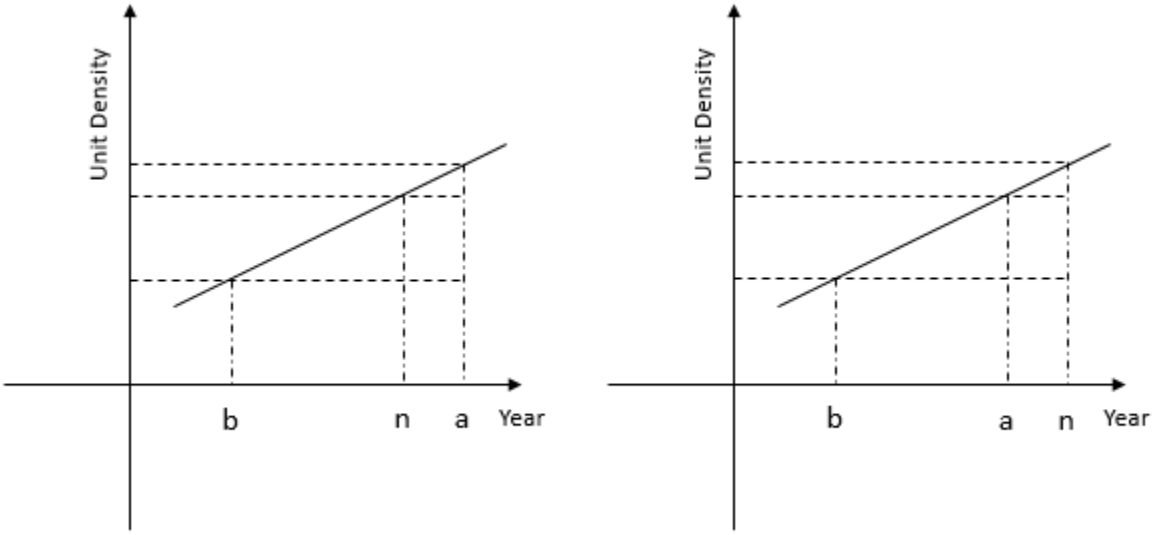


Figure 11. Estimation Unit Density at the Redevelopment Year

Renewing neighbourhood conditions and creating additional housing choices are two expectations for reusing brownfields. The higher the unit density of neighbourhood is, the larger the impacts of the redevelopment project might be in terms of infrastructure revitalization and potential cumulative property value increase. According to a study conducted by Paull (2008), the residential property value within 1.2 kilometers from redevelopment projects can increase by up to 15 percent. It is difficult to estimate the exact neighbourhood property value change. However, the unit density of the neighbourhood, which contains the brownfield redevelopment project, can reflect the impacts of the land repurposing process on built-up areas. What is more, unit density does not necessarily have the same trend as population density. Comparing with population density, the unit density could reflect more information such as household structure and housing stock consumptions.

Unit density is calculated based on the dwelling unit numbers of each census tract and the census tract land area. Dwelling unit refers to a structure that is used as a place of residence

(Statistics Canada, 2016). Similar to the population and employment density, census tract unit density information was collected every five years. Therefore, a linear estimation function is used for calculating the unit density of each census tract for the year of redevelopment (Figure 11). In equation [3], n is the year of redevelopment. a, b are census years. U_{yn} stands for the unit density in year n. U_{ya} and U_{yb} stand for the unit density in census years a and b.

$$Uyn = \frac{|n-b|}{|a-b|} \times (Uya - Eyb) + Uyb \text{ [3]}$$

Table 10 provides some examples of the unit density estimation. For the entire study area, the largest unit density is 2,870, whereas the smallest unit density is 56. The larger unit density would reflect higher potential impacts from the redevelopment projects on residential buildings within the surrounding neighbourhood.

Project Name	Alexandra Lofts	The Heartwood place	The Kaufman Lofts	The Bauer buildings	The Breithaupt Block Project	83 Elmsdale
Redevelopment Time	2000	2001	2004	2009	2014	2016
Unit density (per km^2)	1,208	2,062	1,648	1,528	1,484	221

Table 10. Examples of Redevelopment Projects' Impacted Unit Density Estimation

3.5.2.4 Impacts on Water Body

One of the potential impacts of brownfields is the pollution of water systems. The above or below ground contamination might enter into the water system and threaten the health and quality of life of people in nearby neighbourhoods and the health of the environmental system. At the same time, the existence of aquifer contamination might also be a potential threat. Since contiguous spatial information about the aquifer underlying this region is unavailable, this study

focuses on bodies of surface water. Everything else being equal, the closer a brownfield is to a surface water system, the higher the risk is that it could affect the water in the surrounding neighbourhoods. A map of creeks and rivers is available for Waterloo Region (Figure 12). Using this water body map, brownfield sites' distances from water bodies can be calculated through spatial analysis (Figure 13).

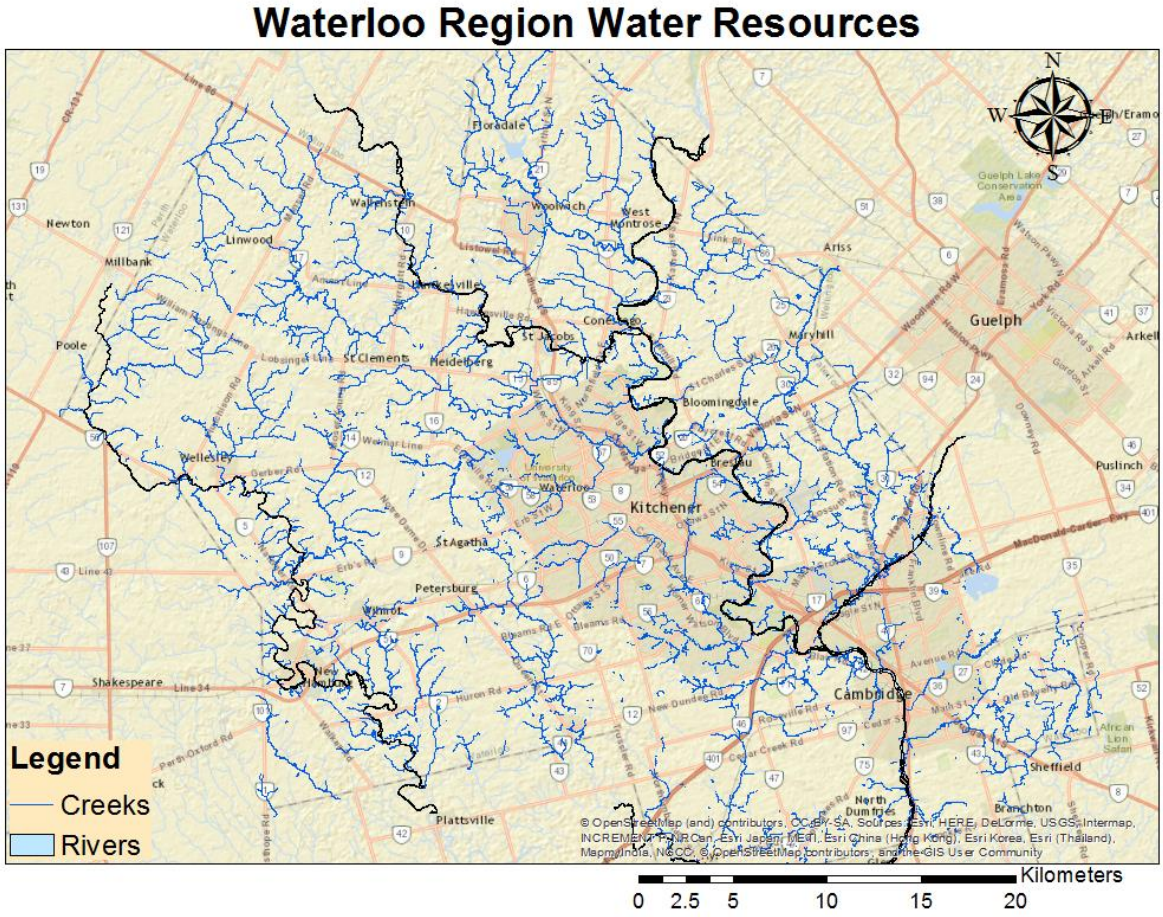


Figure 12. Waterloo Region Natural Water System Distribution

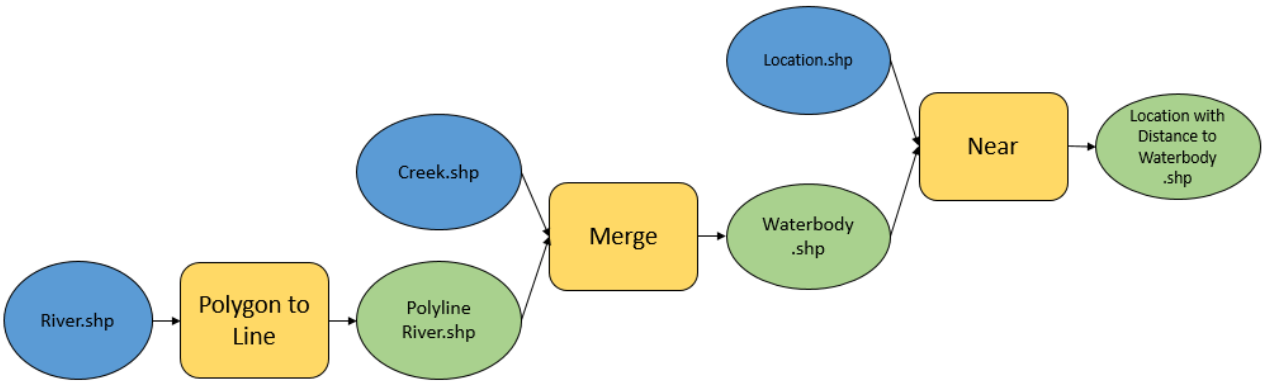


Figure 13. Model for Determining the Brownfield's Distance to Water Body

It is expected that brownfield sites that are closer to a water body may require earlier cleanup because of the increased risk to surface water contamination. Therefore, if development projects are prioritized by the proximity to water features, there should be a positive relationship between distance to the closest water body and the redevelopment's effectiveness, as expressed by its redevelopment prioritization.

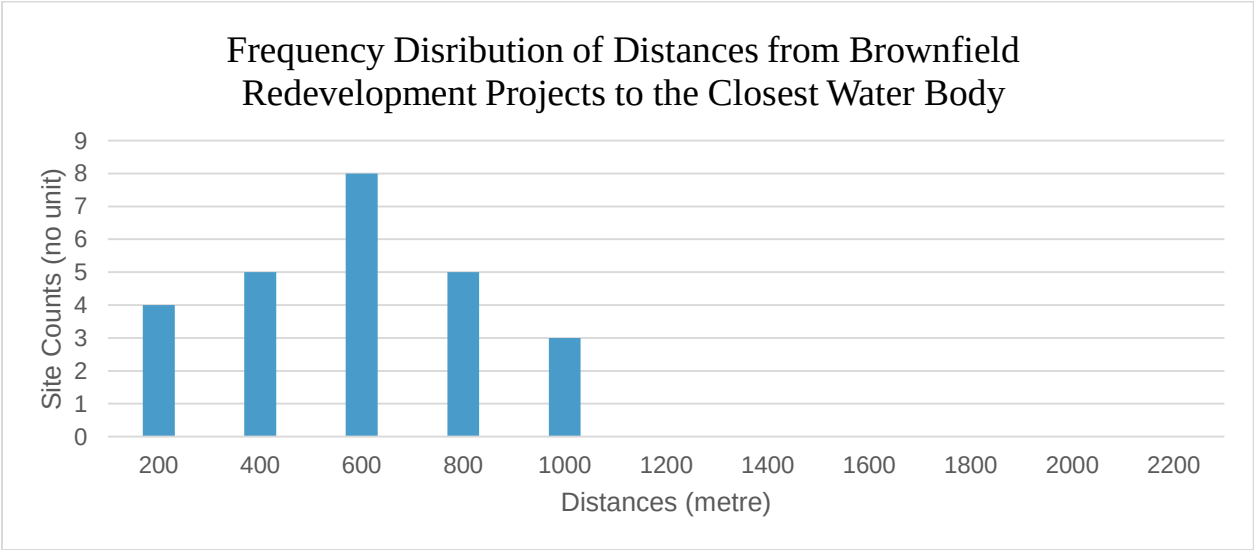


Figure 14. Frequency Distribution of Distances from Brownfield Redevelopment Projects to the Closest Water Body

Figure 14 shows the distribution of distances of redevelopment sites to the closest water body. Brownfield redevelopment distance to the closest water body ranges from 38.19 meters to 994.15 meters. About one third of the sites within the brownfield dataset have a distance to the closest water body that is smaller than 300 meters. The average distance is 487.56 meters, and the median is 488.76 meters.

To investigate whether the above relationship is simply due to an underlying spatial relationship between the locations of all buildings and water bodies, a comparison should be made of distances between brownfield redevelopment locations and water bodies with distances between all buildings and water bodies. For this purpose, a dataset was created of building footprints within Waterloo Region and their distances to the closest water body compared to brownfield redevelopment location distances to the closest water body.

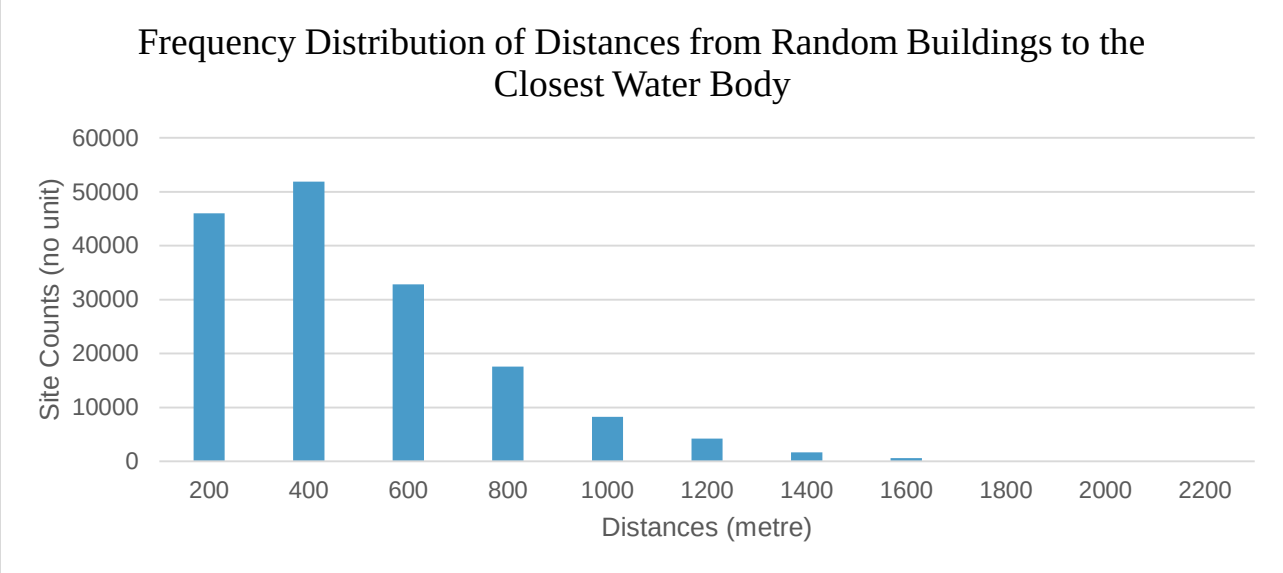


Figure 15. Frequency Distribution of Distances from Random Buildings to the Closest Water Body

The above mentioned comparison was based on the random draw of 163,095 locations across the Region of Waterloo that then led to the identification of an equal number of building that were closest to these locations, henceforth called random buildings. Calculation of the

distribution of distances between buildings and water bodies was based on the thus identified random buildings. Analysis of the distances of random buildings to the closest water body indicates that the minimum distance was 0.1 metres, whereas the maximum distance was 2,042.4 meters. The random building giving rise to the minimum distance was identified as a work shed close to a creek located on a wetland in North Dumfries. The average distance to the closest water body was 392.3 meters, and the median of all distances was 329.6 meters. Figure 15 shows the frequency distribution of distance to closest water body. Half of all buildings are located less than 330 meters away from a water body.

An interesting finding of this analysis is that brownfield redevelopment sites tend to be located farther away from surface water bodies than expected by chance. Having said that, the closer a brownfield site is to a water body, the sooner it should be cleaned up and repurposed, because the existence of abandoned industrial sites' contamination could be harmful to its surrounding natural environment including surface waters. Therefore, the reciprocal for the distance to closest water system is used for representing this criterion.

3.5.2.5 Impacts on Greenfields

In this case 'greenfield' means a vacant sites without development or contamination, which may or may not have municipal services such as hydro and gas (Regional Analytics Inc., 2002). The redevelopment of brownfields has been identified as responsible growth (Government of Ontario, 2014), which could help limit the sprawl of urban developments. Since protecting the countryside is one of Waterloo Region's planning goals (Region of Waterloo, 2015), the impacts from brownfields on undeveloped greenfields should be considered while assessing the brownfield redevelopment effectiveness.

Out of all the brownfield sites within the dataset, the largest site has a surface area of 1.375 km^2, which is an institutional repurposing project, and the smallest site has a surface area of 0.1123 km^2, which has been redeveloped into a residential building. About two thirds of the sites have been redeveloped into residential areas, and the rest was converted into commercial purposes, institutional usages, park lands, and other.

$$Impacts\ on\ Greenfields = Brownfield\ surface\ area\ \times offsite\ ratio \quad [4]$$

The offsite ratio refers to the quantitative relation between developing the same project on a brownfield site and on a greenfield. While taking the planning regulation, development costs, and land prices into consideration, one unit of brownfield redevelopment could save an average of 4.5 units of greenfield with the same purpose (Paull, 2008). This means the average offsite ratio is 4.5. The study also differentiates between different offsite ratios based on the new purpose of the redevelopment. It takes 6.2 units of greenfield for building the same size of industrial projects, 2.4 units of greenfield for building the same size of commercial projects, and 5.6 units of greenfield for building the same size of residential projects (Paull, 2008). Thus, the amount of greenfield area saved by brownfield redevelopment can be estimated based on the brownfield site surface area and the new land use type of the redevelopment. In this study, the offsite ratio for residential, commercial, industrial reuses were used for redevelopment projects of these types, and the average offsite ratio was used for other redevelopment purposes. The higher the greenfields impact value of a redevelopment project is, the greater its effect on preserving greenfields and slowing urban sprawl.

3.5.2.6 Tax Base Rise

According to the regional brownfield brief, since 2007, 2,368 new residential units were proposed to be created by brownfield redevelopment, whereas 1,064,033 square feet of new non-

residential floor area was proposed (Region of Waterloo, 2016). Property tax revenue makes up the major part of municipal revenue; therefore, property tax is an important criterion to consider while evaluating brownfield redevelopment effectiveness. An increase in the property tax base will have direct impacts on the region's financial situation.

In addition, in many previous brownfield redevelopment studies tax base rise has been mentioned as an important criterion of redevelopment success (The U.S. Conference of Mayors, 2000; Thomas, 2002; Doick, et al, 2009). Therefore, including tax base rise as a criterion, which represents the economic impacts from the redevelopment, is necessary for the brownfield repurposing effectiveness evaluation model. According to the observed land use changes of former brownfields within Waterloo Region, there are several major types of new purposes: residential area, commercial and institutional area, and parkland. With the assumption that brownfields have a property value of zero, the tax base rise for each redevelopment project could be assessed as their new property value after redevelopment.

When a brownfield was converted into parkland, no tax base rise was achieved (e.g., McLennan Park in this study). Because parklands are non-profit driven projects, the direct economic impacts these repurposing projects had on the municipality were limited compared to others, such as residential and commercial redevelopment. Equally, conversion of brownfields to non-profit institutional use did not lead to a tax base rise (e.g., Cambridge Waste Transfer Station in this study). When a brownfield was converted into a commercial area, the tax base rise was estimated based on the fair market price, which was taken from real estate databases (Ontario Commercial Brokers, 2016). When a brownfield was converted to residential use, the tax base rise was estimated based on current market value per unit (P) and numbers of new generated unit (U), taking into account the inflation rate (I). After having a current property value estimation,

the tax base rise for the redevelopment year can be back-calculated based on the current property value estimation and inflation rate. This approach does not take into account price fluctuations in the housing market. Appendix A shows housing market price changes and the overall inflation rate from 2000 to 2015.

The largest tax base rise was achieved by "The Breithaupt Project", which is a conversion from a previously industrial site to a mixed commercial and residential area, which had an estimated tax base rise of 0.57 billion dollars. One of the smallest tax base rises resulted from "the Gaukel & Joseph corridor", which was a conversion from a previously industrial site into park area, resulting into a tax base rise of zero.

3.5.2.7 The Ability of Reinforcing Other Redevelopment Projects

Other than the previously described criteria, which were adapted from previous studies, one other important criterion has been included in this study. Based on the spatial distribution of brownfield site developments within Waterloo Region (Figure 16), brownfield redevelopments for the past thirty years were spatially clustered. These spatial clusters were created by the "Find Hot Spots" tool in ArcGIS online based on the distribution of the existing brownfield sites. The ArcGIS online tool quantifies spatial patterns in random distributed features through comparison among neighbouring features (ArcGISonline, 2016). The tool calculates a spatial statistic attribute known as Getis-Ord Gi* (see equation [5]), to represent each point's significance of being a hot spot.

$$Gi^* = \frac{\sum_{j=1}^{n} Wi,jXj - \bar{X}\sum_{j=1}^{n} Wi,j}{S\sqrt{\frac{\left[n\sum_{j=1}^{n} Wi,j^2 - (\sum_{j=1}^{n} Wi,j)^2\right]}{n-1}}} \quad [5]$$

$$\bar{X} = \frac{\sum_{j=1}^{n} Xj}{n} \quad S = \sqrt{\frac{\sum_{j=1}^{n} Xj^2}{n} - (\bar{X})^2} \quad [6]$$

In equation [5] and [6], X_j is the attribute value for point j; $W_{i,j}$ is the spatial weight between point i and j; n is the total number of features. The values of Gi^* represent the significance of the sites becoming a hot spot. Only points that have relatively high G_i^* values and that are surrounded by points with high G_i^* values can be identified as hot spots. The significance of points as hot spots is coded by colors. The yellow and red area in figure 16 indicate redevelopment projects with higher G_i^* values, which can be identified as brownfield redevelopment hot spots in Waterloo Region. A cluster of brownfield sites might be emerging because of several successful redevelopment projects in the area. The larger the redevelopment cluster is that a given redevelopment project falls in, the stronger of a reinforcing relationship it may have with other redevelopment projects within the same cluster.

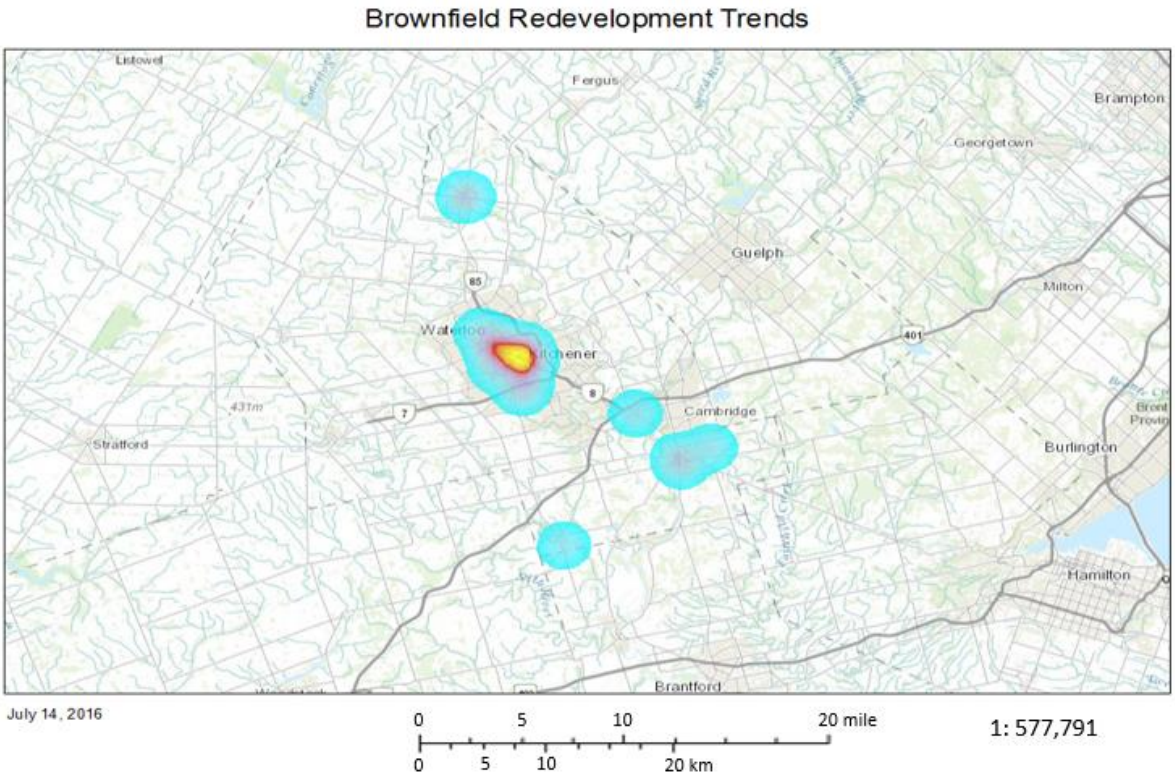


Figure 16. Brownfield Redevelopment Hot Spots in Waterloo Region

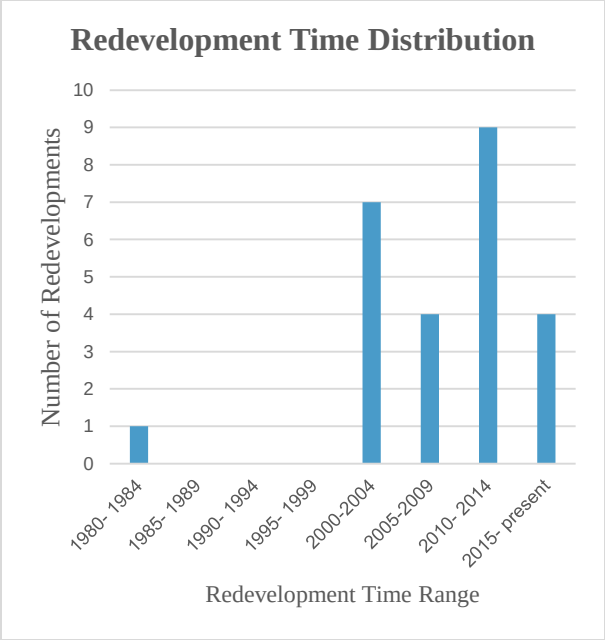


Figure 17. Redevelopment Time Distribution

There are five brownfield redevelopment clusters within Waterloo Region. The average diameter of the brownfield redevelopment clusters in Waterloo Region is 5,000 meters. At the same time, the number of redevelopment projects per year is increasing from 1980s to present (Figure 17). The growing size of the redevelopment clusters during the past decades might reflect the positive effects the redeveloped sites have on each other. What is more, the size of the redevelopment cluster could reflect the reinforcement ability of all the brownfield redevelopments within the cluster. If a redevelopment project is located within a larger redevelopment cluster, it is more likely that this redevelopment will have a higher effectiveness in terms of reinforcing other reuse projects.

The variable that represents the impacts from a target brownfield site on the redevelopments in its vicinity is 'site counts'. It is assumed that this variable captures each site's effectiveness in contributing subsequent land regeneration within a certain distance. To quantify this variable, the redevelopment projects would be categorized based on the spatial cluster they located in. Within a cluster, each site is surrounded by a number of redevelopments that happened before or after its completion. The redevelopments within a cluster together made contributions to their surrounding neighbourhoods. Therefore, the size of the redevelopment cluster could represent the redevelopments' ability of reinforcing other repurposing projects. The size of the redevelopment cluster refers to the number of projects located in it.

3.6 Combining All Criteria for Final Assessment (MCA)

3.6.1 Overall Combining Progress

After gathering site-related information for each criterion, combining all these criteria that represent all perspectives together to reflect the brownfield redevelopment's overall effectiveness is the next step. A possible comparison approach for all redeveloped brownfield sites could be the generation of an evaluation matrix that contains every single criterion for every site. However, problems with this approach include that the criteria have various unit scales and that they vary across different ranges. For example, distances are in metric units, whereas densities are people per square kilometers. To alleviate this problem, it is necessary to normalize the values for all criteria so that scores for all criteria can be combined and compared in the evaluation matrix. Therefore, the aim of normalization in this study is to convert the values for all criteria from their own scale into a 0-100 scoring scale. The normalization equation is as follows:

$$Normalized\ Value = \frac{X - Xmin}{Xmax - Xmin} \times 100 \text{ [7]}$$

The overall evaluation results are generated by combining all the criteria through various combination methods. Population density, employment density, unit density, impacts on greenfields, tax base rise, and the ability of reinforcing other redevelopments are criteria that may directly and proportionally affect the effectiveness of a brownfield redevelopment. Distance to closest water body, however, is a criterion for which the inverse value may show a proportional relationship with a site's effectiveness. Having normalized all criteria to a 0-100 scoring scale, the input values for the multi-criteria model are ready. The next step is to use a reasonable weight distribution mechanism that allocates weights among the criteria. Each

criterion represents a factor that is impacted by the brownfield redevelopment projects. In order to find reasonable methods to combine all criteria together and efficiently reflect the brownfield redevelopment projects' effectiveness, three weight distribution systems, which represent three ways of evaluating brownfield redevelopment effectiveness, have been applied in this study. All three systems could reflect the effectiveness of the brownfield redevelopment projects; however, various weight distributing systems would have different evaluation focuses. Equal weight distribution focuses more on equity among all selected criteria. The SMART weight distribution ensures balance among the impacts of the three overarching aspects: social, economic, and environmental. Finally, the AHP weight distributing system enables more flexibility of weight assignment, and allows participants to conduct brownfield redevelopment evaluation based on their individual preferences.

3.6.2 Mathematical Programming with Equal Weight Distribution

The first weight distribution system is equal weight distribution, which is a multi-criteria assessment model that considers all criteria with the same level of importance. The equal weight distribution model is a kind of mathematical programming. When all considered criteria are assigned the same weight, an evaluation of all brownfield redevelopment projects' effectiveness will be performed. The equal weight distribution ensures that all the impacted aspects are equally considered.

$$Evaluation\ Score = {}^{1}/_{n} \times (S1 + S2 + \cdots + Sn) \text{ [8]}$$

Equation [8] shows calculation of the evaluation score with the equal weight distribution model, where n stands for the number of criteria within the model, and S1, S2, and Sn are the scores that represent each criterion's effectiveness. In this study, n is seven, and Sn is the normalized score for each criterion. The equal weighted distributing model takes all criteria into

equal consideration and provides a basic effectiveness evaluation for all the brownfield redevelopment projects within the dataset. However, this multi-criteria evaluation model performs the analysis regardless of each criterion's actual importance to the brownfield redevelopments' effectiveness, which in reality might be different.

3.6.3 The SMART Mechanism

The SMART weight distribution mechanism is a mathematical approach, which assigns weights based on a multi-level hierarchy. In this weight distribution method, all criteria are categorized by several higher-level aspects (such as social, economic and environmental). Instead of directly distributing the weights to all criteria, the weights are assigned equally within a given higher-level aspect, thus balancing all evaluation criteria from the same higher-level aspect and reducing potential imbalance caused by unequal numbers of criteria within each aspect. For example, this study has seven criteria in total; however, three of them represent the social impacts, three of them represent environmental impacts, and only one of them represents economic aspect. In the SMART weight distribution, a balance will be reached among the social, environmental, and economic aspects regardless how many criteria each aspect contains.

$$Evaluation\ Score = \frac{{}^{1}/_{na} \times SUM(Sna) + {}^{1}/_{nb} \times SUM(Snb) + \cdots + {}^{1}/_{nk} \times SUM(Snk)}{k} \quad [9]$$

Equation [9] shows calculation of the evaluation score based on the SMART weight distributing mechanism, where k is the number of higher-level aspects, nk is the number of criteria within each aspect, and Sn is the normalized score value for each criterion in the model. The seven criteria can be categorized into three aspects: impacts on the society, impacts on the environment, and impacts on the economy. In this case, k is three; na is three; nb is one; nc is three. The SMART weight distributing model provides a well balanced evaluation result of all

the redeveloped brownfields within the dataset regarding to their social, economic, and environmental impacts. A higher evaluation score represents a more effective redevelopment project.

3.6.4 The AHP Weight Assignment

Every selected criterion in this evaluation model represents an important aspect of the entire evaluating process. The previous two types of weight distributing methods have fixed weight distribution and are less flexible. They can hardly be justified in a situation where the brownfield redevelopments' effectiveness evaluation does not align with the weight distribution imposed by the model. AHP is a tool, which works well with qualitative or categorical variables, such as the criteria chosen by this study (Klutho, 2013). This approach can also be useful in engaging concerned parties who have limited knowledge of the application of multi-criteria analysis in an evaluation process. Appendix D shows the AHP weight assigning process. After identifying the selected criteria in the evaluation model, the participants will be asked to complete a comprehensive evaluation of the importance of all criteria. Based on pair-wise comparisons conducted by the participants, a ratio matrix of criteria's importance will be generated.

$$\begin{bmatrix} w1/_{w1} & \cdots & w1/_{wn} \\ \vdots & \ddots & \vdots \\ wn/_{w1} & \cdots & wn/_{wn} \end{bmatrix} \begin{bmatrix} w1 \\ w2 \\ \vdots \\ wn \end{bmatrix} = n \begin{bmatrix} w1 \\ w2 \\ \vdots \\ wn \end{bmatrix} \quad [10]$$

$$Evalaution\ Score = \begin{bmatrix} w1/_{w1} & \cdots & w1/_{wn} \\ \vdots & \ddots & \vdots \\ wn/_{w1} & \cdots & wn/_{wn} \end{bmatrix} \begin{bmatrix} S1 \\ S2 \\ \vdots \\ Sn \end{bmatrix} \quad [11]$$

Equation [10] and [11] shows how to calculate the evaluation score based on the AHP weight distributing mechanism, where wn stands for the participant-selected weight during the

pair-wise criteria comparison and Sn is the normalized score representing each impacted criterion in the evaluation model. Participants' preferred weights for each criterion will be generated based on the pair-wise comparison results. In this study, I'm the only participant for the pair-wise criteria comparison. According to my response to the pair-wise comparison analysis, the AHP weight assigning model's evaluation equation is:

$$Evaluation\ Score = 15.4\%\ Population\ Density + 12.8\% Employment\ Density + 12.4\% Unit\ Density + 18.8\% Impacts\ on\ Waterbody + 13.1\%\ Impacts\ on\ Greenfields + 9.9\%\ Encouraging\ Brownfield\ Redevelopments + 17.7\% Tax\ Base\ Rise \quad [12]$$

The AHP weight assigning model allows more flexibility for performing an evaluation. Not only can the focus of the evaluation change according to various contexts, but also multiple participants' opinions can be included in the evaluating process. The AHP template for this study can include a maximum of 20 participants' inputs into the evaluation process. The larger the evaluation score, the larger the effectiveness brownfield redevelopment projects.

3.7 Models' Sensitivity Analysis

The evaluation models provide the assessment for all the redevelopment projects within the dataset. However, the performances of the multi-criteria models should be assessed with a sensitivity analysis. Because the inputs for multi-criteria analysis models can be imprecise, it is important to confirm that varying inputs to the model provide consistent analysis results (Triantaphyllou & Sánchez, 1997). In this study, the purpose of performing sensitivity analyses is to ensure every criterion indeed has an impact on the final output result. A useful approach in sensitivity analysis is to initially set a target for variation in the results. Equation [13] shows, how this study uses the magnitude of change in the results when one criterion is dropped to represent the model's sensitivity to this criterion. Thus, the evaluation score range of the input group as affected by every criterion will be tested:

$$Model's\ Sensitivity = \frac{Max\ (leave\ one\ out\ score) - Min(leave\ one\ out\ score)}{Max(original\ score) - Min(original\ score)}$$ [13]

In this study, sensitivity test results are categorized into four groups: smaller than ±1%, ±1-5%, ±5-10% and larger than 10% or smaller than -10%. If a criterion falls in the smaller than ±1% category, it means this criterion has limited impacts on the final evaluation result. If a criterion falls in the ±5% category, it means this criterion has some impacts on the final evaluation results. If a criterion falls in the larger than ±10% category, it means this criterion has relatively high impacts on the final evaluation results. This criterion plays an important role during the entire evaluation process.

Results from the sensitivity analysis are presented in Table 11. The absolute value of results shown are sensitivity analysis results of the model without the certain criterion. In the equal weight distribution model, population density, employment density, unit density, impacts on water body, and the ability of reinforcing other redevelopments are the criteria that have the most influence; whereas, tax base rise and impacts on greenfields do not have much influence. In the SMART weight distribution model, tax base rise has the most influence, while population density and unit density have the least influence. In the AHP weight distribution model, population density and unit density have most influence and the ability of reinforcing other redevelopments has least influence.

	Population Density	Employment Density	Unit Density	Tax Base Rise	Impacts on Greenfields	Impacts on Water Body	The Ability of Reinforcing Other Redevelopments
Equal Weighted Model	18.63%	11.29%	16.91%	0.08%	0.04%	-3.52%	8.40%
SMART Weighted Model	-1.27%	-6.53%	-2.65%	28.37%	-13.11%	-16.10%	6.74%
AHP Weighted Model	22.09%	12.35%	16.90%	1.84%	2.23%	-1.46%	0.63%

Table 11. Local Sensitivity Analysis Results for the Three Evaluation Models

These local sensitivity analyses for the three weight distribution models have examined the influence of each individual criterion on the final evaluation score range. Another perspective is to investigate the global sensitivity (across all criteria) of the three weight distribution models. The models' minimum score can be reached while every criterion is at its lowest possible score. While all criteria have reached their largest possible input value, the maximum value of the model could be achieved. The minimum and maximum theoretical scores for equal weighted model and SMART weighted model are both 0 and 100. The minimum and maximum value for AHP are 0 and 105.8. The closer the evaluation range is to ideal range, the more sensitive the model is. The "Theoretical Score" in equation [14] stands for the score that can be reached in an ideal situation.

$$Model's\ Sensitivity = \frac{Max(original\ score) - Min(original\ score)}{Max(Theoretical\ Score) - Min(Theoretical\ Score)} \quad [14]$$

The SMART Weighted Model is the most sensitive model, explaining 58.5% of the ideal scoring situation, followed by the Equal Weighted Model, which explained 47.5% of the ideal scoring situation, and the AHP Weighted Model, which explained 45.4% of the ideal scores (Table 12). Additionally, Table 12 shows global sensitivity results after elimination of the criteria that have least influence as identified by the local sensitivity analyses.

	Included Criteria	Sensitivity	Eliminated Criteria	Sensitivity
Equal Weighted Model	All	47.5%	Tax Base Rise; Impacts on Greenfields.	66.4%
SMART Weighted Model	All	58.5%	N/A	58.5%
AHP Weighted Model	All	45.4%	Reinforcing Other Redevelopments	45.9%

Table 12. Results of Global Sensitivity Analysis of Three Weight Distribution Models Before and After Exclusion of Least Influential Criteria.

Removing the criteria with least influence on the final evaluation might create a new result with a wider scoring coverage. For example, the reduced equal weighted model explained 66.4% of the entire data range, an increase of 18.9% relative to the complete model. The reduced AHP weighted model explained 45.9%, an increase of just 0.5% relative to the complete model. However, a higher sensitivity does not equal a more reliable result. Removal of criteria from the weight distribution models means that the evaluation results will not be able to represent all the potentially important aspects of the brownfield redevelopment projects. The purpose of performing sensitivity analysis is to investigate the influence of all the input criteria in the models. Thus, the sensitivity analysis could provide the effectiveness of each selected input criterion; however, the robustness of the output of a model cannot be investigated with sensitivity analysis.

3.8 Uncertainty Analysis

Unlike sensitivity analysis, which aims at analyzing the influence of inputs in the evaluation models, uncertainty analysis aims to analyze the robustness of the models' outputs. In a multi-criteria evaluation model, uncertainty exists in every step of the modelling process. The final goal of performing uncertainty analysis is to determine the possible sources and levels of the model's uncertainty (US EPA, 2003). Some parts of uncertainty can be quantified, whereas others parts are better characterized qualitatively. In this study, the uncertainty of a model's output is reflected by the possibility of having a reversal of the evaluation order. The differences between the top two sites' evaluation scores under various scenarios are used to determine the uncertainty of a model:

$$Uncertainty = \sum_{i=1}^{n-1}\left(\frac{\Delta(Si)-\Delta(Sn)}{\Delta(Sn)}\right) \quad [15]$$

$$\Delta(Sn) = \frac{Sn1-Sn2}{Sn2} \times 100\% \text{ [16]}$$

Equations [15] and [16] are used for calculating the model uncertainty in this study, where i is the number of the "leave one criterion out" models, n is the number of criteria in the original model, Δ (Sn) is the scores' differences from the original model, and Δ (Si) is the scores' differences from each "leave one criterion out" model. The uncertainty of every criterion can be calculated with the "leave one criterion out" approach. The model's overall uncertainty can be represented by the sum of all "leave one criterion out" model's uncertainties divided by n-1. The model's overall uncertainty reflects the probability of a reversal of the top two sites' evaluation scores (Table 13). An overall uncertainty smaller than zero, indicates a possibility of having a reversal of the two top scores. If the overall uncertainty is above zero, it means the model's output should be robust against reversal results.

	Equal Weighted Model	SMART Weighted Model	AHP Weighted Model
Uncertainty	-2.3%	18.8%	-11.8%

Table 13. Models Uncertainty Analysis Results

The results of the uncertainty analysis indicate that the equal weighted model has 2.3% possibility of a reversal of the two top scores, if changes to the inputs are made. The AHP weighted model has the highest uncertainty of having a reversal of the two top scores, with a possibility of 11.8%. The SMART weighted model has the most robust output, with 18.8% possibility to have a robust result. Thus, the evaluation outputs of equal weighted model and of the AHP weighted model are relatively less robust than the evaluation output of the SMART weighted model.

3.9 Summary of Modeling Progress

This study is not only extending the geographic scale of brownfield redevelopment effectiveness evaluation, but also introduces a more general definition of redevelopment

effectiveness. Information about previously redeveloped brownfields were collected from various sources, whereas, through reviewing previous related studies, impacts on three broader aspects of brownfield redevelopment (i.e., social, environmental and economic) are included into the modelling process. Table 14 below shows a summary of the modelling process.

	Equal Weighted Model	SMART Weighted Model	AHP Weighted Model
Choosing Criteria	Through reviewing previous brownfield redevelopment impacts' studies, seven criteria were chosen as the effectiveness evaluation framework.		
Assigning Weights	This model adapts the mathematical program-ming mechanism. Equal weights were assigned to all seven criteria.	This model is based on the SMART mechanism. First, equal weights were assigned to the three higher-level aspects, then weights were distributed equally within each aspect.	This model is based on the AHP mechanism. The weights were distributed based on participants' opinions.
Combing Multiple Criteria	After standardizing all the criteria's values, the evaluation score of each redevelopment equals the sum of all Criteria's Weight × Value.		
Assessing Model	Sensitivity analysis and uncertainty analysis are used for the assessment of all models.		
Analysis Results	The results from the three models are analyzed and their differences examined.		

Table 14. Summary of Modelling Process

During the combining evaluation criteria stage, three multi-criteria methods are used: the equal weighted evaluation model, the SMART weighted evaluation model, and the AHP weighted evaluation model. The equal weighted evaluation model assigns equal weights to all criteria while generating the final evaluation score. The SMART weighted model assigns equal weights to the three broader aspects (i.e., social, environmental and economic), and then distributes the weights equally to criteria within each group. The AHP weighted model determines the weight distribution based on the participants' opinion towards all seven criteria. Through pair-wise comparison among the seven criteria, an evaluation model can then be generated. After performing evaluation through these three different evaluation mechanisms, the

reliability of the models and the robustness of the results is analyzed through sensitivity and uncertainty analysis.

Chapter 4. Findings

4.1 Overview of New Purposes of Brownfields Within the Dataset

One advantage of having a regional scale brownfield information bank is having a general understanding of how previous brownfields have been recycled. Figure 18 shows the brownfield redevelopments' choices of new purposes in the Region of Waterloo. Half of all redeveloped brownfields on record were redeveloped into residences. One fifth (21%) of the sites were redeveloped into mixed-use area, about one tenth (9%) of the sites were cleaned up and used as parklands, less than one tenth (8%) of the sites were reused as commercial land, and 4% of the sites were recycled for institutional purposes. The remaining 8% of brownfields were repurposed for other uses, such as streetscapes and a waste transfer station.

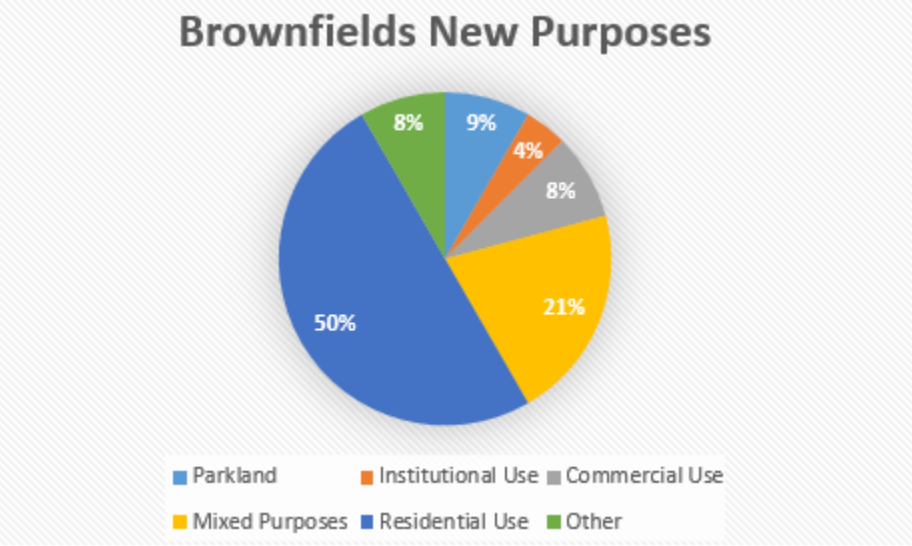


Figure 18. Brownfield Redevelopments' Choices of New Purposes in Waterloo Region

Additionally, the spatial distribution of all the redeveloped brownfields (Appendix F) shows that most of the redevelopments are close to designated Urban Growth Centres. The redevelopments that occur in suburban and rural areas are also located close to settlement areas.

When looking at these redevelopment projects generally, every one of these repurposing activities has an influence to the surrounding neighbourhoods and the region as a whole.

4.2 Evaluating the Effectiveness of All Redevelopment Projects Within the Dataset

The effectiveness of all brownfield redevelopment projects can be reflected by the calculated values that combine all the impacted aspects' (social, economic and environmental) influences scores. Three evaluating models are used, and three sets of evaluation scores and orders are created based on their evaluation focuses. Appendix E shows the evaluation scores and orders for the three models. The ideal range for all scoring systems is from 0 to 100. In the equal weighted model, the evaluation score ranges from 2.7 to 50.2, and has an average of 33.2. In the SAMRT weighted model, the evaluation score ranges from 2.1 to 60.6, and has an average of 27.6. At the same time, in the AHP weighted model, the evaluation score ranges from 3.0 to 48.3, and has an average of 30.2. The equal weighed model has the highest average score, yet none of the three model has a full coverage of the ideal score range. It is possible that during the decision making processes for these redevelopment projects, impacts on the surrounding neighbourhoods were not considered as important factors. Comparing with the equal weighted model and the AHP weighted model, the SMART weighted model covers a wider evaluation score range. Therefore, according to the evaluation score ranges, the SMART weighted model may be more effective than the other two models in regard to the evaluating criteria selected for this study. Since none of the redevelopments has an ideal score, their relative order would be the key for comparison. Thus, the effectiveness of all brownfield redevelopment projects should be evaluated based on their orders in each evaluation model.

The outputs from the three models are different, yet show similar trends. Because the weight distributions are different in three models, also the final evaluation scores are different in

the three outputs. However, after grouping the results of each of three models into high, medium, and low performing redevelopment projects, very similar groupings result from all three models: The very effective redevelopments are located in urban core areas. Redevelopments of medium effectiveness tend to have obvious shortages in more than one criterion. The redevelopment projects with lower evaluation scores are usually the ones located in suburban or rural areas.

	The Equal Weighted Model	The SMART Weighted Model	The AHP Weighted Model
Top Tier: Very effective redevelopments	The Heartwood place; The Breithaupt Block Project; Savic Homes Ltd.; The Corporation of the City of Cambridge; 445 King St.; Northfield Equities Inc.; The Bauer buildings; One 55 Mady Limited.	The Breithaupt Block Project; The Heartwood place; Savic Homes Ltd.; The Bauer buildings; The Corporation of the City of Cambridge; The Tannery District; 445 King St; Northfield Equities Inc.	The Corporation of the City of Cambridge; The Breithaupt Block Project; The Heartwood place; Savic Homes Ltd.; Northfield Equities Inc.; 445 King St; The Tannery District; The Bauer buildings.
Middle Tier: Effective redevelopments	The Tannery District; 1841362 Ontario Inc.; Seagram lofts; 44 Gaukel; Alexandra Lofts; Spadina Apartments; Regional Municipality of Waterloo; The Kaufman Lofts.	One 55 Mady Limited; 1841362 Ontario Inc.; Seagram lofts; 44 Gaukel; The Kaufman Lofts; Alexandra Lofts; Spadina Apartments; Regional Municipality of Waterloo.	One 55 Mady Limited; 1841362 Ontario Inc; Seagram lofts; University of Waterloo School of Architecture; 44 Gaukel; Spadina Apartments; Alexandra Lofts; Regional Municipality of Waterloo.
Low Tier: Regular redevelopments	University of Waterloo School of Architecture; 83 Elmsdale; 2371632 Ontario Inc.; Cambridge Transfer Station; The Millcreek by the Grand townhouse; Elmira core Shoppers Drug Market; Gautam Growth Properties Inc.; MennoHomes Inc.	83 Elmsdale; 2371632 Ontario Inc.; University of Waterloo School of Architecture; The Millcreek by the Grand townhouse; Cambridge Transfer Station; Elmira core Shoppers Drug Market; Gautam Growth Properties Inc.; MennoHomes Inc.	The Kaufman Lofts; 83 Elmsdale; Cambridge Transfer Station; 2371632 Ontario Inc.; The Millcreek by the Grand townhouse; Elmira core Shoppers Drug Market; Gautam Growth Properties Inc.; MennoHomes Inc.

Table 15. Brownfield redevelopment classification based on effectiveness

Generally, all forms of brownfield recycling activities make some kind of contributions to the region. Comparing with developments on virgin lands, reusing brownfield helps cleaning up the potential environmental hazards. Nevertheless, some of the brownfield reuse activities are

more effective than others. The redevelopments, which have larger beneficial impacts, may deserve more resources in support of redevelopment and earlier attention. In order to decide how supportive resources should be allocated across all brownfield redevelopment projects, the overall effectiveness of all the sites could be categorized into three tiers: very effective redevelopment, effective redevelopments, and regular redevelopments.

Table 15 shows the classified evaluation results based on a three-tier hierarchy (i.e., all redevelopments classified by evaluation scores into three groups of equal size). Even though the overall evaluation orders from the three models for all redevelopment projects in the dataset are somewhat different from each other, individual projects tend to fall in the same category across models. The projects that belong to the top tier are mostly residential redevelopments that are located in the urban core. Redevelopments that have shortages in more than one criterion can hardly make it into the top tire in any evaluation model. On the other hand, the redevelopments in the low tier have various new purposes and sometimes are located in suburban or rural areas. A high score in just one criterion can hardly bring any redevelopment out of the low tier into a higher tier.

4.3 Distinguishing the Most Effective Redevelopments from the Least Effective Sites

Out of the three evaluating models' evaluation results, the top three best performing brownfield redevelopments are mostly the same. The top three best performing projects of all models include: "The Heartwood Place", "The Corporation of City of Cambridge", "Savic Homes Ltd.", and "The Breithaupt Block Project". At the same time, the top three worst performing projects are also the same in the three evaluating models: "Elmira Core Shoppers", "Gautam Growth Properties", and "MennoHomes Inc.".

The best performing projects are conversions from brownfields to various purposes, but every one of these three projects ranks first in one of the evaluation criteria. For instance, "The Breithaupt Block Project" is a conversion from a brownfield to a commercial-residential mix area, and has the top rank in tax base rise; "The Corporation of City of Cambridge" is a conversion from a brownfield to a parkland, and has the top rank in impacts on water systems; "Savic Homes Ltd." is a conversion from brownfield to residential area, which has the top rank in population density; and "The Heartwood Place" is a conversion from brownfield to residential area, and has the first place in the employment density score. Therefore, the common aspect for the best performing brownfield redevelopment projects may seem easy to identify.

However, the three sites that performed worst show a variety of patterns. "Elmira Core Shoppers" is a conversion from brownfield to a commercial area and it scores last in four out of seven criteria. "Gautam Growth Properties" is a conversion from brownfield to a residential area, but it scores lowest on only one out of seven criteria. "MennoHomes Inc." is also a conversion from brownfield to a residential area and it scores second lowest in four out of seven criteria. However, the three brownfield redevelopment projects that perform worst have one common characteristic, which is that their location is in the townships. Two of them are located in the Township of Elmira, and one is located in the Township of North Dumfries.

Chapter 5. Discussion

5.1 Are there any differences between real redevelopment time and effectiveness evaluation? What are the causes of these differences?

The evaluation models' outputs show that there are differences between the real redevelopment time order and their effectiveness assessment results. Theoretically, the redevelopment projects that had higher assessment results should have been the ones that were developed earlier. However, there are always differences between the ideal situation and reality. Looking at the redevelopment process from the developers' perspective, redevelopment evaluations are more case specific because of a lack of brownfield redevelopment related information at the regional level. Local level information may be more relevant to a developer during the redevelopment decision-making process, and so the sites' development driver, development potential, environmental condition, and market information are four important categories of indicators for redevelopment potential (Lange et al, 2013). What is more, brownfield recycling projects are also development projects. Thus, all aspects pertinent to normal development projects would also be considered during the decision making process on brownfields, such as a site's location, supply and demand of development land, time constraints, and so on (Syms, 1999). Without a regional scale brownfield information dataset, a comparison between existing brownfields is impossible. Thus, there will be differences between effectiveness order and real redevelopment time when the effectiveness assessment is performed on all previous redeveloped brownfield projects.

From the municipality's perspective, all brownfield repurposing projects could benefit the region both environmentally, socially, and economically. There is an increasing number of

detailed policies that support brownfield redevelopment projects legally and financially (Koch, 1998; Office of the Provincial Brownfields Coordinator, 2010). In Ontario, the Brownfields Statute Law Amendment Act was introduced in 2001 to clarify the potential liability conflicts among developers, former owners, and lenders (Ontario Ministry of Infrastructure, 2013). Also, keeping a record of site condition became a mandatory step before issuing a building permit since 2005 (Government of Ontario, 2006). Ontario's Planning Act enables municipalities to designate their own community improvement areas with local Official Plans (Government of Ontario, 2014). Some municipalities have financial assistance tools, such as clean-up grants, tax increment programs, and planning and development application fee waivers (McMillan Binch LLP, 2008). All of the above principals and policies aim to encourage and support brownfield redeveloping activities. However, as of yet it does not seem that the effectiveness of allocation of supporting resources has become an important factor for the brownfield redevelopment decision-making progress.

To conclude, brownfield redevelopments are profit driven projects for developers. With limited information availability, the overall situation of the region's brownfield redevelopments' effectiveness evaluation can hardly be considered at the time that redevelopment happens. It is suggested that this is one of the main reasons for the disagreement of real development time with the overall effectiveness evaluation order.

5.2 What is the stage of Waterloo Region in terms of brownfield redevelopment effectiveness and efficiency based on the analysis of evaluation results?

In order to determine the current stage of Waterloo Region, a hierarchy should be developed first for municipalities' performance in terms of redevelopment effectiveness and efficiency. A very basic principle of this hierarchy is that the closer a municipality is to the top

stage, the more tools for and awareness of it has with regard to brownfield redevelopment. Based on the US EPA's road map for understanding brownfields investigation and cleanup and the Federation of Canadian Municipalities brownfields redevelopment guidance, this study generates a five-level hierarchy for identifying municipalities' current stage of brownfield redevelopments (FCM, 2015; US EPA, 2005). An application example for the fifth stage is the SMARTe.org, which is an information sharing platform initiated by the U.S. Environmental Protection Agency (EPA) and the German Federal Ministry for Education and Research. The purpose of this website is to share information, available tools and technologies, evaluation procedures, and analysis methods (US EPA, 2002). The ideal situation of a municipality is to have both efficient supportive tools and effective management skills to plan, monitor, and manage brownfield redevelopment activities. The worst situation of a municipality is to be fully ignorant of brownfield redevelopment. Several stages in between are defined accordingly. Table 16 presents a five-level summary of municipalities' attitudes toward brownfield redevelopment.

Waterloo Region has financial support tools and technical consultations available for brownfield redevelopment projects. It follows the Provincial Planning Statement's guidance, has planning tools and policies guiding the repurposing of brownfields. The municipality also puts lots of efforts in changing the development patterns and saving farm lands and green spaces through designating community improvement areas in the Official Plan. What is more, the brownfields legislation amended six provincial acts, the Education Act, Environmental Protection Act, Municipal Act, Ontario Water Resources Act, Pesticides Act, and Planning Act (The Ministry of Municipal Affairs and Housing, 2004). These supports help removing the barriers on environmental liability, planning processing, and financing aspect of brownfield repurposing activities. When assessing the Region of Waterloo's actions and results regarding

brownfield redevelopments, the Region of Waterloo fits in the features of level IV municipalities. Waterloo Region has a full set of supportive tools, yet the effectiveness evaluation results provide evidences for both successful and unsuccessful implementations of resources for the support of brownfield redevelopments.

	Characteristics Description	Attitude About Brownfield Redevelopment	Milestone for Each Stage
I	Treat brownfield redevelopments as regular developments	Have not realized the problem with the existence of brownfields	---
II	Have community improvement designated areas, yet have very limited policy and financial support tools	Realize the importance of cleaning up the brownfields, yet provide very little solutions	Liability Closure
III	Encourage brownfield redevelopment region-wide through planning tools and have financial support from all levels of municipal government	Realize the importance of cleaning up the brownfields, and treat brownfield redevelopment as opportunities	Financial Incentives
IV	Thorough legal, policy, and financial supports for brownfield redevelopment activities	Try to obtain the most possible return from every redevelopment project, yet still lack monitoring and evaluating after redevelopment	Risk Management and Registration
V	All level IV's characteristics and full information accessibility for concerned parties.	Have a thorough guidance of the life cycle of brownfields (from cleanup to effectiveness analysis after redevelopment), and can obtain the most possible return from redevelopment investments	Coordination and Education

Table 16. Five Stages of the Government's Attitudes Towards Brownfield Redevelopment (FCM, 2015; US EPA, 2005)

The number of existing brownfields has exceeded the amount of resources available in the region in terms of brownfield cleanup. Evaluating the effectiveness of the previous brownfield recycling activities could provide an overall description of the redevelopments that are most worthy of supporting resources.

5.3 What is driving the brownfield redevelopment resource allocation in reality?

The resources in the brownfield redevelopment field include financial supports and technical advice. Financial assistance is available for environmental assessments and remediation related processes, which reflect the government's determination of improving the livability of the entire region. Also, there are region-wide programs that offer consultations about minimizing financial risk and ensuring short-term financial profitability (Region of Waterloo, 2015). However, the availability of brownfield redevelopment incentives across the entire region (Table 17) indicates that there is a spatial preference for allocation of supportive resources (Region of Waterloo, 2015). Denser areas have more choices of financial supports. Phase II ESA Grant for Brownfields and Brownfield Regional Development Charge Exemption are available for the entire region. Urban core areas have their own development charge exemptions, and townships do not receive any region-county join tax increment grants (Region of Waterloo, 2015).

	Phase II ESA Grant for Brownfields	Core Area Development Charge Exemptions (Region and City)	Brownfield Regional Development Charge Exemption	Joint Tax Increment Grant
Cambridge	✓	✓	✓	✓
Kitchener	✓	✓	✓	✓
Waterloo	✓		✓	✓
Townships	✓		✓	

Table 17. Development Incentives and Where They Apply (Region of Waterloo, 2015)

Without the initiation of a large-scale brownfield cleanup fund like it exists in the U.S., the remediation activities rely highly on the private sector. What is more, part of municipalities' financial supports for remediation activities come from property taxes. Therefore, the purpose of brownfiled redevelopment is to increase a municipality's revenue through increases from

property tax income. Redevelopment costs are mainly paid for through tax increment financing. This means that the current project costs are financed through the expected future increases in property tax revenue caused by the project. The future property tax increases are then used to pay off the credit that has financed the previous project. This mechanism leads to a focus on the economic impacts (i.e., property tax increases) of brownfield redevelopments. However, the current study encourages planners to consider contributions other than direct property tax base rise. For instance, cleaning up a brownfield likely has many environmental and social benefits that are difficult to capture through property tax increases.

Additionally, redevelopments which could make technical or political contributions to the brownfield redevelopment field receive more supporting resources. The Canadian Brownfield Network awards sites of outstanding sustainable remediation or technological innovations (Canadian Brownfields Network, 2016). These awards aim to promote the activities that made contributions to future remediation projects. To sum up, the brownfield redevelopment resource allocation in reality is a case-based decision-making process, which does not require a horizontal comparison among a group of redevelopment projects. The projects that have special characteristics in terms of their clean-up techniques or their social or economic contributions have higher possibility of receiving more assistance.

5.4 Which of the three models is the most suitable for the region's future use?

It is difficult to identify any one of the three models as the best evaluation model for brownfield redevelopment effectiveness evaluation, because different models could be suitable under different conditions. The equal weighted model provided a very straight-forward combination of all the criteria. The SMART weighted model provides a balance among the criteria that represent social, environmental, and economic impacts. The AHP weighted model

uses a half black-box weight assigning system, which allows more than one concerned participant to be involved in the evaluation process. The equal weighted mechanism and the SMART mechanism are two models, which are useful for general evaluation, whereas the AHP weighted model might be more objective in terms of the evaluation's perspectives.

In this study, SMART weighted model has higher sensitivity and lower uncertainty (highest uncertainty score) compared to the other two evaluation models. That is to say, the SMART weighted model's inputs could provide a better evaluating range, and the evaluation result of this model cannot be easily reversed by changing inputs. While considering both the reliability of the primary inputs analysis and the robustness of the outputs, the SMART weighted model might be the most suitable method for providing Waterloo Region's brownfield redevelopment effectiveness evaluation.

5.5 What are the limitations of using a multi-criteria evaluation model for brownfield redevelopments' evaluation?

Integrating multi-criteria analysis into brownfield redevelopments' effectiveness evaluation can provide an overall picture for a relatively large spatial scale. Instead of providing an in-depth case study for each brownfield, this modeling procedure can provide a comparison for all redevelopment projects' effectiveness within a region. A large-scale brownfield redevelopment effectiveness evaluation can also help municipalities assessing the performance of their redevelopment support tools. However, there are also disadvantages of integrating multi-criteria analysis with brownfield redevelopment effectiveness evaluation.

The first limitation is data availability. Performing multi-criteria analysis requires numeric variables that represent all the evaluation aspects. The more criteria involved in the

evaluation, the more effort is required for data collection. Other than the environmental aspect criteria, which are calculated based on the analysis of the spatial distribution of natural factors, social and economic criteria are all estimations. For instance, all the social aspects' criteria in this study are derived from the past twenty years of census surveys. The national census survey happens every five years, yet the redevelopment activities happen every year. Social characteristics such as population density, employment density, and unit density of the brownfields' surrounding neighbourhoods at the redevelopment time are all estimates based on the census data. What is more, the property tax base rises of the brownfield redevelopment projects are estimated based on the properties' current value and the inflation rate. If the data quality of these input data could be improved, the uncertainty of the models' input would be reduced.

In addition, the brownfield redevelopment projects could have different evaluation results when taking different perspectives. This study conducts the evaluation from the municipal government's viewpoint. In order to consider thoroughly the government's perspective, all possible impacts from redevelopment projects should be included in the evaluation model. The municipal government could use the evaluation results to analyze their brownfield redevelopment support programs' efficiency. Having a brownfield information database and an evaluation model in the future will help the municipality during the brownfield redevelopment decision-making progress.

However, decisions are made by people. An evaluation assessment can be conducted from one perspective or another, such as from a developer's point of view. Some developers might see brownfields in their derelict state as opportunities. Instead of remediating a brownfield site, developers might purchase the site, hold it as a contaminated site, wait for the

property value to increase, and then resell the property for profit. The current multi-criteria evaluation model cannot capture or predict such behavior. Given the common good interest in the cleaning up of brownfield sites, policies that help enforce actual remediation through effectiveness evaluation should be established.

Finally, the sensitivity analysis and uncertainty analysis are associated with the multi-criteria evaluation to ensure the reliability of the models' inputs and the robustness of the models' outputs. This study selected very basic quantitative methods to analyze the models' sensitivity and uncertainty. Future improvements of these models might be integrated with more advanced sensitivity and uncertainty analysis methods.

5.6 What options exist for improvements to the brownfield redevelopment evaluation model?

A good modeling process has three characteristics: "more robust parameter estimation, less complex formulations, and fewer modelling assumptions" (Eynaud et al, 2013). Thus, improving the input accuracy, reducing the modeling complexity, and making less assumptions are the three methods that can improve the evaluation models' performances.

Because of the limited data availability for this study, the estimation of the input criteria can hardly be improved. The assumptions for this study cannot be easily reduced for the same reason. One possible way to improve the evaluation model is to simplify the models through removing the redundant criteria. Out of the three higher-level aspects in the entire evaluating process, the social aspect has the greatest possibility of having correlated criteria. For example, usually an area that has a higher dwelling density also has a larger population density. Even though the brownfield redevelopment projects could have separate impacts on people and the

housing market in the surrounding neighbourhood, there might be a correlation between these two criteria.

Furthermore, the Akaike information criterion (AIC) is a method used in previous studies that could help identifying the efficiency of a set of statistical models (Bozdogan, 1987; Akaike, 2011). The AIC measures a group of models' efficiency through comparing the goodness of their outputs and their complexity. The next step of improving the evaluation models could be involving the AIC as part of the most suitable model selection progress.

Chapter 6. Conclusion and Recommendations

6.1 Summary of Research Findings

Brownfields have become a popular topic for contemporary urban development. These abandoned or idle contaminated sites not only become potential environmental hazards for the surrounding areas, but also influence the health of people who live in the area. As more and more people realize the threats from the existence of brownfield sites, brownfield cleanup activities also become a large concern for municipal governments. Brownfields also provide new opportunities for urban development. Since decelerating urban sprawl becomes a planning goal, brownfields located in urban centres offer alternatives to developing suburban and rural areas. These benefits of brownfield redevelopments make the governments not only increase their attention on encouraging brownfield repurposing activities, but also provide more legal, technical, and financial supports.

As the number of brownfield redevelopments increases, the resources provided by the government are not enough for cleaning up all existing brownfields at the same time. Multi-criteria evaluation models can combine all the important aspects of brownfield redevelopment projects into one matrix, which then can be used to assess the overall effectiveness of brownfield recycling activities. Studying the effectiveness of previously redeveloped brownfields may help the region have a better understanding of their current stage of brownfield redevelopment and increase their land use efficiency.

Through creation of a database of brownfield redevelopment projects within the Region of Waterloo, the new purposes of redevelopment projects, redevelopments' site-specific information (i.e. estimated property values), associated with their surrounding neighbourhoods' social and environmental characteristics have been put together. Half of the brownfields within

the Waterloo Region was converted into residential areas. The remaining half was converted into commercial usage, institutional usage, and mixed use areas. According to the evaluation models' results, the previously redeveloped brownfields' effectiveness does not agree with their redevelopment time. Also, the best performing redeveloping projects are all conversions from brownfields into residential areas, whereas the projects that were performing worst were all located in rural settlements. The Region of Waterloo has legal and technical consultation services available for all brownfield sites regardless their locations. However, some of the financial support programs are only available for urban centres. The disagreement between the redevelopments' effectiveness and their real redevelopment time also provides evidences for inefficient allocation of supporting resources.

6.2 Research Limitation Discussion

First of all, the input data's accuracy will have impacts on the modelling process' performance. If the estimation of each criterion's value would be improved, the effectiveness evaluation results could be enhanced. Each of the three models that were applied have benefits and weaknesses: Out of three models, the equal weighted model is the most straightforward evaluation model. However, the inter-relationships among selected criteria might influence the representativeness of the evaluation output. The SMART weighted model uses a top-down approach. It first distributes the weights equally to a higher-level classification, and then assigns the weights equally into each class. Here, the classification of criteria plays an important role in the model. The AHP weighted model can translate non-numeric opinions into values, and merge multiple participants' opinions. However, the lack of participants might reduce the robustness of the AHP weighted model's output.

An additional limitation relates to the use of density variables. Adopting density as an indicator for social factors can avoid the uncertainty caused by choosing arbitrary spatial scales to assess the impacts of redevelopment projects. However, the inter-relationships among density variables (i.e., population density, employment density, and unit density) might affect the models' overall performance. For example, the density of units may increase while the population density may decrease because of gentrification effects. Therefore, the simple assumption that positive impacts will show through increases in all density variables may not be correct.

Also, this study only has assessed the effectiveness of a brownfield redevelopment at the local level. Indicators for brownfield redevelopments' effectiveness considered included the amount of people who live and work locally and the number of local units that are impacted by the redevelopments. However, the benefits from redevelopments can be much more extensive and therefore depend on the study scale. For instance, the surrounding neighborhood's property values may be impacted, but this effect has not been included in the current study. In this study effectiveness was assessed by asking the question "how large were the impacts?" instead of "what kinds of impacts did redevelopments have?". This latter question is much more explorative and may have required a qualitative research approach.

Generally, the applied modelling process was a simplification of the real world situation. The performed evaluations of redevelopments' effectiveness will not reflect perfectly how these redevelopments performed and how they affected their surroundings. However, the performed evaluations provide a rational approach for brownfield performance assessment within Waterloo Region. Even though this study has some limitations, its results still convey important information.

6.3 Research Contributions

Among all urban development studies that relate to brownfields redevelopments, there were many studies that focused on brownfield related police analysis, legal barriers, environmental justice questions, and investment method innovations. There were also studies that covered new techniques of clean-up process, new purposes for brownfield redevelopments, case studies of specific brownfield redevelopment projects, and so on. Most of the studies were located in the U.S. and the U.K. because of the brownfield related information accessibility. This study combined the information from the Canadian Brownfield Network, the Ontario Records of Site Condition Registration Program, and redevelopment projects' documents from individual planning firms to build a Region of Waterloo brownfield redevelopment database. This database can provide a basis for future brownfield related studies in the region.

Additionally, very little the brownfield redevelopment related studies performed large-scale effectiveness evaluation of redeveloped brownfields. Only based on the dataset generated in this study, the effectiveness evaluation of previous brownfield redevelopments within the Region of Waterloo could be conducted. The effectiveness evaluation result may not only help the municipal government review their previous approvals' efficiency, but also improve the efficiency of the region's future resource allocation processes.

6.4 Recommendations for Future Research

The evaluation results of this study show evidence of inefficient brownfield redevelopment resource allocation within the Region of Waterloo during the past several decades. If more advanced techniques were used for improving the criteria estimation, the accuracy of the brownfield redevelopment effectiveness evaluation could be improved.

The data scheme required by the effectiveness evaluation in this study is similar to some of the prioritizing indices that help decision-makers compare and choose suitable brownfields (Chrysochoou, Brown, & Dahal, 2012). Evaluating the redevelopments' effectiveness afterwards may help municipalities evaluating their previous performances. Such evaluations could also be performed on currently existing brownfields, which could improve the efficiency of the allocation of resources in support of brownfield redevelopment.

It is expected that in the future, information accessibility about brownfield redevelopment activities will be improved and that more efficient resources allocation mechanisms will be implemented. These improvements, however, require the collaboration of multiple stakeholders. Not only should regional brownfields datasets be built, but the same should be done on the national level so that land resources can be used more efficiently during the contemporary rapid urban development processes.

6.5 Concluding Thoughts

The brownfield redevelopment topic is interesting yet challenging. The generation of a historic brownfields databank filled in the knowledge gap about brownfield redevelopments within the Region of Waterloo. The multi-criteria evaluation model provided a mechanism for regional scale brownfield redevelopment effectiveness evaluation. Also the effectiveness evaluation results concluded from the modeling process helped identifying the best performing redevelopment projects and realizing the overall performance of programs in support of redevelopments. It is hoped that this research will provide some contributions for future studies on the brownfield redevelopment topics in Canadian cities.

References:

Akaike, H. (2011). Akaike's Information Criterion. In *International Encyclopedia of Statistical Science*, 25.

Alberini, A., Longo, A., Tonin, S., Trombetta, F., & Turvani, M. (2005). The Role Of Liability, Regulation And Economic Incentives in Brownfield Remediation and Redevelopment: Evidence from Surveys of Developers. *Regional Science and Urban Economics, 35* (4), 327-351.

Alker, S., Joy, V., Roberts, P., & Smith, N. (2000). The Definition of Brownfield. *Journal of Environmental Planning and Management, 43* (1), 49-69.

ArcGISonline. (2016). Find Hot Spots. *ArcGIS Online Help*. Retrieved on 5/13/17 from: http://doc.arcgis.com/en/arcgis-online/analyze/find-hot-spots.htm

Bacot, H., & O'Dell, C. (2006). Establishing Indicators to Evaluate Brownfield Redevelopment. *Economic Development Quarterly, 20* (2), 142-161.

Bartsch, C. (2002). Financing Brownfield Cleanup and Redevelopment. *Government Finance Review, 18* (1), 26-31.

Bjelland, M. D. (2004). Reclaiming Brownfield Sites: From Toxic Legacies to Sustainable Communities. In M. D. Bjelland, *WorldMinds: Geographical Perspectives on 100 Problems* (pp. 197-202). Springer Netherlands.

Bliek, D., & Gauthier, P. (2007). Mobilising Urban Heritage to Counter the Commodification of Brownfield Landscapes: Lessons from Montreal's Lachine Canal. *Canadian Journal of Urban Research, 16* (1), 39.

Bozdogan, H. (1987). Model Selection and Akaike's Information Criterion (AIC): The General Theory and its Analytical Extensions. *Psychometrika, 52* (3), 345-370.

Buglife. (2009). *Planning for Brownfield Biodiversity: A Best Practice Guide.* Retrieved 4 1, 2016, from Buglife - The Invertebrate Conservation Trust: https://www.buglife.org.uk/sites/default/files/Planning%20for%20Brownfield%20Biodiversity.pdf

Canadian Brownfields Network. (2016). *Canadian Brownfields Network*. Retrieved 1 01, 2016, from Brownfield Awards: https://canadianbrownfieldsnetwork.ca/brownfield-awards

Canadian Real Estate Association. (2015). *Redeveloping Brownfields.* Retrieved 3 21, 2015, from Information for Realtors: http://www.mah.gov.on.ca/AssetFactory.aspx?did=5248

Chen, H., Wood, M. D., Linstead, C., & Maltby, E. (2011). Uncertainty Analysis in a Gis-Based Multi-Criteria Analysis Tool for River Catchment Management. *Environmental Modelling & Software, 26* (4), 395-405.

Chrysochoou, M., Brown, K., Dahal, G. et al. (2012) A GIS and Indexing Scheme to Screen Brownfields for Area-wide Redevelopment Planning. *Landscape and Urban Planning* 105:187-198. Doi: 10.1016/j.landurbplan.201 1.12.010.

City of Cambridge. (2012). *Zoning Bylaw No 150-85.* Cambridge: City of Cambridge.

City of Kitchener. (2015). *Living in Kitchener: Water Management*. Retrieved 3 21, 2015, from City of Kitchener Official Website: http://www.kitchener.ca/en/livinginkitchener/WaterManagement.asp

City of Kitchener. (2004). *Zoning By Law 85-1.* Kitchener: City of Kitchener.

City of Waterloo. (2012). *Zoning Bylaw No. 1418 as Amended.* Waterloo: City of Waterloo.

Dair, C. M., & Williams, K. (2006). Sustainable Land Reuse: The Influence of Different Stakeholders in Achieving Sustainable Brownfield Developments in England. *Environment and Planning A, 38* (7), 1345.

Davies, L. L. (1999). *Working Toward a Common Goal: Three Case Studies of Brownfields Redevelopment in Environmental Justice Communities.* Stan. Envtl.

De Sousa, C. A. (2004). The Greening of Brownfields in American Cities. *Journal of Environmental Planning and Management, 47* (4), 579-600.

De Sousa, C. A. (2006). Urban Brownfields Redevelopment in Canada: The Role of Local Government. *The Canadian Geographer/Le Géographe Canadien, 50* (3), 392-407.

De Sousa, C. A., Wu, C., & Westphal, L. M. (2009). Assessing the Effect of Publicly Assisted Brownfield Redevelopment on Surrounding Property Values. *Economic Development Quarterly*, 1-16.

De Sousa, C. (2000). Brownfield Redevelopment Versus Greenfield Development: A Private Sector Perspective on the Costs and Risks Associated with Brownfield Redevelopment in The Greater Toronto Area. *Journal of Environmental Planning and Management, 43* (6), 831-853.

De Sousa, C. (2001). Contaminated Sites: The Canadian Situation in an International Context. *Journal of Environmental Management, 62* (2), 131-154.

Deason, J., Sherk, W., & Carroll, G. A. (2001). Public Policies and Private Decisions Affecting the Redevelopment of Brownfields: An Analysis of Critical Factors, Relative Weights and Real Differentials. *The U.S. Environmental Protection Agency, Washington, D.C.*

Department of the Environment, Transport, and the Regions. (2014, 10 28). *National Land Use Database of Previously Developed Land*. Retrieved 3 20, 2015, from Government of UK: https://www.gov.uk/government/collections/national-land-use-database-of-previously-developed-land-nlud-pdl

Doick, K. J., Sellers, G., Castan-Broto, V., & Silverthorne, T. (2009). Understanding Success in the Context of Brownfield Greening Projects: The Requirement for Outcome Evaluation in Urban Greenspace Success Assessment. *Urban Forestry & Urban Greening, 8* (3), 163-178.

Duarte, D., Gonçalves, J. C., & Monteiro, L. M. (2006, 9). Environment and Urbanization: Microclimatic Variations in a Brownfield Site in Sao Paulo, Brazil. *In 23rd International Conference PLEA*, pp. 497-503.

Eastman, J. R. (1999). Multi-Criteria Evaluation and GIS. *Geographical Information Systems, 1* (1), 493-502.

Eynaud, Y., Nerini, D., Baklouti, M., & Poggiale, J. C. (2013). Towards a Simplification of Models Using Regression Trees. *Journal of The Royal Society Interface, 10* (79), 20120613.

FCM. (2015). *Green Municipal Fund.* Retrieved 10 1, 2016, from Getting Started on Your Brownfield Sites: Committing to Action: http://www.fcm.ca/Documents/brochures/LiBRe/LiBRe_Guidebook_Committing_to_action_EN.pdf

Force, U. T., Britain, G., & Rogers, R. G. (1999). Towards an Urban Renaissance. *London: Spon*.

Government of Ontario. (2009, 12 09). *Environemntal Protection Act.* Retrieved 3 20, 2015, from Ontario Regulation 511/09: Records of Site Condition: Part XV.1 of the Act: http://www.e- laws.gov.on.ca/html/source/regs/english/2009/elaws_src_regs_r09511_e.htm#Top

Government of Ontario. (2006, 7 16). *Ministry of Municipal Affairs and Housing.* Retrieved 5 10, 2016, from Growth Plan of the Greater Golden Horseshoe: https://www.placestogrow.ca/index.php?option=com_content&task=view&id=9&Itemid=14

Government of Ontario. (2011, 7 1). *Ontario Environment and Energy*. Retrieved 1 30, 2016, from Records of Site Condition: https://www.ontario.ca/environment-and-energy/records-site-condition

Government of Ontario. (2014). *Provincial Policy Statement.* Retrieved from Ontario Ministry of Municipal Affairs and Ministry of Housing.

Green, F., & Letsch, C. (2014, 9 21). New High Line Section Opens, Extending the Park to 34th St. *Daily News*.

Greenberg, M. R., & Issa, L. (2005). Measuring the Success of the Federal Government's Brownfields Program. *Remediation Journal, 15* (3), 83-94.

Greenberg, M., Craighill, P., Mayer, H., Zukin, C., & Wells, J. (2001). Brownfield Redevelopment and Affordable Housing: A Case Study of New Jersey. *Housing Policy Debate, 12* (3), 515-540.

Greenberg, M., Lowrie, K., Mayer, H., Miller, K. T., & Solitare, L. (2001). Brownfield Redevelopment as a Smart Growth Option in the United States. *Environmentalist, 21* (2), 129-143.

Hamby, D. M. (1996). Site Remediation Techniques Supporting Environmental Restoration Activities: A Review. *Science of The Total Environment, 191* (3), 203-224.

Hansen, P., & Jaumard, B. (1997). Cluster Analysis and Mathematical Programming. *Mathematical Programming, 79* (1-3), 191-215.

Harrison, C., & Davies, G. (2002). Conserving Biodiversity That Matters: Practitioners' Perspectives on Brownfield Development and Urban Nature Conservation in London. *Journal of Environmental Management, 65* (1), 95-108.

Hayek, M., Novak, M., Arku, G., & Gilliland, J. (2010). Mapping Industrial Legacies: Building a Comprehensive Brownfield Database in Geographic Information Systems. *Planning, Practice & Research, 25* (4), 461-475.

Ho, W., Xu, X., & Dey, P. K. (2010). Multi-Criteria Decision Making Approaches for Supplier Evaluation and Selection: A Literature Review. *European Journal of Operational Research, 202* (1), 16-24.

Howland, M. (2007). Employment Effects of Brownfield Redevelopment: What Do We Know from Literature? *Journal of Planning Literature, 22* (2), 91-107.

Howland, M. (2003). Private Initiative and Public Responsibility for the Redevelopment of Industrial Brownfields: Three Baltimore Case Studies. *Economic Development Quarterly, 17* (4), 367-381.

Hunter, P. (2014). Brown is the New Green: Brownfield Sites Often Harbour a Surprisingly Large Amount of Biodiversity. *EMBO Reports, 15* (12), 1238-1242.

Kattwinkel, M., Biedermann, R., & Kleyer, M. (2011). Temporary Conservation for Urban Biodiversity. *Biological Conservation, 144* (9), 2335-2343.

Klutho, S. (2013). Mathematical Decision Making. *An Overview of the Analytic Hierarchy Process*.

Koch, T. B. (1998). Betting on Brownfields--Does Florida's Brownfields Redevelopment Act Transform Liability into Opportunity. *Stetson L. Rev., 28*, 171.

Lange, D., & McNeil, S. (2004). Clean It and They Will Come? Defining Successful Brownfield Development. *Journal of Urban Planning and Development, 130* (2), 101-108.

Lange, D., Wang, D., Zhuang, Z., & Fontana, W. (2013). Brownfield Development Selection Using Multiattribute Decision Making. *Journal of Urban Planning and Development, 140* (2), 04013009.

Lesage, P., Deschênes, L., & Samson, R. (2007). Evaluating Holistic Environmental Consequences of Brownfield Management Options Using Consequential Life Cycle Assessment for Different Perspectives. *Environmental Management, 40* (2), 323-337.

Li, J., Zhang, P. Y., Guo, M., Guan, L. M., & Liu, X. W. (2010). Spatial-Temporal Characteristic of Urban Land Expansion in Harbin and Driving Mechanism Analysis. *Urban Environment & Urban Ecology, 23* (6), 1-4.

Ligmann-Zielinska, A., & Jankowski, P. (2008, 9). A Framework for Sensitivity Analysis in Spatial Multiple Criteria Evaluation. *In International Conference on Geographic Information Science*, 217-233.

Linkov, I., Welle, P., Loney, D., Tkachuk, A., Canis, L., Kim, J., et al. (2011). The Use of Multi-Criteria Decision Analysis Methods to Support Weight of Evidence Evaluation in Risk Assessment. *Risk Analysis, 31*, 1211-1225.

Liu, K. F., Hsu, C.-Y., Yeh, K., & Chen, C.-W. (2011). Hierarchical Analytic Network Process and Its Application in Environmental Impact Evaluation. *Civil Engineering and Environmental Systems, 28* (1), 1-18.

Lomas-Jylha, T. (2004). *Canadian Brownfields and Guidance for Effective Redevelopment.* Canadian Brownfields Network, About Remediation, Mississauga.

McCarthy, L. (2002). The Brownfield Dual Land-Use Policy Challenge: Reducing Barriers to Private Redevelopment While Connecting Reuse to Broader Community Goals. *Land Use Policy, 19* (4), 287-296.

McMillan Binch LLP. (2008). *McMillan Binch LLP.* Retrieved 11 1, 2016, from Brownfield Tool Kit: http://www.mcmillan.ca/Files/Brownfield_Toolkit_0405.pdf

Meyer, P. B., & Lyons, T. S. (2000). Lessons from Private Sector Brownfield Redevelopers: Planning Public Support for Urban Regeneration. *Journal of the American Planning Association, 66* (1), 46-57.

OCETA. (2008, 3 31). State of Canada's Brownfield Redevelopment Industry: A Review of Canada's Progress in Response to the National Round Table on the Environment and the Economy's 2003 National Brownfield Redevelopment Strategy. Ottawa, Ontario, Canada.

Office of the Provincial Brownfields Coordinator. (2010). *Municipal Financial Incentives for Brownfield Redevelopment Trends among Ontario Municipalities.* Retrieved 10 23, 2016, from Ontario Ministry of Municipal Affairs and Housing: http://www.mah.gov.on.ca/AssetFactory.aspx?did=9590

Ontario Commercial Brokers. (2016). *Ontario Commercial Real Estate Database I.* Retrieved 08 31, 2016, from http://www.iciworld.ca/citiesON.shtml

Ontario Ministry of Infrastructure. (2013, 6). *Growth Plan for the Greater Golden Horseshoe.* Retrieved 5 01, 2016, from Growth Plan for the Greater Golden Horseshoe Office Consolidation: https://www.placestogrow.ca/content/ggh/2013-06-10-Growth-Plan-for-the-GGH-EN.pdf

Page, G. W., & Rabinowitz, H. Z. (1994). Potential for Redevelopment of Contaminated Brownfield Sites. *Economica Development Quarterly, 8* (4), 353-363.

Paull, E. (2008). *The Environment and Economic Impacts of Brownfield Redevelopment.* Northeast Midwest Institute. Northeast Midwest Institute.

Pediaditi, K., Doick, K. J., & Moffat, A. J. (2010). Monitoring and Evaluation Practice for Brownfield, Regeneration to Greenspace Initiatives: A Meta-Evaluation of Assessment and Monitoring Tools. *Landscape and Urban Planning, 97* (1), 22-36.

Planning and Economic Development Department, City of Hamilton. (2007, 12 12). Hamilton's Redevelopment Prioritization Strategy and Recommended Application of Province's $3 Million Brownfields Contribution (PED08015) (City Wide). Hamilton, Ontario, Canada. Retrieved from http://www2.hamilton.ca/NR/rdonlyres/29C5175F-87CE-4D9F-9C6B-1AE58CEFF9E7/0/Jan15PED08015.pdf

Poole, D., & Mackworth, A. (2010). *Artificial Intelligence Foundations of Computational Agents*. Retrieved 5 01, 2016, from Case-Based Reasoning: http://artint.info/html/ArtInt_190.html

Poole, M. A., & O'Farrel, P. N. (1971). The Assumptions of the Linear Regression Model. *Transactions of the Institute of British Geographers*, 145-158.

Rall, E. L., & Haase, D. (2011). Creative Intervention in a Dynamic City: A Sustainability Assessment of an Interim Use Strategy for Brownfields in Leipzig, Germany. *Landscape and Urban Planning, 100* (3), 189-201.

Region of Waterloo. (2015). *Brownfields & Incentives.* Retrieved 09 31, 2016, from Region of Waterloo Development: http://www.regionofwaterloo.ca/en/doingbusiness/brownfieldsincentives.asp

Region of Waterloo. (2016, 3 4). *Brownfields: Moving Projects Forward.* Retrieved 7 1, 2016, from The Breithaupt Block Kitchener, ON: https://www.fcm.ca/Documents/presentations/2016/webinars/Moving_Projects_Forward_The_Breithaupt_Block_Kichener_ON_EN.pdf

Region of Waterloo. (2015). *Regional Offical Plan.* Retrieved 5 12, 2016, from Region of Waterloo: http://www.regionofwaterloo.ca/en/regionalGovernment/PreviousROP.asp

Regional Analytics Inc. (2002, 11 15). A Preliminary Investigation into the Economic Impact of Brownfield Redevelopment Activities in Canada. Ottawa, Ontario, Canada.

Saaty, R. W. (1987). The Analytic Hierarchy Process -- What It Is and How It Is Used. *Mathematical Modelling, 9* (3), 161-176.

Saaty, T. L. (2004). Decision Making-- The Analytic Hierarchy and Network Processes (AHP/ANP). *Journal of Systems Science and Systems Engineering, 13*(1), 1-35.

Schädler, S., Morio, M., Bartke, S., Rohr-Zaenker, R., & Finkel, M. (2011). Designing Sustainable and Economically Attractive Brownfield Revitalization Options Using an Integrated Assessment Model. *Journal of Environmental Management, 92* (3), 827-837.

Siikamäki, J., & Wernstedt, K. (2008). Turning Brownfields Into Greenspaces: Examining Incentives and Barriers to Revitalization. *Journal of Health Politics, Policy and Law, 33* (3), 559-593.

State of Massachusetts. (2011). *Smart Growth Toolkit*. Retrieved 09 20, 2016, from Brownfield Redevelopment: http://www.mass.gov/envir/smart_growth_ toolkit/pages/mod-brownfields.html

Statistics Canada. (2015, 11 27). *Census Tract (CT).* Retrieved 3 21, 2016, from Reference Material 2011 Census Dictionary: https://www12.statcan.gc.ca/census-recensement/2011/ref/dict/geo013-eng.cfm

Statistics Canada. (2016). *Dwelling.* Retrieved from Statistics Canada Definitions, Data Sources, and Methods: http://www.statcan.gc.ca/eng/concepts/definitions/privdwel

Strauss, B., & Biedermann, R. (2006). Urban Brownfields As Temporary Habitats: Driving Forces for the Diversity of Phytophagous Insects. *Ecography, 29* (6), 928-940.

Sun, W., & Jones, B. (2013). Using Multi-Scale Spatial and Statistical Analysis to Assess the Effects of Brownfield Redevelopment on Surrounding Residential Property Values in Milwaukee County, USA. *Moravian Geographical Reports, 21* (2), 56-64.

Syms, P. (1999). Redeveloping Brownfield Land: The Decision-Making Process. *Journal of Property Investment & Finance, 17* (5), 481-500.

Taylor, Z., & Nostrand, J. V. (2008). *Shaping the Toronto Region's Past, Present, and Future.* University of Toronto. NEPIS The Architecture of Urban Regions.

The Ministry of Municipal Affairs and Housing. (2004). *Brownfields Showcase II.* Retrieved 11 01, 2016, from Opportunities in Our Own Backyard: http://www.mah.gov.on.ca/AssetFactory.aspx?did=4860

The U.S. Conference of Mayors. (2000). A National Report on Brownfields Redevelopment. *Recycling America's Land*.

The U.S. Congress. (1980). CERCLA Comprehensive Environmental Response, Compensation, and Liability Act of 1980. *An Act to Provide for Liability, Compensation, Cleanup, and Emergency Response for Hazardous Substances Released into the Environment and the Cleanup of Inactive Hazardous Waste Disposal Sites.*

Thomas, M. R. (2002). A GIS-Based Decision Support System for Brownfield Redevelopment. *Landscape and Urban Planning, 58* (1), 7-23.

Tiedemann, K. H., Beriatos, E., & Brebbia, C. A. (2008, 4). Brownfield Site Rehabilitation: A Canadian Perspective. *In Fourth International Conference on Prevention, Assessment, Rehabilitation and Development of Brownfield Sites*, 15-42.

Township of North Dumfries. (2012). *Zoning Bylaw 689-83.* Township of North Dumfries.

Triantaphyllou, E., & Sánchez, A. (1997). A Sensitivity Analysis Approach for Some Deterministic Multi-Criteria Decision-Making Methods. *Decision Sciences, 28* (1), 151-194.

U.S. Environmental Protection Agency. (2011, 10 4). *Brownfield and Land Revitalization.* Retrieved 3 20, 2015, from EPA US Environmental Protection Agency: https://www.epa.gov/brownfields/overview/glossary

UK Government. (2013, 06 11). *Opening up Government*. Retrieved 05 20, 2015, from Brownfield Sites: https://data.gov.uk/dataset/brownfield-sites

UK National Ecosystem Assessment. (2009). *Concepts Related to Ecosystem*. Retrieved 10 2015, from UK National Ecosystem Assessment: http://uknea.unep-wcmc.org/EcosystemAssessmentConcepts/EcosystemServices/tabid/103/Default.aspx

US Environmental Protection Agency. (2012, 7 16). *Brownfields Laws and Regulations.* Retrieved 3 20, 2015, from EPA US Environmental Protection Agency: https://www.epa.gov/brownfields/brownfields-laws-and-regulations

US EPA. (2003). *Environmental Modeling*. Retrieved 9 1, 2016, from Sensitivity and Uncertainty Analysis: https://www.epa.gov/modeling/sensitivity-and-uncertainty-analyses-training-module

US EPA. (2016, 3 9). *EPA US Environment Protection Agency*. Retrieved 5 20, 2016, from Cleanups in My Community: https://www.epa.gov/cleanups/cleanups-my-community

US EPA. (2012). *Instructions for Completing Brownfields Property Profile from General Instructions.* Retrieved 5 20, 2016, from US Environmental Protection Agency: https://www.epa.gov/sites/production/files/2015-05/documents/2012-property-profile-form-instructions-draft-for-approval.pdf

US EPA. (2005). *Road Map to Understanding Innovative Technology Options for Brownfields Investigation and Cleanup.* Retrieved 10 23, 2016, from https://clu-in.org/download/misc/roadmap4.pdf

US EPA. (2002). *SMARTe.org.* Retrieved 9 1, 2016, from SMARTe Development Status: http://www.smarte.org/smarte/home/index.xml

Wang, Q. (2011). *Facilitating Brownfield Redevelopment Projects: Evaluation, Negotiation, and Policy.* University of Waterloo, System Design Engineering. Waterloo: University of Waterloo.

Wang, Q., Hipel, K. W., & Kilgour, D. M. (2008). Conflict Analysis in Brownfield Redevelopment: The Erase Program in Hamilton, Ontario. In Systems, Man and Cybernetics. *IEEE International Conference*, 2913-2918.

Wcisło, E., Ioven, D., Kucharski, R., & Szdzuj, J. (2002). Human Health Risk Assessment Case Study: An Abandoned Metal Smelter Site in Poland. *Chemosphere, 47* (5), 507-515.

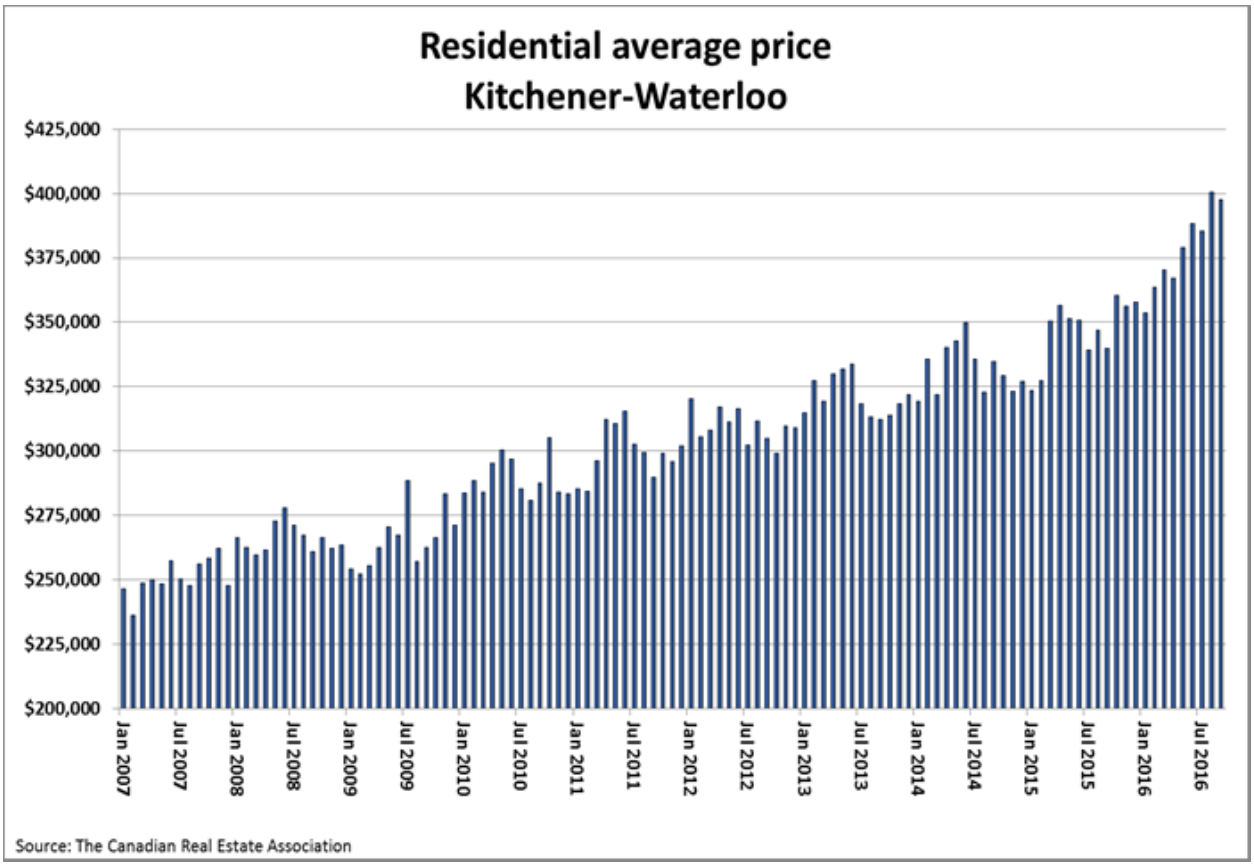
Wedding, G. C., & Crawford-Brown, D. (2007). Measuring Site-Level Success in Brownfield Redevelopments: A Focus on Sustainability and Green Building. *Journal of Environmental Management, 85* (2), 483-495.

Whitney, H. (2003). Cities and Superfund: Encouraging Brownfield Redevelopment. *Ecology LQ, 30*, 59.

Yount, K. R., & Meyer, P. B. (1999). Project Scale and Private Sector Environmental Decision Making: Factors Affecting Investments in Small- and Large-Scale Brownfield Projects. *Urban Ecosystems, 3* (2), 179-193.

Zimmermann, H. J. (2010). Fuzzy Set Theory. *Wiley Interdisciplinary Reviews: Computational Statistics, 2* (3), 317-332.

Appendix A: Housing Market Price and Inflation Rate



Source: http://www.crea.ca/

Historical Inflation Rate Canada								
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
CPI Canada	2.72%	2.53%	2.26%	2.77%	1.86%	2.21%	2.01%	2.14%
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
CPI Canada	2.37%	0.31%	1.78%	2.91%	1.52%	0.94%	1.91%	1.13%

Source: http://www.inflation.eu/inflation-rates/canada/historic-inflation/cpi-inflation-canada.aspx

Appendix B: An Example of Brownfield Redevelopment Data Sources

RESIDENTIAL INTENSIFICATION

CASE STUDIES

Built Projects

SEAGRAM LOFTS — Waterloo, Ont.

3 and 5 Father David Bauer Dr.

Developer
Barrel Works Group Ltd.
(Terra View Homes, with Kiwi Newton Construction)
Date completed
2001
Site area
1.09 ha (2.7 acres)
Number, type of residential units
103 loft-style condominium units;
40 in a seven-storey building,
63 in a 10-storey building.
Floor area
87 to 232 m² (935 to 2,500 sq. ft.)
Gross residential density
95 uph (units per hectare)
Landscaped open space
465 m² (5,000 sq. ft.) rooftop garden on each building
Maximum height
10-storey building 33.5 m (110 ft.)
Parking
153 total: 100 enclosed at grade,
53 open. Average 1.5 per unit.
Non-residential units
Live–work designation for entire site. Five units zoned commercial. Games room, gym, meeting space.
Pre-development usage
Distillery warehouses used to age up to 17,000 barrels of whisky.
Selling price
Starting at $150,000, average $216,377

Figure 1: Seagram Lofts, the redevelopment of two, former whisky-barrel warehouses in downtown Waterloo

Seagram Lofts is adaptive reuse of a brownfield site, which created residential property in the heart of Waterloo's downtown core from two, heritage, whisky-barrel warehouses. As part of downtown Waterloo's revitalization, the project was the subject of much public interest. The project created 103 loft-style condominium units with high ceilings and large windows. Complementing these features are original brick walls and barrel-wood, evoking the old warehouse feel.

Canada

CMHC SCHL

Q-1

Figure 2: The Seagram Distillers sign shows and commemorates the site's history.

PROJECT OVERVIEW

Seagram Lofts is situated on a portion of the former Seagram Lands, a parcel of more than 4.5 ha (11 acres). The Lands were originally developed in 1857 as a distillery. In the mid-20th century, Seagram added two huge warehouses for whisky barrels. The warehouses were the last structures left standing after a devastating fire in 1993. The 150-year history of the site and its connection to the growth of Waterloo were key factors in the City's decision to save the heritage buildings.

City of Waterloo staff worked closely with the developers to give the site new life while preserving the site's heritage. They offered incentives, such as waiving development charges, free road and utility infrastructure and assistance with environmental concerns.

Seagram Lofts is on a site slightly larger than one hectare. The site was given a major overhaul. The land was cleared and the warehouses gutted, leaving only the original brick end-walls. The developer's goal was to preserve the heritage exterior while creating an interior that mixed modern styles with the feel of the original warehouses. This was achieved by re-milling wood from whisky barrels and using it for doors, stairs, window casings and baseboards.

The area around the site is largely retail and residential and the buildings are only one block from King Street, the central downtown business district. The project is just blocks from a large recreation centre, a major park and a trail network. The convenience of being located within 10-minute walk of shopping and amenities is a big draw for many Seagram Lofts residents, many of whom prefer to walk whenever possible.

There is both enclosed and open parking, which provides residents with an average of 1.5 spaces per unit.

A 465 m^2 (5,000 sq. ft.) rooftop garden on each building is accessible to all residents. Each garden offers prime views of the downtown and region.

PROJECT SUCCESS: DEVELOPER'S PERSPECTIVE

We built the parking garages from the original timbers. We had 750 cubic metres of barrel timber so we milled it. We made our own doors, stairs, window casings and baseboards.
Andrew Lambden, Barrel Works Group Ltd.

The Seagram Lofts project was a challenge that was welcomed by the developers. Transforming old warehouses of this scale into attractive residential units is a monumental task, especially when trying to save only portions of the existing structure. The developer made great efforts to reuse much of the original brick and barrel-wood salvaged during selective demolition. This allowed the developer to retain the look and feel of the warehouses while actually creating almost brand-new buildings. The loft approach was utilized to enhance the warehouse atmosphere while also providing residents with the option of using their units as live–work studios.

Costs and financing

The project, financed entirely by the Royal Bank, cost $25 million. This was lower than it could have been due, in part, to measurable assistance and co-operation from the City of Waterloo. The site, purchased from the City, cost $1.1 million. The City agreed to treat $1 million of the purchase price as a vendor take-back mortgage at an interest rate of zero per cent. Under the terms of the vendor take-back mortgage, actual payment was deferred and the developer made periodic repayments to the City. The low purchase price, the vendor take-back mortgage, along with the absence of development charges and infrastructure costs, helped make the project feasible.

Development Costs	
Land and buildings	$ 1.1 million
Building construction	$ 21.6 million
Soft costs (e.g., taxes, DCCs, consultants)	$ 2.3 million
Infrastructure	$ 0 (paid by City of Waterloo)
Total	**$25 million**

Marketability and profitability

The downtown location and relatively higher purchase prices attracted mostly young professionals, but also included first-time buyers and older couples. This demographic was targeted using media such as newspapers, signage, the Internet and general community outreach. Salespeople with experience in the downtown market and buyer incentives were also instrumental in attracting prospective owners to Seagram Lofts.

Both buildings were 95 per cent sold-out within three years, which is considered a marketing success for such a large project. Some delays and additional costs involved in retaining heritage components resulted in slightly lower profit than expected. However, the exposure the developer gained from this high-profile project opened some doors and resulted in a few awards, such as Best Project of the Year (2000) from the Waterloo Region Home Builders' Association.

Obstacles

The major challenge to the development came not only with reconstructing the warehouses and selling the new units, but also with the initial risk and financial investment involved in a project of such scale. In this case, the financial risk was immense.

Heritage redevelopments are often extremely time-consuming, with many unexpected situations that result in additional costs. Seagram Lofts was hampered with unexpected costs connected with saving the warehouse facades.

The developers were fortunate that there were no significant public objections, because they can often cost time and money. The neighbourhood was able to comment through open houses and community consultations and endorsed the plan.

Figure 3: The enclosed parking garages (in front) incorporate timbers from the old warehouses.

Municipal support

As mentioned, the City of Waterloo council was unanimously in favour of the project and redevelopment.

With a project such as Seagram Lofts, with high upfront costs and profitability that is more difficult to achieve, the support of the municipality is fundamental to success. The developer said: "Waterloo has invested in the downtown area. There is a lot of political will and staff support…and the City readily provided assistance that was absolutely necessary for this type of project."

Lessons learned

When embarking on a project of this size and stature, the political and economic environment has to be suitable to achieve success. Shared visions and goals between the developer and the municipality are also key elements in a necessary partnership. Unique projects like Seagram Lofts are financially risky, but also personally rewarding and reputation-building. Developers, therefore, need to have the dedication and interest to succeed.

PROJECT SUCCESS: RESIDENTS' PERSPECTIVE

> *They've done a nice job. The buildings were brought back to life; units incorporate original brick and the old wooden racking from the whisky barrels. I picked [Seagram Lofts] because of the character and style.*
> ***Resident***

Affordability

Seagram Lofts suites range in size from 87 m^2 (935 sq. ft.) to penthouses as large as 232 m^2 (2,500 sq. ft.) Residents say that the costs were not high, considering the prime downtown Waterloo location, accessibility to almost every need, esthetic appeal and general convenience. The units initially started at $150,000 and averaged $216,777, although resident-approved upgrades and design features were incorporated at additional cost.

All of the residents surveyed were happy to pay what they did for their units and were impressed with the options and flexibility available to personalize the space. The zoning of ground floor units as commercial–residential allows for even greater opportunities to create a vibrant area.

Design features

The resounding success of the Seagram Lofts redevelopment project is clearly evident in the residents' knowledge of and pride in their homes. All of the residents interviewed were aware of the history of the Seagram whisky distillery and could explain how the bricks and barrel wood were preserved and reused in the project. Residents enjoy the old warehouse look in the hallways and the additional sunlight the enormous south-facing windows allow.

The views are described as excellent by most of the residents, especially those from the penthouses and upper floors. The loft ceilings and large windows allow for a wider perspective, thus enhancing these already enjoyable vistas. For lower-level residents without prime vantage points, there is access to the rooftop gardens.

Figure 4: The huge windows offer grand views and allow maximum sunlight.

Neighbourhood and transportation

Aside from design and character, the prime reason residents are pleased with Seagram Lofts is convenience. A large grocery store is across the street and restaurants and theatres are nearby. A huge park with pedestrian–cycling trails is a short stroll away. The transit system is convenient, with various routes available within blocks. Despite this, of the five residents interviewed, the three who are currently employed drive to work. In the Waterloo Regional Municipality nine per cent of workers walk, bicycle or take public transit to work.[1]

With a relatively large amount of housing for a downtown neighbourhood, residents describe the surrounding streets as being busy day and night. The diversity of residents within the Seagram Lofts properties ranges from young, single professionals to retired couples, creating a dynamic mix.

PROJECT SUCCESS: MUNICIPAL PLANNER'S PERSPECTIVE

The City of Waterloo purchased the entire Seagram's Lands, totalling 4.65 ha (11.5 acres), because Seagram had shut down its operations and been unsuccessful finding developers. The City and staff had a vested interest in preserving the barrel warehouses and requested development proposals that would fulfil such a demand. The opportunity to bring new residential and commercial units to Uptown Waterloo while holding onto the heritage of the site was of primary concern.

Neighbourhood opposition or support

The Seagram Lands had been cleared, save for the two historic barrel warehouses, and the City of Waterloo was eager to bring some vitality to the area adjacent to the city centre. This sentiment seemed to be shared by the residents and neighbourhood. Pre-development community consultations were held without controversy and were very encouraging of the proposal.

Planning objectives

The City of Waterloo purchased the former Seagram property in 1997, but the zoning had already been changed to accommodate new development early in 1994 when Seagram had tried to sell the land to developers. This new zoning allowed for office–commercial or residential.

The City was enthusiastic about the project and was willing to compromise on some of the zoning bylaws to allow the Barrel Works Group to move forward. Some areas of leniency were density, height, required landscaped open space and the option for all units to have a live-work designation.

[1] Statistics Canada, 2001 Census

For example, height restrictions were extended from 25 to 28.8 m (82 to 94.5 ft.) and landscaped open-space was reduced from 30 per cent to 27 per cent. These exemptions were not drastic but were enough to make the project feasible for the developer.

The vision for the Seagram Lands is to "create a mixed-use development which would compliment the existing Uptown by unifying the surrounding Waterloo Park, Canadian Clay and Glass Gallery, and Waterloo Square."[2] The City enabled mixed use by introducing a live–work designation on the site. This is an increasingly popular way to assist individuals with private businesses and is becoming a trend in downtown cores throughout the country. The home professions permitted in the residential areas are: "office, artist studio, hairdresser, barber, beautician, [and] seamstress/tailor."

The City proposes a large public space, Millennium Square, on the Seagram Lands. This is another contribution the City intends to make to the vitality of the area.

Does it fit into the neighbourhood?

The development is a unique preservation project a nd it was meant to stand out and be celebrated. Even so, the downtown surroundings complement the renovated Seagram buildings and their taller, larger block design. The remaining few acres on the Seagram site have yet to be developed but will more than l ikely be modelled along the same lines as the barrel warehouses and create a specific character for the area. The addition of the possible Millennium Square concept may bring a public centre to the new neighbourhood.

Regulations and approvals

The zoning had been changed before the City bought the Seagram Lands and some public consultation had taken place at that time. The developer needed several minor variances, which were granted with no controversy. Examples of the minor variances are: shorter setbacks, a smaller amenity area, building heights over 25 metres, less landscaped open space and an allowance for live-work units. The approvals were easily obtained because the bylaw relief was still in keeping with the Official Plan and appropriate for the development, no objections were made from neighbouring properties and the changes were considered minor.

LESSONS LEARNED

Seagram Lofts is a resounding success story in several respects. The partnership forged between the City of Waterloo and the Barrel Works Group was constructive. Both parties had something to gain and because they showed flexibility they were rewarded for their efforts. The restoration of the warehouses keeps some memory of the past alive while locating housing units near the city centre. By creating such a quality development in the initial phase of the larger site, the future developments have a high standard to meet and a unique character to build on.

FURTHER INFORMATION

Further information can be obtained from:

Developers: The Barrel Works Group partnership, made up of:

Andrew Lambden, Terra View Homes
Phone: (519) 763-8580 (ext 41)
E-mail: andrew@terra-view.com
Web: www.terra-view.com

Edwin Newton, Kiwi Newton Construction
Phone: (519) 822-5281 (ext. 250)
E-mail: enewton@kiwi-newton.com
Web: www.kiwi-newton.com

Municipality: Paul Eichinger, director of economic development and marketing City of Waterloo
Phone: (519) 747-8748
E-mail: peichinger@city.waterloo.on.ca
Web: www.city.waterloo.on.ca

Architect: L. Alan Grinham Architects Inc.
Landscape architect: Wendy Shearer Landscape Architect Ltd.

[2] City of Waterloo, *The Seagram Barrel Warehouses: A Call for Expressions of Interest for the Adaptive Re-use of the Historic Barrel Warehouses*

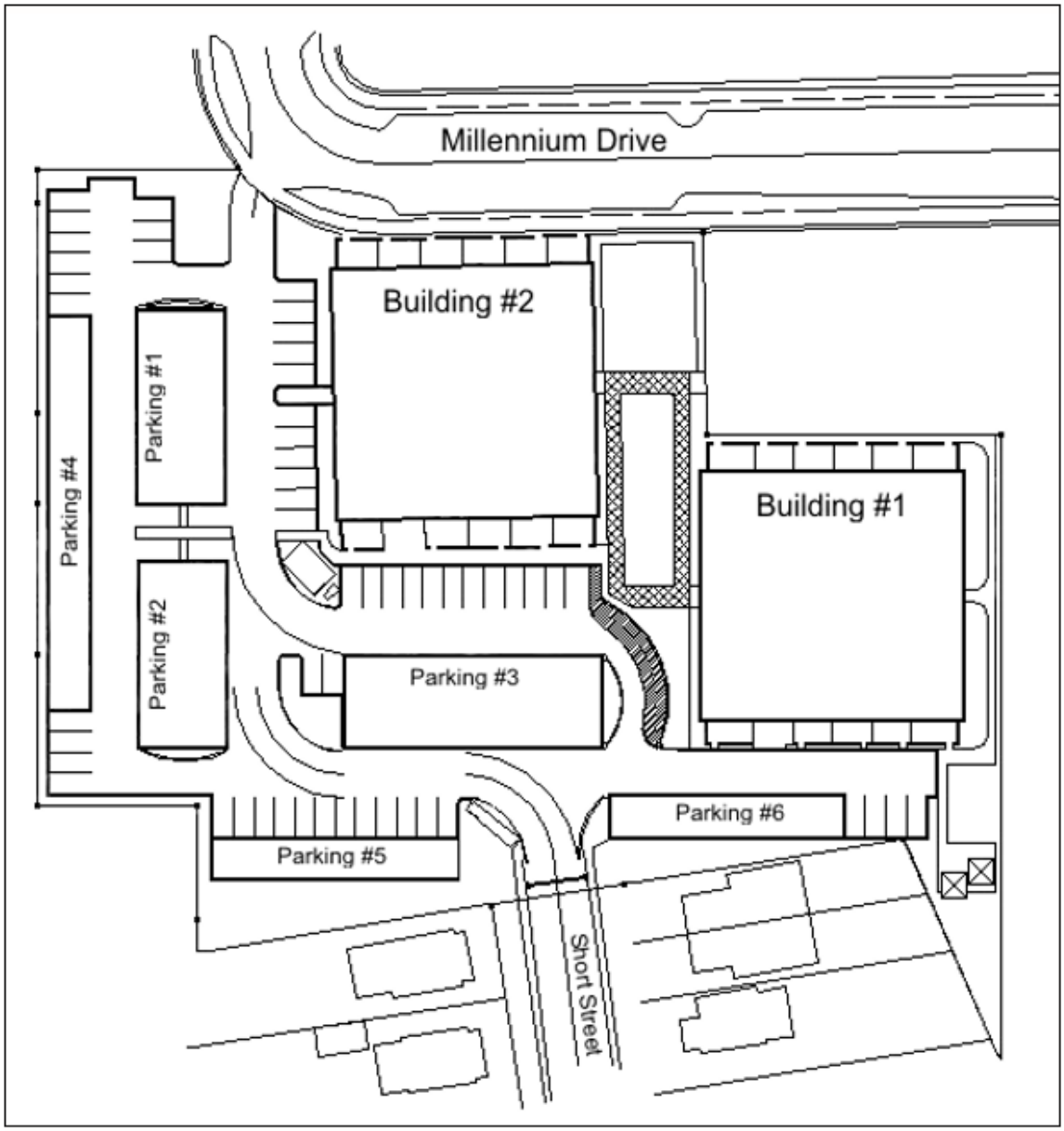


Figure 5: Site plan of Seagram Lofts including the two residential buildings, and the six parking garages (adapted from a drawing provided by L. Alan Grinham Architects)

Source: https://www.cmhc-schl.gc.ca/en/inpr/su/sucopl/upload/Seagram-Lofts-Waterloo-Ontario.pdf

Ontario Ministry of the Environment - Record of Site Condition # 211949

Record of Site Condition

Under Part XV.1 of the Environment Protection Act

Summary

Record of Site Condition Number	211949
Date Filed to Environmental Site Registry	22/01/2014
Certification Date	03/12/2013
Current Property Use	Industrial
Intended Property Use	Residential
Certificate of Property Use Number	No CPU
Applicable Site Condition Standards**	Full Depth Generic Site Conditions Standard, with Potable Ground Water, Medium and Fine Textured Soil, for Residential property use
Property Municipal Address	145 Caroline Street South N2L 1Y6, 156 Park Street N2L 1Y6, 141 Caroline Street South N2L 1Y6

Notice to Readers Concerning Due Diligence

This record of site condition has been filed in the Environmental Site Registry to which the public has access and which contains a notice advising users of the Environmental Site Registry who have dealings with any property to consider conducting their own due diligence with respect to the environmental condition of the property, in addition to reviewing information in the Environmental Site Registry.

Contents of this Record of Site Condition

This record of site condition consists (RSC) of this document which is available to be printed directly from the Environmental Site Registry as well as all supporting documentation indicated in this RSC to have been submitted in electronic format to the Ministry of the Environment.

Source: http://www.downloads.ene.gov.on.ca/files/besr/RSC%20211949.pdf

Appendix C: Normalized Evaluation Matrix

Priority Assumption	Name	Redevelop Time	Population Density	Employment Density	Unit Density	Tax Base Rise	Impacts on Greenfields	Distance to Nearest Waterbody	Number of Reinforced Sites
1	Alexandra Lofts	2000	40.91	68.59	40.93	1.03	0.17	5.59	100.00
2	Seagram lofts	2001	42.45	65.71	42.19	3.02	1.74	15.22	100.00
3	Spadina Apartments	2001	61.01	34.66	46.32	0.58	0.88	11.13	100.00
4	The Heartwood place	2001	78.47	100.00	71.28	0.37	0.88	0.08	100.00
5	Cambridge Transfer Station	2003	8.79	3.96	6.30	0.00	100.00	1.20	11.76
6	University of Waterloo School of Architecture	2003	42.40	27.88	38.37	3.84	0.46	89.71	11.76
7	The Kaufman Lofts	2004	50.18	28.14	56.58	7.65	1.47	2.75	100.00
8	The Millcreek by the Grand townhouse	2005	37.94	23.68	28.10	2.43	2.72	20.70	11.76
9	44 Gaukel	2007	65.07	28.14	67.82	0.00	0.43	4.16	100.00
10	Elmira core Shoppers Drug Market	2008	0.00	0.00	0.00	2.62	0.00	16.11	5.88
11	The Bauer buildings	2009	45.36	71.48	52.31	15.74	1.09	4.10	100.00

12	The Tannery District	2011	62.35	27.62	81.54	10.40	5.09	2.22	100.00
13	The Corporation of the City of Cambridge	2012	74.89	61.24	79.55	0.00	1.59	100.00	0.00
14	Savic Homes Ltd.	2012	100.00	39.41	71.66	1.91	0.63	10.75	100.00
15	Northfield Equities Inc.	2013	61.53	67.08	39.62	0.44	27.36	2.32	100.00
16	2371632 Ontario Inc.	2013	11.64	1.91	57.43	16.05	1.59	1.41	100.00
17	The Breithaupt Block Project	2014	57.06	34.86	50.73	100.00	2.81	0.00	100.00
18	Gautam Growth Properties Inc.	2014	3.87	6.05	2.15	0.46	1.81	7.44	0.00
19	One 55 Mady Limited	2014	45.36	80.14	58.63	2.25	0.12	3.50	100.00
20	MennoHomes Inc.	2014	0.02	0.01	0.13	0.11	0.74	11.79	5.88
21	1841362 Ontario Inc.	2015	57.04	76.18	50.82	3.00	0.33	0.39	100.00
22	83 Elmsdale	2016	58.87	28.85	5.87	10.60	1.45	3.06	100.00
23	445 King St	2016	70.87	27.62	100.00	2.78	0.30	1.13	100.00
24	Regional Municipality of Waterloo	2016	42.47	53.02	48.05	1.30	0.08	5.18	100.00

Appendix D: The AHP Weight Distribution Template

n=	7	Number of criteria (2 to 10)	Scale:	5		Balanced
N=	1	Number of Participants (1 to 20)	α:	0.1	Consensus:	n/a
p=	0	selected Participant (0=consol.)	2	7	Consolidated	
Objective	The AHP weight assignment for brownfield redevelopment proeject effectiveness evaluation					
Author	Jialei Pan					
Date	10-Nov-16	Thresh: 1E-07	Iterations: 4		EVM check: 1.0E-08	

Table	Criterion	Comment	Weights	Rk
1	Criterion 1	Population Density	15.4%	3
2	Criterion 2	Empolyment Density	12.8%	5
3	Criterion 3	Unit Density	12.4%	6
4	Criterion 4	Impacts on Water system	18.8%	1
5	Criterion 5	Impacts on Greenfields	13.1%	4
6	Criterion 6	Encouraging Brownfield Redevelopment	9.9%	7
7	Criterion 7	Tax Base Rise	17.7%	2
8	Criterion 8		0.0%	
9		for 9&10 unprotect the input sheets and expand the	0.0%	
10		question section ("+" in row 66)	0.0%	

Result					
Eigenvalue			lambda:	7.235	
Consistency Ratio	0.37	GCI: 0.11	CR:	2.9%	

Matrix

	1 Criterion 1	2 Criterion 2	3 Criterion 3	4 Criterion 4	5 Criterion 5	6 Criterion 6	7 Criterion 7	8 Criterion 8	9 0	10 0	normalized principal Eigenvector
Criterion 1	1 -	1	1 1/2	2/3	1 1/2	1 1/2	1	-	-	-	15.40%
Criterion 2	2 1	-	2/3	3/7	1	2 1/3	2/3	-	-	-	12.77%
Criterion 3	3 2/3	1 1/2	-	2/3	1	1 1/2	3/7	-	-	-	12.41%
Criterion 4	4 1 1/2	2 1/3	1 1/2	-	1	1 1/2	1	-	-	-	18.78%
Criterion 5	5 2/3	1	1	1	-	1	1	-	-	-	13.11%
Criterion 6	6 2/3	3/7	2/3	2/3	1	-	2/3	-	-	-	9.85%
Criterion 7	7 1	1 1/2	2 1/3	1	1	1 1/2	-	-	-	-	17.67%
Criterion 8	8 -	-	-	-	-	-	-	-	-	-	0.00%
0	9 -	-	-	-	-	-	-	-	-	-	0.00%
0	10 -	-	-	-	-	-	-	-	-	-	0.00%

Please compare the importance of the elements in relation to the objective and fill in the table: Which element of each pair is more important, **A or B**, and **how much** more on a scale 1-9 as given below.
Once completed, you might adjust highlighted comparisons 1 to 3 to improve consistency.

n	Criteria	Comment	RGMM
1	Criterion 1	Population Density	16%
2	Criterion 2	Empolyment Density	12%
3	Criterion 3	Unit Density	12%
4	Criterion 4	Impacts on Water system	19%
5	Criterion 5	Impacts on Greenfields	13%
6	Criterion 6	Encouraging Brownfield Redevelopment	10%
7	Criterion 7	Tax Base Rise	18%
8	Criterion 8		
9		for 9&10 unprotect the input sheets and expand the	
10		question section ("+" in row 66)	

Participant 1	1		α: 0.1	CR: 3%	5
Name	Weight	Date		Consistency Ratio	Scale

A
B

i	j	Criteria A	Criteria B	more important ? A or B	Scale (1-9)
1	2	Criterion 1	Criterion 2	B	1
1	3		Criterion 3	A	3
1	4		Criterion 4	B	3
1	5		Criterion 5	A	3
1	6		Criterion 6	A	3
1	7		Criterion 7	B	1
1	8		Criterion 8		
2	3	Criterion 2	Criterion 3	B	3
2	4		Criterion 4	B	5
2	5		Criterion 5	A	1
2	6		Criterion 6	A	5
2	7		Criterion 7	B	3
2	8		Criterion 8		
3	4	Criterion 3	Criterion 4	B	3
3	5		Criterion 5	A	1
3	6		Criterion 6	A	3
3	7		Criterion 7	B	5
3	8		Criterion 8		
4	5	Criterion 4	Criterion 5	A	1
4	6		Criterion 6	A	3
4	7		Criterion 7	B	1
4	8		Criterion 8		
5	6	Criterion 5	Criterion 6	A	1
5	7		Criterion 7	A	1
5	8		Criterion 8		
6	7	Criterion 6	Criterion 7	B	3
6	8		Criterion 8		
7	8		Criterion 8		

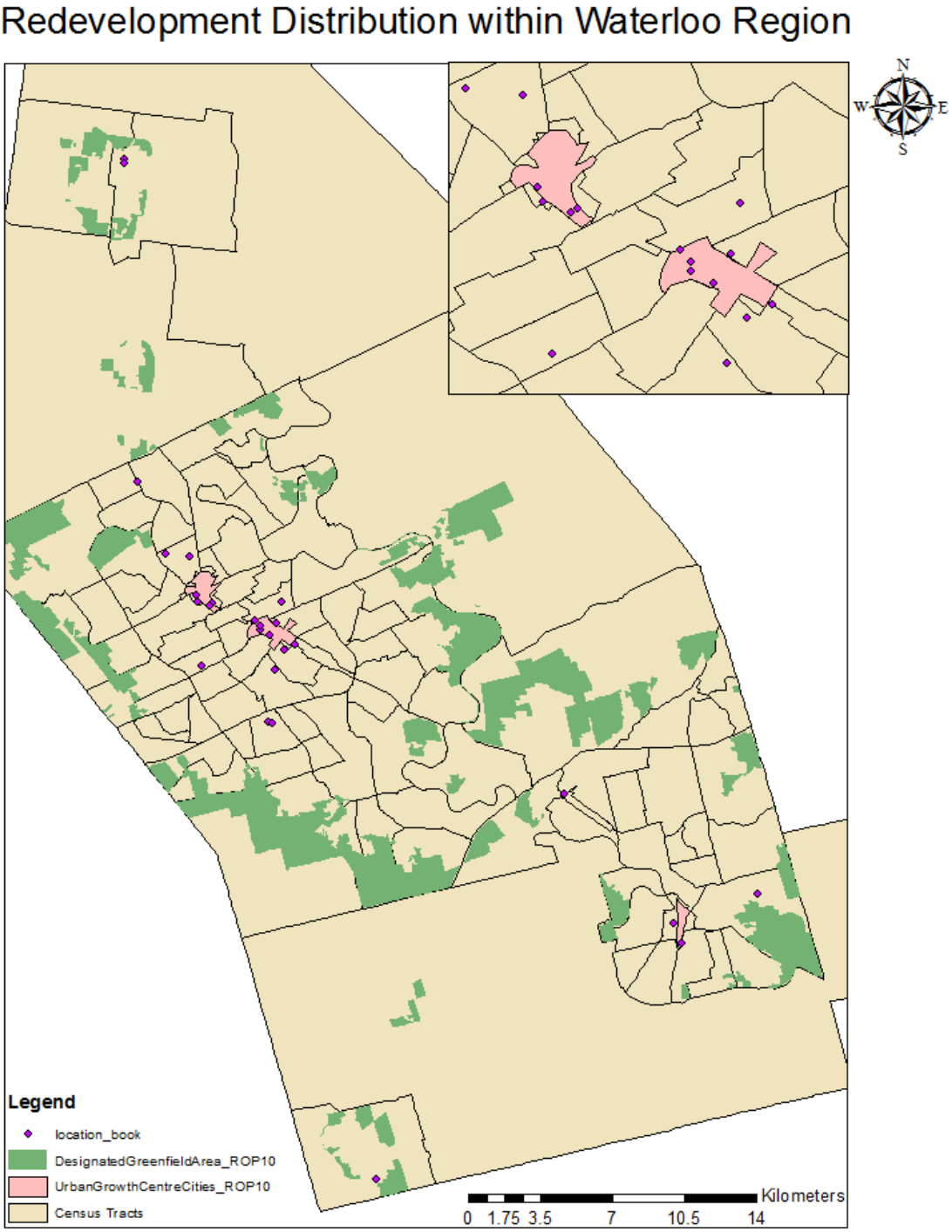
The Explanation of Intensities		
Intensity	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor on element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another, its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
2, 4, 6, 8 can be used to express intermediate values		

Appendix E: Evaluation Score and Order Before Adjustments

Priority Assumption	Name	Redevelop Time	Equal Weighted Score	Equal Weighted Order	SMART weighted Score	SMART weighted Order	AHP weighted score	AHP weighted Order
1	Alexandra Lofts	2000	36.75	13	28.81	14	31.32	15
2	Seagram lofts	2001	38.62	11	30.71	11	33.80	11
3	Spadina Apartments	2001	36.37	14	28.42	15	31.84	14
4	The Heartwood place	2001	50.15	1	39.09	2	43.87	3
5	Cambridge Transfer Station	2003	18.86	20	14.67	21	22.83	19
6	University of Waterloo School of Architecture	2003	30.63	17	24.68	19	33.65	12
7	The Kaufman Lofts	2004	35.25	16	29.12	13	30.39	17
8	The Millcreek by the Grand townhouse	2005	18.19	21	14.69	20	18.36	21
9	44 Gaukel	2007	37.95	12	29.51	12	32.80	13
10	Elmira core Shoppers Drug Market	2008	3.52	22	3.32	22	4.08	22
11	The Bauer buildings	2009	41.44	7	35.73	4	36.28	8
12	The Tannery District	2011	41.32	9	34.45	6	36.36	7
13	The Corporation of the City of Cambridge	2012	45.32	4	35.25	5	48.33	1

14	Savic Homes Ltd.	2012	46.34	3	36.46	3	41.71	4
15	Northfield Equities Inc.	2013	42.62	6	33.25	8	38.53	5
16	2371632 Ontario Inc.	2013	27.15	19	24.68	18	22.46	20
17	The Breithaupt Block Project	2014	49.35	2	60.61	1	47.67	2
18	Gautam Growth Properties Inc.	2014	3.11	23	2.52	23	3.46	23
19	One 55 Mady Limited	2014	41.43	8	32.72	9	35.49	9
20	MennoHomes Inc.	2014	2.67	24	2.10	24	2.98	24
21	1841362 Ontario Inc.	2015	41.11	10	32.64	10	35.40	10
22	83 Elmsdale	2016	29.81	18	25.54	17	26.11	18
23	445 King St	2016	43.24	5	34.25	7	37.51	6
24	Regional Municipality of Waterloo	2016	35.73	15	28.08	16	30.40	16

Appendix F: Brownfield Redevelopment Distribution



Soure: University of Waterloo Geospatial Center; Region of Waterloo Open Data Catalogue
Produced by Jialei (Jocelyn) Pan
April 4th, 2016