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Neighbourhood Resilience to Extreme Weather Events: An Assessment Methodology for Canadian Cities

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Neighbourhood Resilience to Extreme Weather Events:

An Assessment Methodology for Canadian Cities

by

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ABSTRACT

The escalating intensity and increasing frequency of extreme weather events caused by climate change, necessitates an examination of how urban form can support or undermine a city's resilience to these weather events. A single, uniform strategy to increase resilience in a city is unlikely, because while regional weather patterns impact an entire area, individual neighbourhoods are affected differently because of their age, design, size, (infra)structures, land-use policies, etc. Furthermore, they are not all sited on identical topography, for example, some are located on a flood plain, some on the crest of a hill. Because neighbourhoods are generally built-out within a finite window of time, they are 'development units' reflecting the contemporary norms, technology, architecture, etc. of the era in which they were built. Because of these multitude of factors, every neighbourhood within a city is unique, and thus each possesses inherent strengths and weaknesses to extreme weather events, either by design or by accident.

This thesis proposes a series of 24 metrics to assess individual neighbourhood form, local elements, and circumstances to uncover its inherent functionality. By understanding how a neighbourhood functions, i.e. the mechanisms operating within it that support residents, we are better placed to recognize any points of vulnerability or strength. Two case studies are provided as a means to test the proposed assessment framework in a real-world setting. The metrics provide information on neighbourhood and resident vulnerabilities dependent on weather, location, amenities, transportation, food, energy, and water provision. Metric results offer an overview for residents, planners, or other stakeholders, to understand the interplay of different elements within a neighbourhood, and support these stakeholders into the future for climate change adaptation planning or retro-fitting.

PREFACE

This thesis is original, unpublished, independent work by the author, N. Robertson.

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Dedicated to the memory of my father

Gordon W. Robertson

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We shape our buildings; thereafter they shape us.

-Winston Churchill

INTRODUCTION

Alongside research documenting the escalating intensity and increasing frequency of extreme weather events caused by climate change (IPCC 2014), research related to responding to these events has also increased (Stumpp 2013; Cutter et al. 2008; Renschler et al. 2010; UNISDR 2015). There is a global need to adapt to the shifting climate not only because of escalating financial impacts (Economics of Climate Adaptation Working Group 2009), but because of increasing human costs as well (Weber et al. 2016). Finding a uniformly applicable strategy to increase resilience in a city is difficult because while regional weather patterns impact entire areas, areas within a city are affected differently because of their age, design, (infra) structures, land-use policies, etc. Furthermore, a development built on a flood plain, for example, maintains different vulnerabilities than one located on a hilltop, even though they may be otherwise identical.

For residential developments in North America, these different areas tend to be planned and treated as independent neighbourhoods with boundaries, built and sold to the public over a finite window of time. As such, a neighbourhood can be considered a ‘development unit’. As a defined unit they are a product of the era in which they were built – embodying and reflecting contemporary planning policy and philosophy, technology, architecture, resource availability, culture, and infrastructure. Because of this, there is a degree of homogeneity within each neighbourhood (Sandalack & Nicolai 2006).

Outside of any location-specific risks, the systems operating within a neighbourhood also maintain specific vulnerabilities because of the factors mentioned above; age, land-use, etc. These systems, the mechanisms relied on by residents to meet their daily needs, are the lens through which neighbourhoods are used and experienced. Systems established to meet these needs are a product of contemporary planning philosophy, zoning laws, technology and technological legacy, resource availability, road design, architecture, and infrastructure, among others. The lives of residents are impacted by the expression and organization of these systems in subtle and overt ways, many of which are examined within this thesis. Disruptions to these neighbourhood systems, to the point that resident needs are not met, reflect a lack of resilience. In this context, the concept of resilience is tied to a definition originally applied in Ecology: the ability to bounce back and remain functional after a disruption (Holling 1973). It is this 'functionality' providing the lens through which urban, and specifically neighbourhood, resilience is examined here. A neighbourhood functions if residents can meet their needs, and conversely, it is dysfunctional when needs are not met: – residents are hungry (food), there is no energy supply, homes are uninhabitable (shelter) etc. Within this thesis, resident experience is used to define (dys)functionality, and therefore, neighbourhood resilience.

<u>Objectives</u>

This thesis proposes an assessment framework for understanding neighbourhood system functionality. Understanding functionality under routine or normal conditions provides an opportunity for recognizing strengths and weaknesses in the system in the event of stressors or disruptions caused by climate change-related weather events. Using *Basic Needs,* as defined by Christopher Sarlo (2001) in his work for the Fraser Institute, as a foundation, the proposed framework here divides Basic Need systems into their component parts and provides representative metrics to evaluate system functionality. The metrics are devised to be 'neutral', that is, they uncover information without interpretation. Interpretations based on the acquired information are done after the fact and are examined within the context of local vulnerabilities and hazards. Conclusions and paths forward can be drawn based on this local context, and strategies for retro-fitting and redevelopment, or in the initial planning of greenfield sites, are more easily identified.

This research supports the work of cities everywhere as they attempt to integrate "resilience" into their policy and decision-making. There is no shortage of inspirational examples of flood adaptive landscapes, sustainable architecture, distributed energy systems, local food production etc. but how these types of initiatives work together as part of an urban system is less understood. The methodology outlined herein highlights correlations that are often ignored in planning and development at the neighbourhood scale. By uncovering these links, the metrics offer a unique opportunity for municipalities to examine all development projects through a resilience lens.

Overview

This thesis is divided into six chapters. Chapters 1 and 2 provide a background for understanding resilience in general, and urban resilience, in particular. Chapter 1 describes the attributes of a resilient system, and Chapter 2 applies these attributes to an urban context, outlining connections between sustainability, neighbourhood form, and climate change mitigation and adaptation. Using a Basic Needs framework provides a common baseline and frame of reference across municipalities and neighbourhoods. A synopsis of other resilience evaluation systems is also provided. Chapter 3 introduces the concept of resilience at the neighbourhood scale using residents' basic needs as the basis. It gives an overview of the six basic need systems operating within neighbourhoods and introduces issues and broad strategies, policies, and paradigms affecting those systems.

The metrics for the proposed evaluation are introduced here, and quantification and measurement criteria are explained. Chapter 4 applies the metrics and methodology to two case study neighbourhoods: 1) Drake Landing in Okotoks, Alberta, and; 2) Sunnyside in Calgary, Alberta. Using local and extreme weather data, as well as local topography, vulnerabilities within these neighbourhoods are uncovered. Chapter 5 provides a discussion on the results, the implications for current municipalities, and recommendations for further research.

CHAPTER 1 - RESILIENCE

This chapter outlines current thinking surrounding the concept of resilience and its relationship to climate change. It provides a review of literature outlining the nature of resilience as a system attribute and applies this to other related areas such as sustainability, mitigation and adaptation. It further explores urban climate resilience in terms of deployable strategies and examines different methods resilience is evaluated and quantified.

1 Understanding Resilience

Broadly speaking, resilience is the ability of a system to bounce back or re-organize and remain functional during and after a disruption or shock (Holling 1973). This understanding, grounded in Ecology, allows for system re-organization (Quinlan et al. 2016; Walker et al. 2004) because the focus lies on *functionality* and *operations*, not a system's original identity or recoverability back to its original state (Holling 1996). Fundamentally, however, resilience is an attribute, not a destination (Folke et al. 2010), and can then be understood as "the ability to adjust to changing, locally unstable conditions" (Pickett et al. 2014), implying that the *capacity to adapt* lies at the heart of resilience. This approach, that of 'adaptive capacity', is not only foundational to much of current resilience research (Childers et al. 2015; Stumpp 2013; Davoudi 2012; Folke et al. 2010; Folke 2006; Cumming 2011), it speaks to the neutrality of resilience – that it is neither good nor bad, but describes the capacity to *functionally* endure through adaptation (Walker et al. 2004; Holling & Walker 2003). A system may 'endure' though its components or component parts may change. For example, a city's road network endures even though automobile and transportation paradigms shift with the addition of sidewalks, fluctuating gasoline prices, traffic laws, street lighting, autonomous cars, mass transit, or increased bicycle use.

1.1 Resilient Systems

As a system descriptor, resilience forms part of internal system organization and it is this inherent organization and its feedback responses that support or undermine adaptive capacity (Folke et al. 2010). This capacity does not suddenly appear, nor is it triggered by a crisis, it is inherent, and is therefore part of routine, as well as disrupted, functionality (Cutter et al. 2008). Resilience and adaptive capacity are not interchangeable terms, however. A system is resilient *because* it has adaptive capacity (Walker et al. 2004). Thus increasing adaptive capacity should be the focus of resilience efforts in terms of design or organization (Klein et al. 2003). Increased adaptive capacity is also contingent on the presence of other attributes: redundancy, diversity, efficiency, autonomy, strength, interdependence, and collaboration (Ahern 2013; Ahern 2011; Godschalk 2003). These attributes support a system's ability to *absorb*, *resist*, or *dissipate* stressors and disruptions (Bahadur & Tanner 2014; Francis & Bekera 2014), and so these are also hallmarks of a resilient system.

1.2 Climate Change Resilience

Where the concept of resilience is broad, 'climate change resilience' refers specifically to the ability of human and natural systems to bounce back and remain functional during and/or after climate change-related stressors that potentially occur over a variety of temporal and spatial scales. Short term stressors include extreme weather incidents like extreme winds, ice or hail storms, extreme rainfall, storm surges; middle term stressors include droughts or heatwaves, and; long term stressors include sea level rise and global temperature increase (Dotto et al. 2010; Stone et al. 2010; Thompson et al. 2009; IPCC 2007).

These events have the potential to disrupt or overwhelm human lives, affecting services such as energy provision (Li et al. 2015; Cheng et al. 2012), food production and distribution (World Economic Forum 2015; Porter et al. 2014; Fresco 2009), water and sanitation systems (Andrey et al. 2014), economics, industry (Lemmen et al. 2014), healthcare, and transportation etc. (NRTEE 2011). Furthermore, impacts are unencumbered by geo-political boundaries (Uda & Kennedy 2015), so while an event may ‘land’ in one location, ramifications potentially extend beyond jurisdictional boundaries because of the interconnected nature of cities and nations (Fekete et al. 2010; Cutter et al. 2008). Furthermore, because of this interconnectivity, climate-driven extreme weather events are then also linked to economics and political unrest (O’Sullivan 2015; IPCC 2007).

Within this thesis, the concept of resilience refers primarily to continuity of service in an urban environment, and therefore the ability to exist, or endure as above, despite extreme weather disruptions or stressors. This framing of resilience is quite narrow considering the variety of research on the topic, but supports the proposed framework which addresses extreme weather events specifically and their influence on urban environments, both built and natural, in their capacity to support residents/citizens.

1.2.1 Sustainability

Like resilience, the concept of sustainability maintains multiple dimensions, and these are usually summarized as the three Es: Ecology, Economy, Equity (for example, see Ndubisi (2008)). Within this thesis sustainability is understood more narrowly to encompass inter-generational justice and equity in terms of resource depletion, access, and use (Derissen et al. 2011). This understanding implies that a reduction in current resource consumption levels is necessary (Brundtland & Khalid 1987), and omits social, governance, and economic elements. This version of sustainability closely resembles the concept of urban metabolism (UM) as first described by Wolman (1965), where inputs (water, energy) and outputs (waste) are tracked and any imbalances identified. This understanding, however, assumes a stable urban form existing into the future (Ahern 2011), an assertion at odds with climate resilience thinking. If sustainability is understood as achieving equilibrium in a (global) system coupled with stable urban form, and resilience is an attribute of a dynamic system, then on a fundamental level, the two concepts are incompatible (Ahern 2013). To reconcile this tension, this thesis looks at sustainability more broadly and recognizes that reducing consumption and increased resilience are closely linked. For example, a building requiring less energy to operate is more sustainable, and is, therefore, also more able to function if its energy supply is disrupted. This diminished consumption, or efficiency, also serves to reduce the amount of greenhouse gases (GHG) emitted into the atmosphere – thereby mitigating further climate change. Given that mitigation efforts alone are unlikely to be sufficient to undo the current climate trajectory (Wilbanks & Sathaye 2007), adapting to existing and projected circumstances is necessary, and so resilience encompasses both *mitigation* and *adaptation*. Because there is broad international consensus that climate change is anthropogenically caused (IPCC 2007), mitigation efforts are largely centered on cities because the global population is largely urban (United Nations Department of Economic and Social Affairs 2013).

1.3 Urban Resilience

With the increase in frequency and intensity of extreme weather (IPCC 2014), cities are finding themselves ill-prepared to withstand unfamiliar natural forces. Built infrastructure, designed for weather and climate different than what occurs today, is increasingly vulnerable to these weather extremes, in the short and long term, putting urban populations at risk. While the exact impacts of these extreme events are not entirely calculable or accurately predictable (World Economic Forum 2015), patterns have emerged such that the nature of different events are known, even though their severity may not be. Because of the concentrated population found in cities, disaster recovery forms a significant part of urban climate change resilience discourse and is frequently addressed from an engineering perspective (see Cutter 2016; Oddsdottir, F; Lucas, B; and Combaz 2013; Matthews et al. 2014; Stumpp 2013). While this approach is important it does not necessarily incorporate the multi-faceted nature of urban resilience.

1.3.1 Defining Urban Resilience

Much like 'resilience', the term 'urban resilience' supports multiple meanings, scopes, and understandings, not only because of the multidimensional nature of resilience, but because of flexibility in the word 'urban'. Meerow et al (2016) provides a comprehensive definition of the term, and this research is based in part around this understanding:

> "Urban resilience refers to the ability of an urban system-and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales-to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity" (p.39).

The above definition also provides context for the term 'endure' as a component of functionality and/or provision. Using the example from Section 1, the transportation system, i.e. the road network, *endures* because it maintains functionality regardless of fuel, behaviour, disruption, or vehicle type. This means the system is self-sustaining and also adaptive. Or, as Holling (1973) states, "the constancy of (its) behavior becomes less important than the persistence of the relationship(s)" (p.1).

Cities are not merely a collection of engineered spaces and (infra)structures, that is, a socio-technical fabric on a landscape (Hassler & Kohler 2014), they are centres for interaction between people, structures, behaviours, governance, and ecological systems – they are *socio-ecological* (Childers et al. 2015; Pickett et al. 2014; Wu & Wu 2013; Gallopín 2006; Walker et al. 2004). From this, Folke et al. (2010) parallel Holling's assertion that socio-ecological resilience is the:

> "…capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure and feedbacks, and therefore identity, that is, the capacity to change in order to maintain the same identity" (p.3).

A socio-ecological systems (SES) framework examines the interplay between *people* (laws, social networks, customs) and *ecology* (habitat, species, biophysical environments), by addressing issues like water quality, or timber production (Cumming 2011). Generally though, this approach has, thus far, not addressed the interaction between social networks and natural ecology *within* cities (Wilkinson 2012).

1.4 Urban Resilience and Extreme Weather

Urban resilience to extreme weather involves examining the robustness of urban structures and infrastructures to specific weather-related hazards. This is an important part of understanding the recoverability and vulnerability of a city, but does not necessarily address un-disrupted routine operations and functions. For the most part, climate change resilience to extreme weather has been largely a ‘response’ exercise (Solecki et al. 2011) and not a pro-active endeavor. As discussed earlier, resilience as part of system organization forms part of routine functionality, and daily operations of urban systems are integrated explicitly and implicitly. Any overlapping functionalities occurring within systems is typically excluded from the system design process, largely because elements maintaining many functions are not yet fully embraced by the planning profession (Mandle et al. 2015). The productive potential of urban form, either single-purpose or multi-functional, is part of system functionality and is a key component of this thesis, as is recognizing the benefits of decentralized and integrated urban systems (Pandit et al. 2017; Derrible 2016; Xu et al. 2012).

1.4.1 Ecosystem Services

Approaching urban form and the urban landscape as a productive and integral part of urban system functionality parallels the concept of *ecosystem services* (ESS) (Mooney & Ehrlich 1997). Because consideration of natural systems is not a regular part of municipal planning practice, at least in terms of infrastructure, the degree to which the natural environment within or surrounding the city has been eroded or supported has also been largely ignored from a planning and policy perspective. Historically, this has led to a lack of knowledge of the effectiveness of urban ecosystems to perform functions that support a city's built systems (Childers et al. 2015; Beatley & Newman 2013; Ellin 2013; Pickett et al. 2004).

Approaching urban ecosystems and ecology as a 'tool' to increase resilience has more recently been incorporated into the field of Landscape Ecology. In the past, Landscape Ecology, examined the internal function of green spaces like parks, riparian zones, or urban wildlife corridors (Ahern 2013), but has recently moved to encompass research on green infrastructure (Voskamp & Van de Ven 2015; Demuzere et al. 2014; Niemelä 2014), biophilic urbanism (Beatley & Newman 2013) and sustainable urban design (Childers et al. 2015). The results of this shift have provided extensive information of built form's impact in and on a city, beyond ecology, and so includes subjects like urban heat island (Rafiee et al. 2016; Santamouris et al. 2015), storm water management (Payne et al. 2015), carbon sequestration (Nordbo et al. 2012) and walkability (Sandalack et al. 2013; Southworth 2005). Given that natural elements do support urban functionality and built systems, integrating these two typically separated components exploits the strengths of both. Through integration, the entirety of an "urban system" is made more resilient because it then contains increased flexibility, redundancy, and diversity. Treating resilience as only an infrastructural issue or only an environmental issue fails to recognize the potential benefits in overlapping these elements.

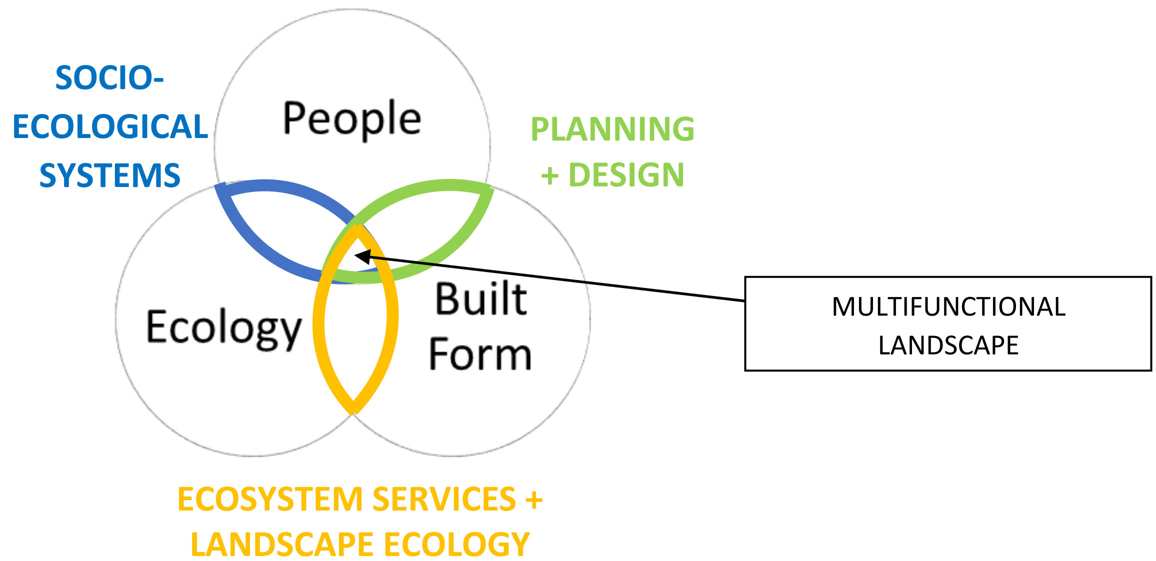
1.4.2 Land use Planning

The relationship between built form and resilience to climate change-related stressors is also well documented, for example, Newman (2014), Brown et al. (2012), Saavedra & Budd (2009), and contemporary architectural or urban design initiatives with weather extremes in mind are increasingly common (Bowman et al. 2012; Hamin & Gurran 2009;

Saavedra & Budd 2009). While these are important, focusing only on the design of structures, or integrating green elements into structures, ignores human behaviour and agency as actors within urban systems.

A city's physical layout exerts an influence on resident behaviour by dictating the spectrum of choices available to residents either through distance, availability, or accessibility. Available options, the result of neighbourhood planning and design decisions, resonate across areas like transportation mode (Hachem-Vermette 2016; Cervero et al. 2013; Ratner & Goetz 2013), food access (Shannon 2015; Fresco 2009), or energy distribution etc. (Sharifi & Yamagata 2016b; Bouffard & Kirschen 2008; Littlefair 1998). And so in this way, planning decisions exert a direct influence on the sustainability and resilience of a neighbourhood (Codoban & Kennedy 2008). Figure 1, below, provides an illustration of the above interrelationship between ecology, people, and cities, with the central nexus indicating the area explored within this thesis in terms of understanding the relative resilience of one urban area over another.

Figure 1 – Schematic Relationship Between People, Ecology, and Cities



Resilience-based thinking within cities, then, represents a convergence of Planning, Urban Ecology, and Ecosystem Services and Landscape Design (Wilkinson 2012). This can be contextualized within the 'multifunctional landscape' framework outlined by Lovell & Taylor (2013). In this context, a multifunctional landscape, either built or natural, plays a variety of roles within an urban environment. For example, a wetland cleans storm water runoff, traps excess water during extreme rain events, cools and purifies the air, and with a paved pathway, can serve as an active transportation corridor. Though full of nuances, the triangulated relationship illustrated above demonstrates that cities are comprised of complex systems of people, nature, and built form, with each element influencing, being influenced by, others. Given this, maintaining a city and its systems in the face of disruptions involves not only exploiting the inherent strengths of each component and recognizing interdependencies and influences among them, but also supporting increased adaptive capacity within and across systems, by adding redundancy and flexibility. As much of the literature suggests, this can be done using existing natural systems to add to or increase functionality.

The assessment framework presented in Chapter 3 supports pro-actively addressing planning, architecture, and ESS by focusing on performative and multifunctional landscapes. Contained within most metrics is the degree to which urban form maximizes its functional role in supporting residents in meeting their needs. And while this addresses only some aspects of urban resilience issues and ignores economics, governance, community, and social cohesion (Tyler & Moench 2012), these less infrastructural aspects are often supported through built resilience-based actions. For example, street trees mitigate heat island (Adachi et al. 2014) and promote walkability (Southworth

2005), and walkability facilitates social connectivity and emotional/physical well-being (Lafortezza et al. 2009) – all attributes of social resilience. These aspects are not discussed within this research but they are relevant to the overall resilience of a city and so are included in many of the resilience assessments currently used globally, and discussed later in Section 1.7 of this chapter.

1.5 Mitigation and Adaptation

As discussed in Section 1.2, addressing urban climate change resilience requires that climate change be slowed through reduced emissions (mitigation), and that current extreme weather events also be addressed (adaptation). Here, the focus on adaptation rather than on the *adaptive cycle*, is an acknowledgement of the role played by transformability within SES. Transformability within systems allows for flexibility in the short term or at a smaller scale, in order to support larger scale or long-term transition within SES systems (Folke et al. 2010). Within an urban context, the extreme weather stressors have yet, for the most part, been large enough to complete undermine an urban environment, though many have created enough crisis to initiate a re-thinking of existing system organization to support a transformation.

Above, Section 1.4 highlights the importance of recognizing the potential of urban form and systems to be multi-functional, and therefore supportive in increasing adaptive capacity and resilience. What this involves in terms of specific strategies requires direct examination.

1.5.1 Mitigation Initiatives

The majority of GHG emissions are produced in cities (Swilling et al. 2013) with 70% of those emissions coming from building energy consumption and transportation, combined

(Sims et al. 2014) This is the result of a number of factors ranging from neighbourhood design/urban form (Hess et al. 2013; Codoban & Kennedy 2008), transportation planning (Karen C. et al. 2014; Cervero & Murakami 2010), cheap fuel costs, technological inefficiency (Touchie et al. 2013), and consumption/behavioural patterns (Konroyd-Bolden & Liao 2015; Cervero et al. 2013). Therefore, lowering emissions requires addressing demand/consumption in these areas and limiting emissions with a combination of increased efficiencies, behavioural change, and carbon sequestration. This would necessitate that mitigation and mitigative actions be included at the outset to actively encourage and discourage specific behaviours.

Efficiencies: Lowering building-related emissions involves increasing the use of passive design strategies for thermal comfort, deploying efficiency measures, and using energy from non-fossil fuel sources (Sims et al. 2003). There are three broad approaches to achieve this: 1) architectural design and features; 2) technology, and; 3) blue/green infrastructure[1], with some strategies straddling more than one approach. Table 1.1 on the following page, outlines the contributions these three approaches provide in terms of decreasing energy consumption.

[1] Blue and green infrastructure refers to the use of water (blue) and vegetation (green) elements within the urban environment to support urban functions.

Table 1.1 Diminishing Consumption/Increasing Efficiency

APPROACH	CONTRIBUTION
Architectural Design and Features[2]	Designing buildings for solar heating or with features that 'exploit' local conditions (wind, geothermal access etc.) for heating and cooling reduce energy requirements. Adding indoor or outdoor features to cast shadows, block wind, increase are other options to increase passive buildings.
Technology[3]	Using specific building materials and/or efficiency-rated appliances diminishes consumption by decreasing demand for energy by building inhabitants/users. This also involves using renewable energy over fossil fuels, or alternative systems like district heating, or solar-heated water
Blue/Green Infrastructure[4]	Strategically-placed outdoor vegetation/water features can reduce cooling load demand in summer months by lowering ambient air temperatures with shadow casting and evapotranspiration. They can also reduce demand on water filtration systems through pre-treating with passive bio-filtration

On the following page, Table 1.2 provides a partial list of common strategies deployed at the building scale for implementing these three approaches and indicates any sequestering potential.

Sequestration: Vegetation and soil are the two primary sinks for GHGs. Soil-based sequestration occurs primarily in the untouched soils of riparian zones, wetlands, wilderness, and grassland areas, and is largely contingent on leaving these areas undisturbed (Paustian et al. 2006). Planting and green space, then, becomes the prime source for carbon sequestering in cities, and this can take multiple forms such as street trees, green roofs and walls, green space, as well as yards and vegetable gardens. Beyond individual sites and buildings, mitigation strategies implemented over a wider area work together to reduce and sequester GHG emissions. As indicated in Table 1.1, the presence

[2] Hachem et al 2013; Knowles 2003; Grosso 1998; Littlefair 1998
[3] Santamouris 2014; Villarroel Walker et al. 2014; Grosso 1998; Syneffa et al. 2008
[4] Santamouris et al 2015; Voskamp & Van de Ven 2015; Demuzere et al. 2014; Pickett et al. 2014; McPherson 1990

of blue and green infrastructure lowers ambient temperatures and so the relative amount of surface area with these features throughout a city reduces urban heat island (UHI) and sequesters CO_2 (Nordbo et al. 2012) – something easily addressed through land use planning.

Table 1.2 – Mitigation Strategies for Buildings

ARCHITECTURE/DESIGN	SEQUESTERING	REFERENCE
Thermal mass heating/cooling		(Littlefair 1998)
Solar chimney		(Haase & Amato 2009)
Glazing ratio restrictions		(Mikler et al. 2009; Omar 2002)
Daylighting/orientation		(Littlefair 1998; DeKay 1992)
Reflective surfaces		(Syneffa et al. 2008; Santamouris 2014)
Green Roof/Wall	X	(Santamouris 2014)
Screens/Louvres/Overhangs		(St. Clair 2009)
TECHNOLOGY		
Triple glazing		
Low-e glass		
Increased Wall Insulation		
Rooftop Solar Panels		
Solar hot water		
Green Roof/Wall	X	(Santamouris 2014)
BLUE/GREEN INFRASTRUCTURE		
Tree shading	X	(McPherson 1990)
Pond/water feature		(Robitu et al. 2006)
Green Roof/Wall	X	(Santamouris 2014)

Land use planning also plays a role in decreasing transportation-related GHG emissions by either encouraging or discouraging the use of private vehicles. Table 1.3, on the following page, provides a partial list of public space strategies related to building energy consumption and transportation, and includes physical as well as governance aspects.

Table 1.3 – Mitigation Strategies for Public Space

URBAN GREENING	SEQUESTERING	REFERENCE
Green belt	X	(Voskamp & Van de Ven 2015)
Street trees	X	(Rafiee et al. 2016; Santamouris et al. 2015)
Mutual shading		(Littlefair 1998)
Preserved wetlands	X	(Musacchio 2008)
Green networks	X	(Rafiee et al. 2016; Santamouris et al. 2015; Voskamp & Van de Ven 2015)
Creek daylighting	X	(Schwab 2016; Jones & Macdonald 2007)
PLANNING		
Grid/Fused-grid street layout	X	(Hachem-Vermette 2016; Sandalack et al. 2013; CMHC 2008)
Sidewalks		(Bronson & Marshall 2014)
Cycling infrastructure		(Cervero et al. 2013)
Lowered speed limits		(Bronson & Marshall 2014)
Transit Oriented Development		(Wey & Chiu 2013)
Human Scale Architecture		(Brown et al. 2009)
Mixed-use Development		(Brown et al. 2009)

1.5.2 Adaptation Initiatives

The tables presented in Section 1.5.1, while not exhaustive, demonstrate the role individual buildings and the broader urban area play in mitigating further climate change by reducing GHG emissions. Their efficacy is tied to their presence and their relative size within the area, and also their connectivity and pervasiveness throughout a city (Scyphers & Lerman 2014; Nordbo et al. 2012). Many of these above mitigation efforts can be deployed in most developed countries, adaptation initiatives however, vary in their appropriateness. Risks and hazards change with geographic location and regional weather patterns (IPCC 2007), thus adaptation strategies must be locally-focused.

Furthermore, some risks and vulnerabilities are tied to system and network design, not just the integrity of physical built (grey) infrastructure, and so adaptation strategies also include this dimension. Earlier, the concept of adaptive capacity was introduced as a component of system resilience. Ideally adaptive capacity is incorporated into system design at the outset, however cities must necessarily deal with the legacy of their existing systems and networks (Ferguson et al. 2013). While this legacy can be problematic because of its entrenchment in the urban fabric not only behaviourally, but physically, it also works to support increased flexibility and redundancy of systems by ‘forcibly’ adding elements in anticipation of increased burdens. Depending on the system in question and the anticipated stressor, these redundancies often include green and blue elements, such as storm water biofiltration or flood parks, because of the lack of energy consumption associated with their implementation, coupled with the speed of recovery and flexibility of natural systems (Beatley & Newman 2013)

On the following page, Table 1.4 provides a partial list of adaptation action for a variety of systems, organized by extreme weather event. Strategies presented include urban design, architecture, and legislation/policy, and operate at a variety of temporal and development scales for implementation.

Table 1.4 – Extreme Weather Strategies

EXTREME RAIN EVENT	REFERENCE
Permeable surfaces	(Lamond et al. 2015; Jacobson 2011; Goonetilleke et al. 2005)
Separated storm and sewer systems/re-directing downspouts	(Kovacs et al. 2014; ICLR 2010)
Green networks	(Hunter 2011; Shouquan Cheng et al. 2011)
Green roof	(Beatley & Newman 2013; Montalto et al. 2007)
Green belt	(Beatley & Newman 2013)
Natural topography retention	(Schwab 2016)
Raingardens/bioswales	(Bowman et al. 2012)
Wetland preservation	(Spatari et al. 2011)
Adaptive landscapes/flood parks	(Matos Silva & Costa 2016)
Storm water catchment/ponds	(Roy et al. 2008)
Daylighted creeks	(Schwab 2016; Jones & Macdonald 2007)
HIGH WINDS	
Vertical load construction	(Deltec 2015; ICLR 2010)
Modified roof slope	(Deltec 2015)
Reinforced anchors and trusses	(Deltec 2015; FEMA 2010; ICLR 2010)
Planted wind-breaks	(Government of Ontario 1995)
EXTREME HEAT	
Urban canopy	(Rafiee et al. 2016; Adachi et al. 2014; McPherson 1990)
Strategic planting	(Beatley & Newman 2013; Ko 2013; Hunter 2011; Young 2011)
Architectural features	See Table 1.1
Pond/water feature	(Beatley & Newman 2013; McPherson 1990)
Natural ventilation	(Haase & Amato 2009)
Reflective surfaces	(Santamouris 2014; Syneffa et al. 2008)
Narrow streets	(Knowles 2003)
Street trees	(Hamin & Gurran 2009)
DROUGHT	
Water metering	(Boyle et al. 2013)
WSUD*	(Wong & Brown 2008)
Increased topsoil depth	(Bryce & Porter 2010)
Rain harvesting	(Rijke et al. 2014; van Roon 2007)
STORM SURGE**	
Coastal preservation/retreat/reclamation	(André et al. 2016)
ICE STORM	
Underground power lines	(Sharifi & Yamagata 2016a; Bouffard & Kirschen 2008)
OVERLAND FLOODING	
Flow-through main floor	(Schwab 2016; FEMA 2010)
Elevated utilities	(FEMA 2010)
Elevated construction	(Schwab 2016; FEMA 2010)
Floodplain retreat/reclamation	(André et al. 2016)

* WSUD: Water Sensitive Urban Design

** Storm surges are worsened by on-going sea level rise, but these parallel overland flooding and high winds in terms of adaptation strategies, as such, only coastal strategies are listed here to avoid repetition. Sea level rise is not addressed here because it is not an extreme weather event.

The information presented in Section 1.5 of this chapter demonstrates the role played by green and blue infrastructure in terms of mitigating climate change and adapting to climate change-related extreme weather. The content summarized in the tables is not a complete list of possible strategies, but does highlight the need for integrating green and blue infrastructure into urban systems as part of resilience system design, rather than relegating it to environmental departments or ministries (Birkmann et al. 2010). Not addressed in the tables above is the importance this type of infrastructure plays in supporting urban environments beyond physical resilience in terms of filtering pollutants from air and water, or encouraging biodiversity (Ahern et al. 2014; Colding 2007). Additionally, the above information omits correlations between social and economic resilience afforded by green and blue infrastructure because this falls outside the scope of this research.

1.6 Assessing Resilience

Creating and supporting urban resilience necessitates understanding not only what vulnerabilities and hazards exist or could impact an area, but what capacity exists to deal with any impacts. The focus of urban resilience in this thesis is on systems – incorporating a combination of engineered, human, and natural elements. Their capacity is explored through their functionality and this is the goal of the methodology presented in Chapter 3.

Breaking down this functionality to understand adaptive capacity forms part of other resilience assessments. The scale of these assessments range in scope from individual structures such as bridges or buildings, to international political and economic zones, like the European Union, or they are industry-focused, such as forestry or tourism. Capturing an accurate picture of compounding vulnerabilities while including temporal differences in recovery and risks, as well as post-disaster functionality has led to escalating levels of complexity in assessment tools especially for deployment at city or regional scales. This complexity can be demonstrated by the assessment developed for the *100 Resilient Cities* (100RC) initiative, which identifies eight resilience aspects for a city. A city…

> "delivers basic needs; safeguards human life; protects, maintains and enhances assets; facilitates human relationships and identity; promotes knowledge; defends the rule of law, justice and equity; supports livelihoods; stimulates economic prosperity." (p.4)
>
> from *City Resilience Index* (Rockefellar Foundation 2015)

All these aspects are important, obviously, but many involve broad social justice goals or administrative functions un-related to extreme weather events. Infrastructure-focused evaluations operate at different scales from individual pieces, like the PIEVC (Public Infrastructure Engineering Vulnerability Committee) protocol (Engineers Canada 2005) or the Climate Resilience Evaluation & Awareness Tool (CREAT) (USEPA 2015). Regional or disaster-specific capabilities (institutions, circumstances, or the interplay of the two, such as the financial system or socio-psychological factors (UNISDR 2015)); specific social circumstances such as the relationship between social resilience and disaster (Cohen et al. 2013; Pfefferbaum et al. 2013), or even; emergency response readiness in terms of communications and evacuation (NIST 2016) are also assessing resilience capacity in cities. This narrow focus, though simpler to execute, and likely useful for specific applications or for limited resources, misses the interplay of systems within urban centres and so provide incomplete resilience pictures, especially given that resilience in one area can often have detrimental effects on the resilience of other areas, physically, financially, or otherwise, by diverting resources or services away (Bahadur &

Tanner 2014). This thesis centres on neighbourhood systems design, and so while not addressing social justice or governance, supports both these aspects by potentially alleviating added burdens during disruptions.

Cutter (2016) provides a synopsis of 27 of the more well-known assessments, and these range in scale from country down to specific pieces of infrastructure. Cutter distinguishes between tools, scorecards, and indices (p.744), though, in many cases tools can be used to provide data for indices, so overlap does exist. Additionally, assessments are examined as either a baseline examination or an asset evaluation, the scale further divides the metrics into scope, including categories such as Country, Infrastructure, City or Community. Outside of the 27 methodologies examined by Cutter, still others exist, and in terms of similarity to the proposed methodology herein, the LEED-ND (Leadership in Energy and Environmental Development – Neighborhood Design) provides an important comparison by acknowledging the interplay of building design, urban systems, green space etc., as does the new RELi system (RELi Collaborative 2014) recently adopted by the US Green Building Council. On the following page, Table 1.5 provides a synopsis of resilience assessments operating at a variety of scales but addressing the adaptive capacity of infrastructure and systems specifically. Also included are the systems/infrastructural components of larger assessments.

Table 1.5 – Other Resilience Assessments

SYSTEM	SCALE	FOCUS	REFERENCE
LEED-ND	Various	**Primarily for new developments** Applicable area contains at least two habitable buildings and be no larger than 1500 acres (p.52) -Points-based certification for neighbourhood design examining: building design, circulation pattern, green infrastructure, density, employment statistics, natural area protection, light pollution, transportation,	(US Green Building Council 2014)
RELi	Neighbourhood	**Primarily for new developments**	(RELi Collaborative 2014)
PIEVC Protocol	Built form	Assessment of individual pieces of built (grey) infrastructure to specific climate change hazards incorporating risk level.	(Engineers Canada 2005)
PEOPLES	Various	Has a *Physical Infrastructure* component addressing existing built form: residential, commercial, cultural, healthcare, communications/media, food, utilities, transportation. Addresses resilience by highlighting interdependencies with the other components (social, economic etc.) and examines these interdependencies at a variety of scales with a view to understanding vulnerability	(Renschler et al. 2010)
Rockefeller 100RC/CRI	City	*Infrastructure and Ecosystems* is one section with three main areas: mobility + communications; critical service provision; reduced exposure + fragility NB: food, water, energy + housing fall under 'human vulnerability' in the *Health and Wellbeing* section. This system is designed for cities everywhere and so the assessment includes access to food, water etc. through affordability etc. Results are Qualitative and Quantitative. Qualitatives are assessed for meeting 9 criteria (robust, reflective, resourceful, redundant, flexible etc) and assessed on a continuum of 0-5 from worst to best-case scenario. Quantitative metrics are devised by cities themselves and then measured and documented.	(Rockefellar Foundation 2015)
UNISDR Disaster Resilience Scorecard for Cities	City	Uses a scale from 0 – 5 for all areas, with 5 as "deploying best practice" Infrastructure assessed includes: Water, Sanitation, Gas, Electricity, Transportation and examines not only likelihood of disruption, but probabilities of days of service interruption.	(UNISDR 2015)

The above assessments demonstrate not only the appetite for establishing institutional frameworks and protocols to support resilience, but also a means to evaluate decisions and planning from governance and also a disaster readiness perspective. The methodology presented in this thesis, while not ‘better’ or ‘worse’ than those described above, supports these types of more well-known or widely-adopted systems by narrowing the focus and helping planners build and plan for existing and future neighbourhoods. Much like resilience itself, the methodology presented here is only one of many parts of a resilience assessment. A city is a manifestation of a society’s collective priorities, recognizing the current climate reality necessarily shifts these priorities. *Resilience Oriented Design* recognizes this shift and meets the challenges of future-proofing neighbourhoods.

CHAPTER 2 – CREATING THE METHODOLOGY

This chapter contextualizes neighbourhood systems individually and examines current research into each system in terms of resilience and sustainability. The organization of the proposed methodology is outlined with reference to that research and criteria and metrics are introduced. Clarification is provided on some terminology and the scale of the proposed methodology.

2 Neighbourhoods

Within this thesis a distinction is made between 'neighbourhood' and 'community'. Here, a neighbourhood is understood as a physical area within a city with defined, yet arbitrary, boundaries. A community, however, though it may inhabit a neighbourhood, is more dynamic. It implies a commonality of belief, background, interests, or income etc. and is therefore not confined to a specific geographic area.

In a North American context urban development generally occurs at the neighbourhood scale, and as such, neighbourhoods can be considered 'development units'. As development units they are a product of the era in which they were built – embodying and reflecting contemporary planning philosophy, technology, architecture, resource availability, culture, and infrastructure. Because of this, there is a degree of homogeneity within a neighbourhood. Despite many similarities, all neighbourhoods of the same era are not identical, especially in terms of climate change vulnerability, because they maintain different risks due to their location or topography.

A neighbourhood built on a floodplain is subject to different potential hazards than one located on a hilltop, or vulnerability may vary because of the degree to which pre-existing natural systems have been undermined (Gunderson 2010; Forman 2008). Acknowledging the uniqueness of each neighbourhood in terms of its location and history highlights the potential for designing neighbourhoods with a view to decreasing risk and vulnerability.

2.1 Systems in Neighbourhoods

In cities, households are the smallest scale operating to satisfy the fundamental human physiological needs outlined by Maslow (1954) - food, water, warmth, rest, safety, and security. In a Canadian cultural and climatic context, basic needs extend further and include: food, water, energy, shelter, transportation, and waste management (Sarlo et al. 2001). Whether using Maslow's or Sarlo's list, a Canadian household's ability to access needs is tied to the existence, integrity, and reliability of a variety of systems operating both within the neighbourhood and extending outside its boundaries. In this way, neighbourhoods can be understood as the smallest collective scale at which household needs are met. At this scale, urban form, including distance to amenities, road network design, sidewalks, green space, infrastructure design, and pathways etc., influence the way residents meet their basic needs.

This causal relationship is demonstrated in research on urban food deserts, where the absence of a local grocery outlet with fresh produce, coupled with limited transit access impacts resident food access negatively (Coveney & O'Dwyer 2009). While neighbourhood built form exerts an influence on need acquisition, the ability to do this during a disruption is further affected by the resilience of the wider system supporting this need. For example, if food access requires private vehicle transportation because there are no local outlets and the road network becomes impassable, then the neighbourhood food system is vulnerable. To recognize specific vulnerabilities, system structure, organization, and limits require understanding (Francis & Bekera 2014) and the threshold for dysfunctionality requires identifying.

2.1.1 Thresholds

Though with multiple land use designations, a neighbourhood serves a specific function, as residential, light industrial, or commercial, in a municipality. Neighbourhoods evolve over time through redevelopment, but also as green elements (trees etc.) mature, and (infra)structures age. Despite a gradual shift over its life span, a neighbourhood retains its function within a larger urban system, though it may evolve from residential to mixed-use to commercial, for example. This is very different from retaining *functionality* under acute stressors, however. Functionality refers to a neighbourhood's own systems and their routine operations. The ability to maintain this functionality under stress is a manifestation of its adaptive capacity, as discussed in Section 1.2. The point where stressors overwhelm a system's adaptive capacity and disrupt functionality is referred to as a *threshold* (Folke et al. 2010; Walker et al. 2004). This point differs between and among neighbourhood systems, and so defining expectations or baseline functionality is part of understanding adaptive capacity (Carpenter et al. 2001), and this requires defining not only the system, but what functionality entails – without these parameters, describing a system as resilient or not, is meaningless (Cumming 2011).

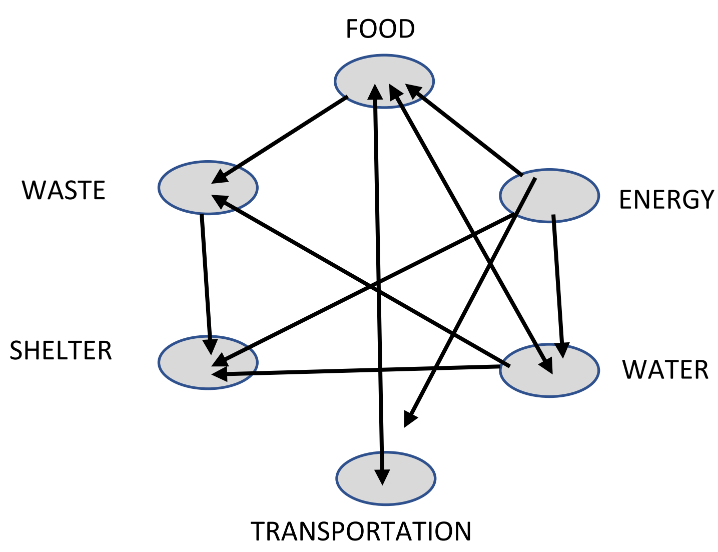
As mentioned above, neighbourhood systems supporting residents in meeting their needs are used to examine neighbourhood resilience. The adaptive capacity of these systems is overwhelmed when resident needs are not met; they are hungry (food), cold (energy), exposed (shelter), stranded (transportation), etc. Met needs indicate functionality, though functionality in one need system is not necessarily contingent on functionality in others.

For example, homes (shelter) may be intact and safe, but have no access to electricity (energy) and so cooking is impacted (food). Within this thesis, (dys)functionality is examined as a local neighbourhood phenomenon, not in terms of broad municipal disaster caused by other natural events such as tsunamis or earthquakes that affect multiple neighbourhoods or entire cities at once.

2.1.2 Interplay of Basic Needs

Some neighbourhood basic need systems are obvious, such as food and transportation. Here, infrastructure is visible, and once established, exists permanently as part of the built environment. Other systems are subtle and complex because they operate at multiple scales, may require constant input, or have connectivity to other systems. For example, the food system is connected to energy and transportation because food requires storage and preparation (energy) and is accessed by residents and produced outside the area (transportation). Below, Figure 2 illustrates the connectivity between neighbourhood systems in an urban North American context.

Figure 2 – Connectivity and Interdependence Between Needs



2.2 Needs in Context

Food:

Food resilience includes two primary facets: a) production and distribution, and b) consumption. In the face of more extreme weather, growing food becomes increasingly unpredictable, thereby affecting consumption because a potential lack of availability (Porter et al. 2014; Schmidhuber & Tubiello 2007; Motha & Baier 2005). This can be seen in Canada with the destruction of crops by hail storms. Beyond coping with shifting weather patterns, the pervasiveness of industrial agriculture includes additional vulnerabilities. Reliance on fossil fuel-based mechanization, as well as the increasing proliferation of 'super' pests and weeds from the interplay between mono-cultivation, gene manipulation, and breeding (Altieri & Nicholls 2012), all contribute to food supply vulnerability. This vulnerability, largely tied to the enormous scale of food production (Hendrickson 2015), is felt at the household level in terms of fluctuating availability and unpredictable pricing, it is exacerbated by the vast distances food covers to arrive at grocery outlets (Ruhf 2015; Fresco 2009). Smaller 'peasant' or community-based agriculture lacks the energy intensity of large-scale farming (Altieri & Nicholls 2012), and because of this, local and small scale farms, likely with more crop diversity, are not only more resilient in the short term, but also more sustainable in the long term (King 2008). Key to a resilient food system, therefore, is the existence of transportation networks as well as access to energy to move supplies, coupled with a diversity of sources, from local to regional (Barthel & Isendahl 2013).

The lack of food system awareness and action in urban planning practice was identified almost two decades ago by Pothukuchi & Kaufman (2000), but to date, only 200

‘Agrihoods’ exist in the USA (ULI.org, 2015). Because neighbourhood food production is not planned for, insecure land tenure is one of the primary issues with urban food production (Guitart et al. 2012), indicating the necessity to include it at the development and zoning stages of neighbourhood planning. Even though urban food self-sufficiency is unlikely in a North American context because of the land area required to generate enough fresh produce, grain, and meat during a finite growing season for an urban population (Grewal & Grewal 2012), growing food in cities contributes to food source redundancy. Edible landscapes offer an opportunity to integrate food production with green networks, park space, and private property in existing urban spaces (Lovell 2010; Bhatt & Farah 2009).

Energy:

Climate change impacts to the energy sector fall within three areas: generation, transmission/distribution, and demand (Canadian Electricity Association 2016). In terms of generation, fuel source plays a significant role, not only because of complex networks involved in fossil fuel extraction and processing (Bouffard & Kirschen 2008), but also because of emissions related to energy production (Sims et al. 2003). Production methods, such as combined heat and power (CHP) plants, as well as District Energy (DE), community grids, or on-site generation using building integrated photo-voltaic (BIPV), roof top solar, geothermal heating, or micro wind turbines, decreases these emissions by exploiting ‘by products’ of energy production such as waste heat, or by using renewable sources. Smaller and local production also increases efficiency (Miceli 2013) and decreases emissions by eliminating losses associated with long distance transmission. Under the current system, more electricity is produced than is required because of significant losses during transmission and conversion (Harvey 2013). Furthermore, local production lacks the vulnerabilities associated with above-ground, long-distance transmission lines (Sharifi & Yamagata 2016b; Bouffard & Kirschen 2008).

Demand and consumption are impacted by a number of factors including: 1) urban form for exploiting passive heating and cooling with solar access or mutual shading (Adachi et al. 2014; Stone et al. 2010; Hamin & Gurran 2009; Grosso 1998; Littlefair 1998); 2) green infrastructure for shading, urban heat island mitigation, or with green roofs (Rafiee et al. 2016; Adachi et al. 2014; Demuzere et al. 2014; McPherson 1990), and; 3) building materials and design with reflective materials, architectural details, and energy efficient technologies (Hachem et al. 2013; Santamouris 2014; Syneffa et al. 2008; Knowles 2003; Santamouris et al. 2001). Efficiency and reduced-demand strategies can be addressed at the design and planning stages and be included in new neighbourhood covenants.

Additionally, at the consumption end, power and heat can be generated from similar or different fuel type sources, for example, in the Atlantic provinces in Canada, natural gas heating for homes is uncommon, and electrical sources are used, whereas gas-fired furnaces are the norm in many prairie provinces, though less so in more rural communities (NRCan 2003). Gathering information about the energy system in a neighbourhood requires preliminary research into dominant local fuels. This is also relevant for understanding distribution network scale, for example, neighbourhoods could never have a local nuclear power plant, or a run-of-stream plant may not generate enough power for a local supply.

Water:

Guaranteeing access to this fundamental physiological necessity involves not only maintaining and creating appropriate urban infrastructure, but also managing water resources effectively. Water access is on the frontline of climate change resilience not only because of its necessity to human life, but also because of its vulnerability to shifting precipitation patterns globally (Howard & Bartram 2010). Curbing waste, diminishing use, and capturing storm water all play important roles in the urban water cycle (van Roon 2007). This implies that effective water management is a resource-based socio-technical endeavour (Pahl-Wostl 2007), that is, based on a combination of human behaviour, infrastructure, and governance of a natural resource. It should also be noted here that potable water accounts for only 15% of global water use, whereas agriculture accounts for 70%, or higher in some regions (Howard & Bartram 2010), – tying urban water conservation to food accessibility.

Many of the current inefficiencies surrounding water management and governance are ‘legacy’ problems stemming from policies and infrastructure established in the past. As such, despite a current shift in thinking around what is desirable, compatibility with established systems is necessary (Marlow et al. 2013). Understanding water delivery in a neighbourhood is unique because urban water systems are not confined to neighbourhoods, but form part of a wider municipal system. This connection to a wider network is addressed by not limiting research to the neighbourhood scale. Research surrounding water sensitive urban design (WSUD) by Wong & Brown (2008) provide an extensive list of strategies and technologies appropriate at the neighbourhood scale. Grey water systems, also known as third pipe systems, or rain capturing cisterns, offer potential for curbing water use and energy spent on treatment by using non-potable water for outdoor watering or flushing. Legislation and neighbourhood covenants also play important roles with 'watering days', metering, rain barrels and cisterns, regulating topsoil depth, xeriscaping, or requiring drought-tolerant plants, native species etc.

Transportation:

Transportation in an urban centre is both local and municipal. Choosing between a private vehicle, walking, biking, and transit is a function of a number of factors such as street network layout (Hachem 2016; Hess et al. 2013; Sandalack et al. 2013; CMHC 2008; Randall & Baetz 2001), architecture (Wey & Chiu 2013; Krizek 2003), land use and distance (Shannon 2015; Ratner & Goetz 2013; Wey & Chiu 2013; Guitart et al. 2012; Olaru et al. 2011; Cervero & Murakami 2010; Hoedl et al. 2010; Coveney & O'Dwyer 2009), and infrastructure (Cervero & Murakami 2010; Hoedl et al. 2010; McNeil 2010; Saelens et al. 2003). In North America, most post-war neighbourhoods have car-centric designs (Sandalack et al. 2013), and so examining neighbourhood transportation using car access as a 'default' can highlight the relative (in)accessibility of other modes.

Shelter:

Broadly, the term *shelter* refers to a place where regular routines, such as washing, eating, and sleeping, take place. Given this, shelters in neighbourhoods are vulnerable in two primary ways: a) *functionally*, that is, tied to thermal comfort, running water, and reliable electrical access, and; b) *structurally*, tied to safety and security (Uda & Kennedy 2015). Depending on the nature of a disruption, alternative housing may be required by some or all residents, and so vulnerability is tied to accessing alternative housing and having a functioning shelter. Understanding the relationship of a shelter's functionality, that is, its ability to provide thermal comfort and clean water and safety, links regular shelters/dwellings to other neighbourhood systems. The greater a shelter's capacity to be independent, or less reliant, on these other systems, increases its independence and resilience. Related to this is the nature of any alternative housing and the length of time it may be required by residents. Quarantelli (1995) distinguishes among four types of post-disaster/disruption shelters: 1) *Emergency Shelter*, involving short-term safety over several hours or overnight; 2) *Temporary Shelter*, referring to temporary displacement over several days, without re-establishing normal routines, but meeting other needs such as food and water; 3) *Temporary Housing*, referring to shelters where normal routines are re-established, and re-building of Permanent Housing is a long-term goal, and; 4) *Permanent Housing*, involving a return to previous homes, or the construction of replacement homes either in the same place or another area (p.45). Within this thesis, the focus is on *Emergency* and *Temporary Shelter* simply because *Temporary Housing* and *Permanent Housing* do not exist until after a major disruption occurs. Furthermore, the scale of this research assesses disruption as a local phenomenon, or affecting the immediate or adjacent neighbourhoods only, and not widespread municipal destruction. Shelter can be affected by a wide variety of hazards differentially throughout a neighbourhood. Additionally, some shelters are more resistant to specific local conditions. A house built on stilts, for example, is less likely to be affected by flooding, and so appropriateness of shelters to location is important.

Waste Management:

Within developed countries, waste produced within a neighbourhood falls under five main 'types': human; green (food preparation and garden maintenance); domestic refuse (packaging, textiles etc.); construction debris, and; hazardous materials (used lightbulbs, paint, cleaning products etc.). Managing all five waste streams is important to urban functionality and global sustainability, but in terms of climate change adaptation and mitigation and meeting basic needs, the human and green streams are more critical because of the health risks and diseases associated with putrefaction (Howard & Bartram 2010). This category is further complicated by gaps in research. There are numerous studies outlining best practice, or assessments of, waste management in developing countries, and the viability or feasibility of different types of systems (for examples see Sekito et al. (2013); Asase et al. (2009); Ngoc & Schnitzer (2009); Colon & Fawcett (2006); Al-Jayyousi (2003)) but waste management systems in developed countries are already well-established. Furthermore, in developed countries it generally follows one type of water-borne system – a system that is energy and water intensive, inefficient, polluting, and expensive (Cordova & Knuth 2005).

There are several overlapping aspects in waste and water systems: both are part of a wider municipal network, both rely on a supply of water originating outside the immediate area, both are systems with a behavioural component, and, in developed countries, both maintain legacy issues for integrating new strategies. Because of its close relationship to water supply, two main threats associated with climate change impacts on waste systems exist: 1) diminished access to water supplies for water-borne sanitation caused by drought or low ground-water levels, and; 2) undermining of underground infrastructures from increased precipitation (Howard & Bartram 2010). This second vulnerability includes problems caused by increased ground water levels, as well as issues surrounding merged storm water and sewer systems. In North America, this type of merged system was more common in the past, and so the age of the neighbourhood is relevant to any assessment. Storm water, however, is omitted from the waste section of this proposed methodology, even though it could be considered a 'waste' product, as it is not a by-product of the local population. This presents some confusion in terms of sustainable systems because storm water can be used within waste systems, as grey water for toilets for example – because of this connection, this aspect is addressed in the Water section.

2.2.1 Observations

Evidence from the above research surrounding neighbourhood systems suggests there are two levels of assessment required to understand system functionality - an *accessibility* level, and a *network* level, that is, how needs are accessed by the public, and how networks operate. The interplay of these two levels differs depending on the system in question, but this distinction does provide an effective point of departure. The methodology presented in Chapter 3 is based on these two levels, and these two levels are addressed in depth in Section 2.3.1, below.

2.3 Neighbourhood System Functionality

Dysfunctionality in a basic need system is recognizable when needs are not met – residents are hungry (food), there is no electricity (energy), homes are uninhabitable (shelter) etc. Using the experience and perspective of residents to define (dys)functionality, that is, recognizing its threshold, provides the necessary parameter for defining what is meant by neighbourhood resilience in this thesis. There is resilience in the system if a need is met regardless of disruptions.

As outlined in Section 1.1.2, a resilient system possesses adaptive capacity and this is tied to the presence of certain system attributes: redundancy, flexibility, diversity, efficiency, autonomy, strength, interdependence, and collaboration. Furthermore, research described in Section 2.1 indicates the importance of using specific strategies within urban environments to support resilience to climate change-related events. These include: green (vegetative) and blue (water) infrastructure; accommodating existing natural systems; energy efficiency and passive design, i.e. reducing consumption levels with designs not requiring operational energy input; local/regional resources; renewable energy production, and; urban planning for active transportation (walking, cycling, transit). Creating an assessment of a neighbourhood's "state of resilience" then, requires uncovering the presence of these strategies in routine system functionality. Furthermore, because of interplay between systems, overlap must also be acknowledged.

2.3.1 Assessing Functionality

As described in Section 2.2.1, assessing regular functionality requires two levels of inquiry: the household level and the network level. For the proposed assessment framework, these are addressed using one of two metric Categories: *Access* for households, and *Operations*, for networks. Within each Category there are two metrics employed to assess functionality: *Proximity* and *Diversity* for *Access*, and *Efficiency* and *Autonomy* for *Operations*. These two levels of inquiry are not necessarily separate, and overlaps or interdependencies are addressed at the end of the assessment when results are interpreted.

Additionally, neighbourhood systems differ in two important ways: they are either based on incoming elements, such as Food, Water, and Energy, or they are part of the fabric of the built environment and include Transportation, Shelter, and Waste Management. This difference is acknowledged by separating systems into one of two types: *Supplies* or *Supports*. Below, Table 2.1 illustrates the breakdown between *Supplies* and *Supports*, *Categories*, and *Metrics*. While no one metric provides all the required information about a system, a holistic picture is achieved through the interplay of metrics.

Table 2.1 – Breakdown of Categories, Metrics, and System Types

		NEIGHBOURHOOD SYSTEMS + TYPES					
		SUPPLIES			SUPPORTS		
CATEGORIES	METRICS	FOOD	ENERGY	WATER	TRANSPORTATION	SHELTER	WASTE MGMT
ACCESS	PROXIMITY						
	DIVERSITY						
OPERATIONS	EFFICIENCY						
	AUTONOMY						

2.4 Metric Development

Similar information is required for both *Supplies* and *Supports*, however, acquiring pertinent data involves two different approaches because of the nature of their relationship to residents. The sections below outline metric criteria within Supplies and Supports, and following Sections 2.4.1 and 2.4.2, Table 2.2 on page 38, provides an illustration of the metrics. Context, criteria, and evaluation parameters are provided in Chapter 3.

2.4.1 Supplies – Food, Energy, Water

Metrics employed to assess *Supplies* are designed to extract information regarding production, distribution, and consumption. Because Supply Needs require constant input, understanding how and where food, energy and water originate and arrive into the neighbourhood and municipality, as well as how they are used by households individually, or by the community is important. Additional vulnerabilities are tied to increased distances because the point of origin maintains its own hazards. Examining the consumption of these Needs highlights connections to other Needs, for example, cooking food is tied to access to energy, further tied to a shelter's integrity.

Access: As mentioned above, two metrics are used to assess access: *Proximity* and *Diversity*. The *Proximity* metric traces **Distance** of a need. Tracing distance travelled, and so origins, provides information on how easily it is obtained by households in terms of transportation or infrastructure, subsequently highlighting any potential vulnerabilities. The *Diversity* metric examines the **Options** available to residents in the neighbourhood in acquiring the Need. This information is important for uncovering any redundancies in the system.

Operations: Two metrics are also used here to assess system operations: *Efficiency* and *Autonomy*. The *Efficiency* metric tracks **Use** of the supply to acquire information either on the network's relative vulnerability to disruption in the dominant energy supply, or its conservation/consumption levels in the neighbourhood. The *Autonomy* metric examines the network's **Complexity** to assess its relationship to outside networks, thereby providing information on its relative in- or inter- dependence.

2.4.2 Supports – Shelter, Transportation, Waste Management

For these systems, the metrics examine neighbourhood built form and (infra)structures and how the two meet, or do not meet, resident needs. Because the goal is to uncover system attributes contributing to resilience, mitigative, collaborative, passive, and redundant strategies are sought.

Access: Again, two metrics are used to assess access: *Proximity* and *Diversity*. The *Proximity* metric here traces travelling **Distance** within the neighbourhood because the ability of households to access these needs is dependent on location. The *Diversity* metric examines the **Options** available within the neighbourhood in meeting the need, and so the metric is designed to uncover redundancies in service.

Operations: The metrics used to assess operations are, again, *Efficiency* and *Autonomy*. The *Efficiency* metric tracks **Use** for each need to uncover its capacity to operate in the face of energy disruption. The *Autonomy* metric examines **Design** within the neighbourhood and documents strategies or initiatives currently existing to support neighbourhood operations in terms of infrastructure or features.

Table 2.2 – Breakdown from Table 2.1, with Metric Titles

		NEIGHBOURHOOD SYSTEMS					
		SUPPLIES			SUPPORTS		
METRIC CATEGORIES	METRICS	FOOD	ENERGY	WATER	TRANSPORTATION	SHELTER	WASTE MGMT
ACCESS	PROXIMITY	DISTANCE			DISTANCE		
	DIVERSITY	OPTIONS			OPTIONS		
OPERATIONS	EFFICIENCY	USE			USE		
	AUTONOMY	COMPLEXITY			DESIGN		

CHAPTER 3 – METRICS AND METHODOLOGY

This chapter outlines the metrics and framework used to examine each neighbourhood system satisfying basic needs of residents: Food, Water, Energy, Shelter, Transportation, and Waste Management. For simplicity, systems are divided by type, Supplies and Supports, and a glossary of terms is provided at the beginning of each section. The metrics described below serve as representatives for the functionality of systems operating in the neighbourhood. Together they document key information that can be examined alongside the specific extreme weather or locational vulnerabilities occurring in the neighbourhood.

3 Overview

Sections 1.4 and 1.5 in Chapter 1 examine the interplay and impact of neighbourhood features and elements on Food, Water, Energy, Shelter, Transportation, and Waste Management system functionality. In this chapter, these features and elements, specifically land use, layout, size, distances, green elements, resources, infrastructure, and local amenities, are used to examine neighbourhood systems. Tabulating these elements involves several steps and metrics and results are gathered in a matrix designed specifically for each Need using the categories outlined in Sections 2.4.1 and 2.4.2 in Chapter 2. Each Need has their own matrix, and these are shown at the beginning of each section, and each metric is explained individually.

3.1 Supplies

As mentioned in Chapter 2, Section 2.3.1, basic needs within neighbourhoods can be broadly grouped in two types, either as *Supplies* or *Supports*. Supply needs require constant input, and so these include Food, Energy, and Water. How the Food, Energy, and Water systems are examined individually is explained in Sections 3.1.1, 3.1.2, and 3.1.3, respectively.

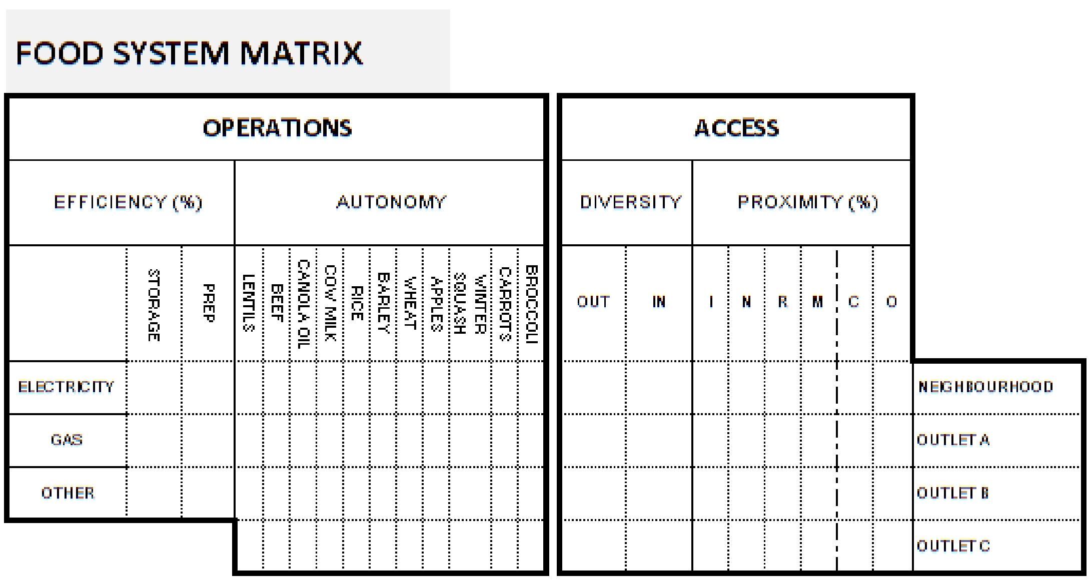
For all Supply needs systems, the *Proximity* metric uses relative, not physical, distance and so 'distance groups' are used and these are found in Table 3.2, on the following page.

Not all distance groups are applicable in each Supply need, for example, an On-site or Community source of potable water is unlikely, so these distance groups are omitted in the Water metrics. Also, because this methodology is customized to a Canadian context, the R (Regional) distance group is based on Transport Canada delivery guidelines.

3.1.1 Food

Below, Figure 3 illustrates the entire Food System Matrix.

Figure 3 – Food System Matrix



The four metrics in this section uncover information on food consumed in the neighbourhood: where it is grown, where it is bought, how it is prepared, as well as the networks supporting this production, purchase, and preparation. To do this, backyard/community vegetable gardens and nearby grocery stores must be identified. Ideally there would be a food outlet within neighbourhood boundaries, but if not, a walkshed is mapped for the nearest option(s). To map the walkshed, all possible walkable routes beginning at the food outlet and covering a 600m distance are mapped. This distance is used as the average distance covered on foot between five and ten minutes (Sandalack et al. 2013). A route is deemed 'walkable' if it meets the following two criteria: a) it includes a paved surface, no worn paths, and; b) it does not share space with vehicles – such as a length of road without a sidewalk or a back lane. If 33% of the subject neighbourhood's households fall within a food outlet's walkshed, then the outlet is included within the assessment. This assumption is based on the 33% threshold used by The United States Department of Agriculture (USDA) to identify food deserts[5]. This threshold is used specifically because of its widespread use and familiarity in food system discourse. Potential outlets include grocery stores and specialty shops (e.g. butcher), CSA drop off points, farmer's markets, and community gardens, and these terms are defined in Table 3.1, below. Excluded are outlets with more inconsistent supplies of fresh food like gas stations or convenience stores.

Table 3.1 – Glossary of Food Terminology

TERM	DEFINITION
Community Garden	Food production on public land located within the subject neighbourhood and grown by residents.
Community Supported Agriculture (CSA)	A system where households purchase a 'share' in a local farm each year and receive weekly deliveries of seasonal produce. Produce is either delivered directly to households or available at a municipal drop-off point.
Farmer's Market	Locally-grown produce sold in a temporary, public location within the municipality.
Key Foods	To simplify tracking all food available in a neighbourhood *key foods* (KF) are used as a proxy for food in general. These are established prior to the assessment and are dictated by local culture and any available government dietary standards.

Because the case study neighbourhoods in this thesis are Canadian, the most recent edition of the *Canada Food Guide* (CFG) (Health Canada 2007) is used to select key

[5] A food desert is a neighbourhood with no regular and permanent access to fresh produce at a retail food outlet. It is a label ascribed to a census tract falling at or above 33% access according to a variety of potential indicators (Ploeg et al. 2015)

foods (KF). These are listed in the Food System Matrix and used to assess neighbourhood food in general. Limiting the number of food items makes the assessment less cumbersome and more accurately reflects a 'crisis' situation where luxury food items are unnecessary to basic survival. Identified food outlets are not required to supply all KFs to be considered for the assessment.

The CFG recommends a variety of foods, and from their extensive list, the following items were selected because they a) are capable of being grown in most of Canada (excluding rice), and; b) reflect the relative amount of recommended foods from each food group:

Vegetables/Fruits:	Broccoli, Carrots, Winter squash, Apples
Grains:	Wheat, Barley, Rice
Dairy/Fat:	Cow milk, Canola oil
Proteins:	Beef, Lentils

Assessing the Food System: With KFs and food outlets identified, the assessment begins and uses the structure introduced in Table 2.2 from Chapter 2. Beginning with the *Access* category, the *Proximity* and *Diversity* metrics examine where food is produced and how it is accessed by residents, respectively. The *Operations* category examines food processing within households using energy supply, and the complexity of the food supply network using the *Efficiency* and *Autonomy* metrics, respectively.

3.1.1.1 Food Access

Proximity

For Supply Needs, the *Proximity* metric examines food ***Distance***. To do this, food origins are used to provide information on residents' relative dependence on outside networks to meet this need. Food production is examined as being either within the neighbourhood, as backyard production or in a community garden, or outside the neighbourhood, with each scale tracked differently. This metric is about network connections and not the actual distance food travels, so distance groups (see Table 3.2 below) are used with the O (On-site) and C (Community) distance groups used for food produced within neighbourhood boundaries, and M (Municipality), R (Regional), N (National), and I (International) used for food produced outside the neighbourhood.

Table 3.2 – Distance Groups

DISTANCE GROUP	DEFINITION
On-site	Within the property lines of the household or multi-family building
Community	Within the subject neighbourhood
Municipality	Within the municipality, outside the neighbourhood
Regional	Outside the municipality, within one-day return trip's distance (6.5 hrs** driving)
National	Outside one day's driving, within national borders*
International	Crossing an international border, regardless of distance

**13 hours is the maximum driving time allowed for delivery drivers in a 24 hour period (Transport Canada)

In the Food System Matrix, O and C cells are documented as a percentage of total neighbourhood households, with O calculated as the number of private yards with vegetable gardens, and; C as the number of public plots available to households. Acquiring this information requires examining satellite imagery, a site visit, and/or local community association or community garden research. For the purposes of this research, private and community gardens are assumed to produce only vegetable/fruit KFs, as neighbourhood beef production or wheat fields are unlikely.

The M (Municipality), R (Regional), N (National), and I (International) distance groups are assessed by visiting the food outlets identified at the beginning of this assessment and examining the origins of KFs available for sale. This provides some information about the degree to which neighbourhood residents are dependent on long-distance transport for food, a fact that increases vulnerability (Ruhf 2015; Fresco 2009). Results also reflect diversity of food sources – a crucial aspect of a resilient food system (Barthel & Isendahl 2013).

Results of food outlet site visits are documented as a percentage of all KFs, if more than one origin is available, the closest geographically is used. For example, a survey of all 11 KFs found at a *Safeway* in a Regina, Saskatchewan neighbourhood reveals the following information and the associated distance groups, shown in Table 3.3, below:

Table 3.3 – Sample Results

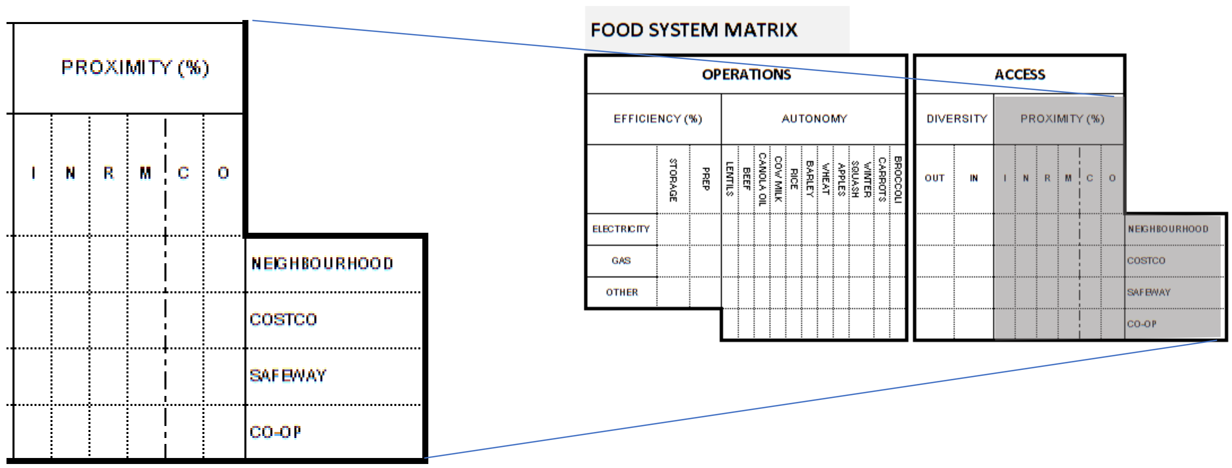
KEY FOOD	ORIGIN	DISTANCE GROUP
Broccoli	Ontario	National
Carrots	Ontario	National
Winter Squash	Ontario	National
Apples	Regina Orchard	Municipal
Wheat	Central Saskatchewan	Regional
Barley	Central Saskatchewan	Regional
Rice	Vietnam	International
Cow milk	Quebec	National
Canola Oil	Southern Alberta	National
Beef	Southern Alberta	National
Lentils	Southern Saskatchewan	Regional

The number of times each distance group is represented in the above results indicates the percentage of the 11 KFs available from each distance group.

Municipal: 1/11 = 9%
Regional: 3/11 = 27%
National: 6/11 = 54%
International: 1/11 = 9%

Figure 4, below, highlights the section of the Food System Matrix documenting the information gathered in this metric, using three fictional examples for neighbourhood food outlets: *Costco*; *Safeway*, and; *Co-op*. The ‘Neighbourhood’ outlet category refers to any potential CSA drop-off points or neighbourhood farmer’s markets.

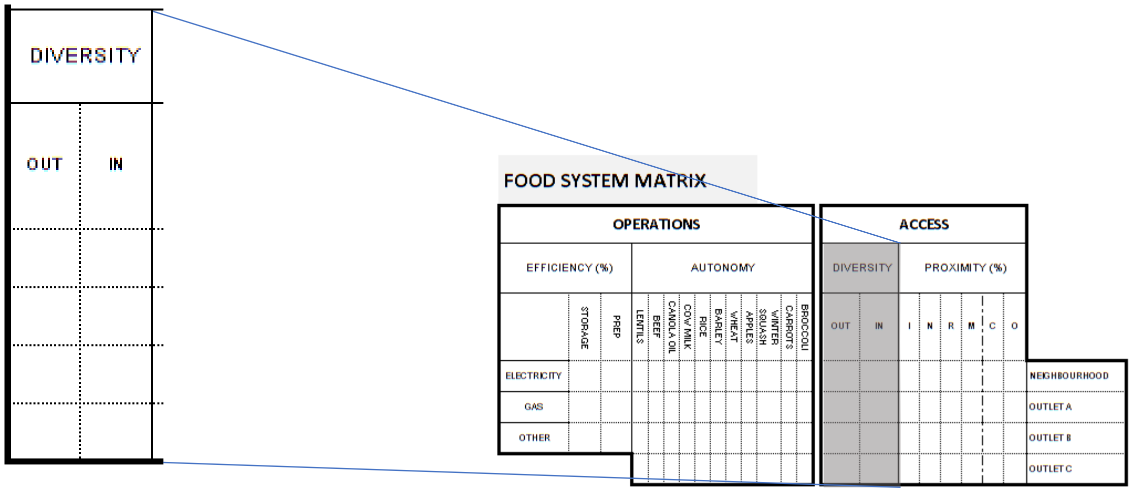
Figure 4 – Food System Matrix, Access Category, Proximity Metric



<u>Diversity</u>

The *Diverisity* metric examines food ***Options*** and refers to the number of outlets available to residents. Tracking the number and location of food outlets provides information on resident dependence on private vehicles to acquire food and/or also the choices available to them for accessing food without a vehicle. To do this, food outlets used in the *Proximity* metric are documented as either inside or outside neighbourhood boundaries and results are indicated with a X in the appropriate cell. Documenting each individual household’s method of access to these food outlets occurs in the Transportation section. Figure 5, on the following page, highlights the section of the Food System Matrix to document these results.

Figure 5 – Food System Matrix, Access Category, Diversity Metric



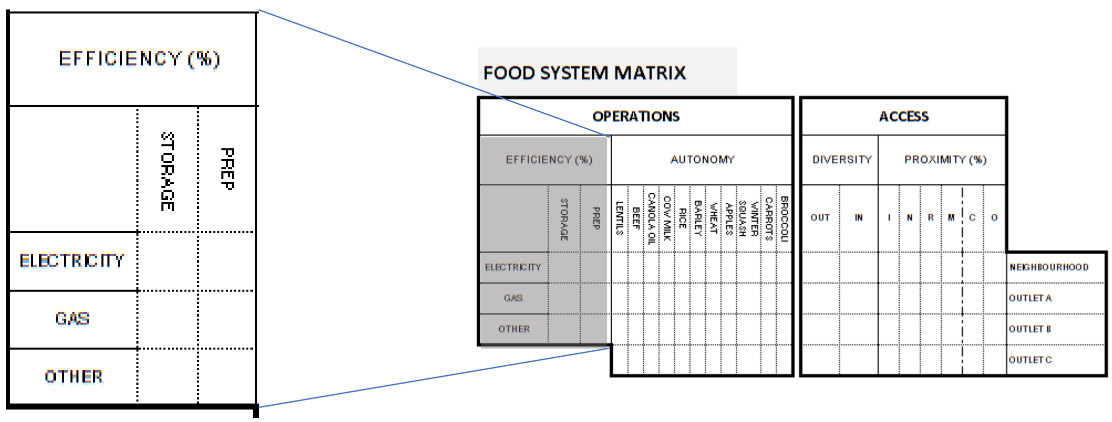
3.1.1.2 Food Operations

<u>Efficiency</u>

The *Efficiency* metric examines food ***Use*** and refers to household food preparation and storage in terms of energy. Tracking links between food and energy highlights potential food vulnerabilities relating to spoilage (storage) or dangers associated with eating undercooked or raw food (preparation). Specific aspects of electrical energy supply and distribution are addressed later in the Energy section, and so this metric explores the dependence of household food consumption on external energy supply.

Depending on the common fuels used in the municipality or region, food preparation is generally done either with gas or electricity, while electricity is used exclusively for food storage (fridge and freezer). Information on the type of cooking range (electric or gas) used in each household is difficult to acquire. In new neighbourhoods, home builders keep data on the type of ranges chosen by new homebuyers. In older neighbourhoods, a redevelopment date map combined with broad consumer trends can be used to estimate the breakdown of gas versus electric range use. Government data or anecdotal community housing developer experience/information may provide the information to estimate market breakdown. Results are documented as a percentage of total households in the neighbourhood using either Electricity or Gas (or another option) for food preparation and storage. Figure 6, below, highlights the section of the Food System Matrix for documenting these results.

Figure 6 – Food System Matrix, Operations Category, Efficiency Metric



Autonomy

The *Autonomy* metric examines food network ***Complexity*** and the degree to which food supply is tied to other networks, such as transportation. Tracking this provides information on ways that neighbourhood food vulnerability lies beyond the immediate control of residents. To do this, the supply chain of KFs are examined. Local, small scale farming involves lower levels of energy consumption, as does processing and preparing food on-site, with the opposite being true of large-scale industrial farms (Ruhf 2015). This 'embodied energy' is difficult to track consistently so instead food's logistical journey is traced. To do this, a system based on the cumulative "node" system outlined by Toth, Rendall & Reitsma (2016) in their research on food resilience, is used, with each node representing one 'stop' in a KF's journey. Each node is summarized in Table 3.4, found below, and node scores for each KF at all outlets identified earlier are tabulated. Lower numbers indicate a less complex network but do not address exact distances travelled. Results provide a broad reflection of the complexity of the network, not its energy consumption.

Table 3.4 – Food Nodes

STAGE	CODE	ACTIVITY	DESCRIPTION
Production	A	Growing and harvesting	This involves all the elements associated with food production such as feeding and raising cattle; watering, spraying, and harvesting crops, and; milking cows.
Central Processing	B	Slaughter, milling, freezing, drying, baking, canning, packaging	Depending on the KF in question, a number of different processes may be included here. For example, 'fresh' lentils are not sold to the public and so these are dried or canned before they are available to consumers; beef is usually hung and aged before butchering; milk is treated and given additives, etc. Regardless of the number of steps occurring for each food specifically, it is the added step of required processing being traced.
Transportation A	C	Crossing an international border	This tracks the journey of KFs across international borders, and each border crossed is tabulated.
Transportation B	D	Outside one day's driving, within national borders**	This node recognizes jurisdictional boundaries within one country. Because this methodology is based on Canadian geography, vast distances are often involved in food delivery. Like in *Transportation A*, each provincial border is counted.
Storage	E	Central distribution warehousing	Depending on the KF in question, this node can include long-term storage through freezing, or in inventory supply management.
On-site Processing	F	Processed at a food outlet	Some food outlets bake their own bread or butcher their own meat, and occasionally, they may even grow some vegetables. Having production and processing on-site eliminates complexity within the food system and also eliminates the above *Storage* node.
Distribution	G	Food outlet	The outlet where food is accessed by residents. It can be a CSA drop-off point, farmer's market, specialty shop, or grocery outlet

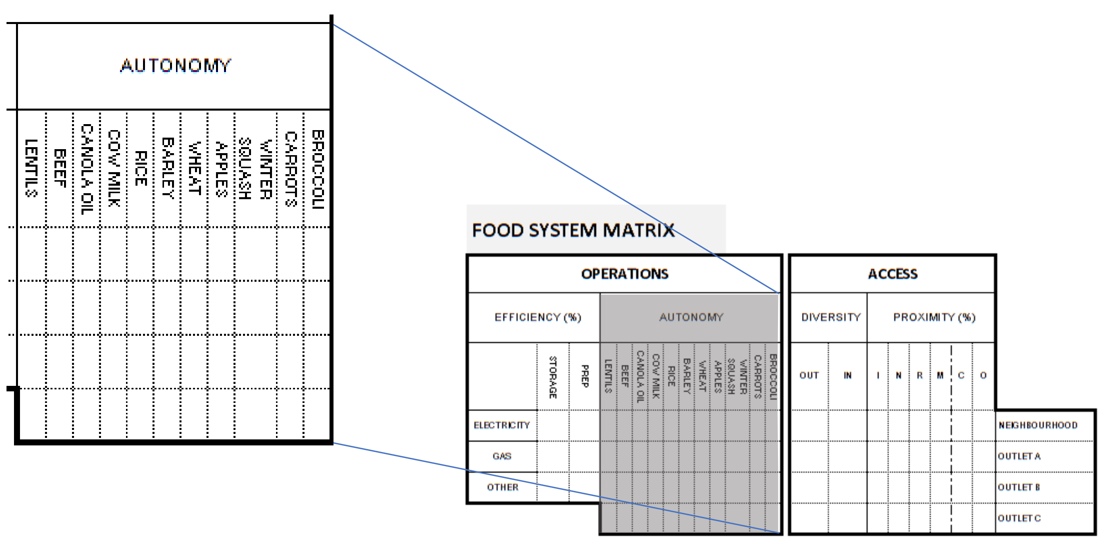
Calculating the number of nodes for each KF may involve making some assumptions about large chain warehousing and distribution, but details can often be inferred by reading labels or by visiting a company website to learn about their processes. An example of how to use the node system is provided below using two KFs, lentils and rice, available at a food outlet in Calgary:

Lentils: Grown in Saskatchewan, dried and packaged at a Saskatchewan facility, shipped to Alberta, distributed through a central warehouse, sold at a food outlet = 5 nodes (ABDEG) (see Table 3.4 for letters explanation)
Rice: Grown in Vietnam, packaged in Australia, ship to port at Vancouver, truck/train to Calgary, distributed through a central warehouse, sold at a food outlet = 7 nodes (AB**CC**DEG). **2 Cs are included because of the Vietnam, Australia, Canada international border crossings, see Table 3.4, above.

The results, 5 and 7 for lentils and rice, respectively, are input into the Food System Matrix in the cell corresponding not only to their food (lentil or rice) but also to the appropriate food outlet identified earlier.

Figure 7, below, highlights the section of the Food System Matrix for documenting these results.

Figure 7 – Food System Matrix, Operations Category, Autonomy Metric



Below, Table 3.5 provides a summary of all food metrics described above, and the methods used to measure or assess them and document the results. Within the table's three columns, *Metric*, *Resources*, and *Methods*, *Metric* explains the aspect being measured; *Resources* indicates how information is acquired; *Methods* outlines any relevant limitations or specifications in gathering the information.

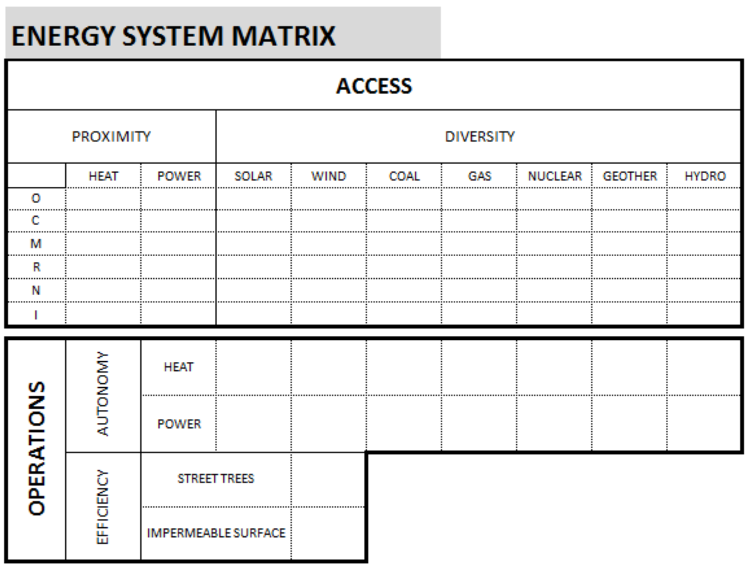
Table 3.5 – Summary of Food System Metrics

CATEGORY	METRIC		RESOURCES	METHODS
ACCESS	PROIMITY (DISTANCE)	Food within neighbourhood boundaries	Satellite imagery and neighbourhood site visit	If on-site or satellite examination for backyard food growing is limited, a sample of 25% of all neighbourhood yards is used size of backyards is used.
		KF analysis at each identified food outlet B) origins of KFs at outlets	Private company website research may be required to uncover processing or product procurement information or food outlet site visit to document place of origin. Some internet research on private company operations may be required	B) - site visit at each food outlet Closest geographical source is used when KFs are duplicated - food outlets include specialty shops (butcher, bakery)
	DIVERSITY (OPTIONS)	Variety/number of food outlets or sources located within neighbourhood boundaries	-internet research on CSAs operating locally -community websites and newsletters to locate possible farmer markets - walkshed mapping to track access	- located IN the neighbourhood or if outside boundaries must have 33% household penetration
OPERATIONS	EFFICIENCY (USE)	Fuels used for A) food preparation (cooking) B) food storage (fridge and freezer)	A) statistics from new home buyer appliance selection (electric/gas stove) B) storage: satellite imagery and local utility information	A) in older neighbourhoods the dominant/typical appliance choice from the era of construction is used.
	AUTONOMY (COMPLEXITY)	KF supply chain	- number of nodes between production and household access (see Table 3.3)	-using outlets/sources identified in Diversity metric

3.1.2 Energy

Below, Figure 8 illustrates the entire Energy System Matrix.

Figure 8 – Energy System Matrix



Prior to completing this metric, research on dominant local fuel type, as well as the nature of electrical distribution and generation, is required. The case study neighbourhoods in this thesis are both located in Alberta, which has a unique approach to energy provision and generation. In Alberta, electricity is pooled and managed by AESO (Alberta Energy System Operators), a provincial body, and is purchased by different retailers through AESO. There are some exceptions to this, however, for example in Calgary, the Shepard Energy Centre (SEC) is owned and operated by Enmax a City of Calgary organization, which is also an AESO customer. While AESO electricity is predominantly coal-fired in Alberta, the SEC is a combined heat and power (CHP) facility fueled by natural gas. Given that the SEC cannot supply all of Calgary’s electrical needs, uncovering the energy mix for individual Calgary neighbourhoods involves making some assumptions. Beyond this Calgary example, other assumptions are made, for example, the combination of fuel type and distance from households provides information about the type of distribution system deployed, though it is not specifically articulated. No one metric provides all the required information, but together metrics provide a more nuanced understanding.

Assessing the Energy System: The organization of the Energy System Matrix follows the structure introduced in Table 2.2 from Chapter 2. Beginning with the *Access* category, the *Proximity* and *Diversity* metrics examine where residential energy supply is produced and how it is accessed by residents, respectively, and these are divided by end uses: Heat or Power. The *Operations* category examines energy use and the relative complexity of the energy supply networks using the *Efficiency* and *Autonomy* metrics, respectively.

3.1.2.1 Energy Access

Proximity

For Supply Needs, the *Proximity* metric examines energy ***Distance***. Tracking where energy is generated provides information on residents' relative dependence on outside networks to meet this basic need. This metric does not reflect actual distance travelled, and so distance groups (see Table 3.6 below) are used with the O (On-site) and C (Community) distance groups representing energy produced within neighbourhood boundaries, while M (Municipality), R (Regional), N (National), and I (International) are used for energy generated outside the neighbourhood.

Table 3.6 – Distance Groups

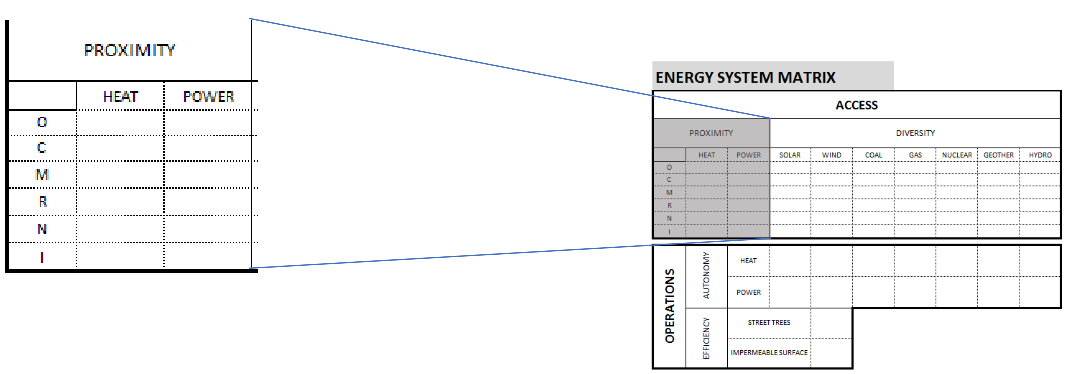
SOURCE	DEFINITION
On-site	Within the property lines of the household or multi-family building
Community	Within the subject neighbourhood
Municipality	Within the municipality, outside the neighbourhood
Regional	Outside the municipality, within one-day return trip's distance (6.5 hrs** driving)
National	Outside one day's driving, within national borders*
International	Crossing an international border, regardless of distance

**13 hours is the maximum driving time allowed for delivery drivers in a 24 hour period (Transport Canada)

The O and C groups are identified using satellite imagery to locate roof-top solar or neighbourhood solar arrays and wind turbines. Other potential local energy sources include rooftop solar thermal collectors, geothermal heating, and district heating systems. From this, reasearch can be completed to assess the number of households served by any communal or independent arrays. Results from this initial research can also provide additional information on consumption. For example, the solar thermal collectors on the roofs of some homes in Drake Landing, Okotoks, have eliminated the need for natural gas furnaces in those houses.

Tracking where energy is generated also provides information on the distribution network. Long distance transmission is more vulnerable to disruption (Blair & Sanger 2016). Small and local generation is not only more efficient (Li et al. 2017; Mora et al. 2017), but also lacks the vulnerabilities associated with increased distances. As mentioned in the beginning of this section, some assumptions may be required regarding the location of electrical generation, especially if a variety of electricity plants or sources are used within one municipality. Results of this metric are documented as a percentage of total households. Figure 9, below, highlights the section of the Energy System Matrix documenting the information gathered in this metric.

Figure 9 – Energy System Matrix, Access Category, Proximity Metric



Diversity

This *Diverisity* metric examines energy ***Options***. Tracking neighbourhood energy options provides information on fuel sources for neighbourhood heat and power. Fuel types listed in this metric are established using information gathered in the *Access Proximity* metric. Acquiring the information to populate the cells of this metric can be difficult depending on the nature of local regulations and legislation. In some cases, providers cannot divulge customer information, or as discussed earlier, electricity may be a pooled resource as it is in Alberta with AESO (see Section 3.1.2), and so approximations must be made using consumer trend reports, energy provider website information on energy mix etc. in the absence of a neighbourhood survey.

A fictional breakdown for a neighbourhood with 600 households, is provided in Figure 10, below, with H referring to *Heat*, and P to *Power*:

Heat:

- 70 households (11.6%) with rooftop solar thermal collectors
- 530 households (88%) using natural gas-fed furnaces

Power:

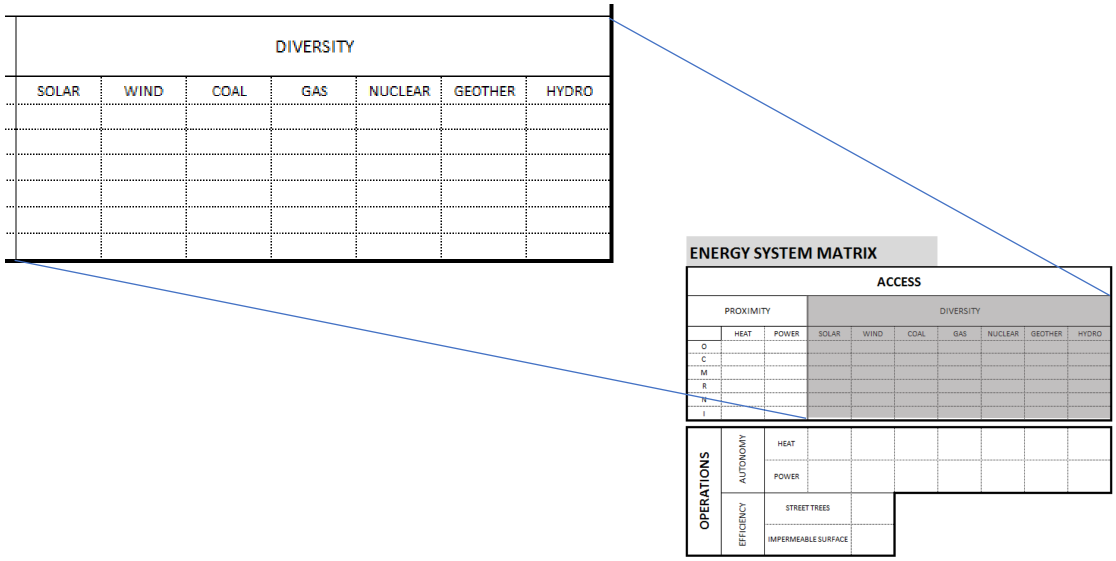
- 70 households (11.6%) with rooftop photo voltaic (PV) systems for electricity
- 150 households (25%) using a neighbourhood PV array for electricity
- 380 households (63%) using energy from a power plant located 50km outside city limits with a fuel mix of 80% coal and 20% wind

Figure 10 – Example Matrix

ACCESS									
PROXIMITY (%)			DIVERSITY (%)						
	HEAT	POWER	SOLAR	WIND	COAL	GAS	NUCLEAR	GEOTHER	HYDRO
O	12	12	H+P: 12						
C		25	P: 25						
M									
R	88	63		P: 12.6	P: 50.4	H: 88			
N									
I									

Figure 11, below, highlights the location within the Energy System Matrix for documenting these results.

Figure 11 – Energy System Matrix, Access Category, Diversity Metric



3.1.2.2 Energy Operations

<u>Efficiency</u>

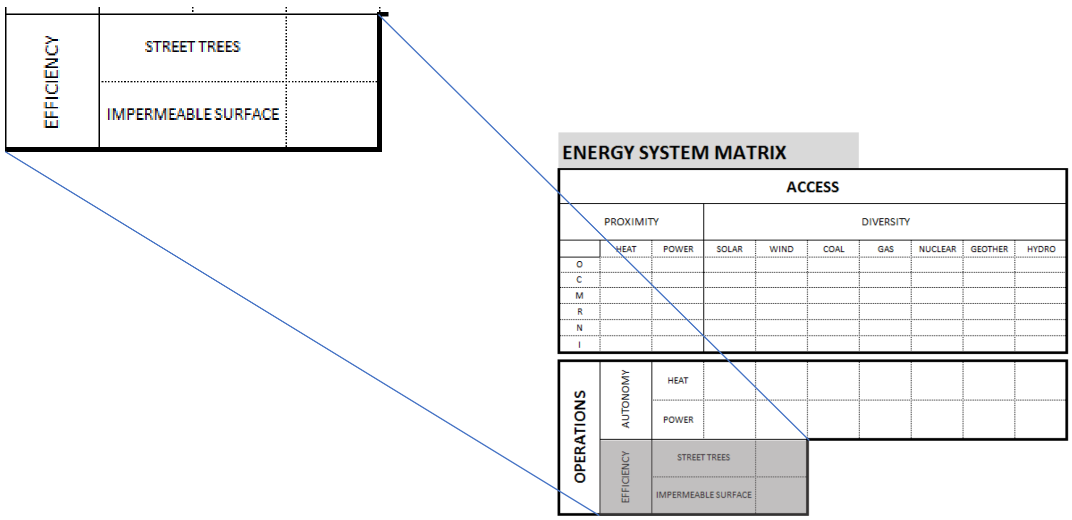
The *Efficiency* metric examines energy ***Use*** impacted by neighbourhood design and so the focus of this metric centres on elements diminishing overall energy consumption of households. As discussed in Section 2.2, natural/green elements play a significant role in offsetting energy consumption by mitigating urban heat island (UHI) effects either by casting shadows in summer, limiting the albedo effect of building materials with rooftop planting, or by replacing paved surfaces with grown elements or water features etc. Mitigating heat island is increasingly important because summer temperatures and heat waves are predicted to continually increase in intensity and frequency in the coming decade in most of the northern hemisphere (Sullivan 2011). While cooling represents only part of energy consumption, heating efficiency of individual structures is addressed later in the Shelter section of this chapter (Section 3.2.1). To assess the collective and cumulative impact of these neighbourhood elements, an online area measurement tool (McCartney 2007) and the distance measurement tool available at Google Earth are used. Two features are examined here: *street tree coverage*, and *impermeable surface area*, not only because canopy size can reduce energy consumption in summer by lowering ambient temperatures, and potentially reducing energy demand for air conditioners. A household requiring less energy to operate will be better able to cope with a disruption to the energy system. Below, Table 3.7 outlines the methodology of how each element is quantified. Results are documented as a percentage of either: total neighbourhood road length (street trees), or total neighbourhood area (surfaces).

Table 3.7 Energy Conservation Metrics

ASPECT	MEASURED BY:
Street tree coverage	Length of paved road with street trees planted within municipal egress **on both sides** as a percentage of total neighbourhood road length - using distance measurement tool at Google Earth
Impermeable surface area	Percentage of paved surface area (m^2) as a percentage of total neighbourhood area. -Includes: building footprints, roads, paved pathways, laneways, parking lots, driveways. - Building footprints and driveway surface areas are tabulated by averaging twenty random single-family homes and multiplying this by the number of detached dwellings in the neighbourhood. Multi-family units are measured individually. - online area measurement tool and satellite imagery found at www.freemaptools.com

Figure 12, on the following page, highlights the location within the Energy System Matrix for documenting these results.

Figure 12 – Energy System Matrix, Operations Category, Efficiency Metric



<u>Autonomy</u>

The *Autonomy* metric examines energy system ***Complexity*** and traces connectivity and dependence of local energy on outside networks. Dividing energy by end-use (Heat or Power), fuel supply and generation associated with different fuel types, are documented using information already gathered in the previous *Access Proximity* and *Diversity* metrics. Results are tabulated using the 'node system' created by Toth et al. (2016) to assess food system resilience, and provide a reflection of energy system complexity <u>not</u> consumption levels. Table 3.8, on the following page, provides an explanation of each node.

Table 3.8 – Energy Nodes

STAGE	CODE	ACTIVITY	DESCRIPTION
Extraction	A	Resource mining, drilling, fracking, collecting	This involves all activities surrounding the collection of fuel either as a natural resource (like coal or wood) or as a recycled resource (like biomass from waste)
Transportation	B	Transporting raw materials	This step recognizes the import of raw materials such as coal or oil to generate electricity – because resource extraction tends to be isolated from urban centres, this uses Regional, National or International transportation
Processing	C	refining, scrubbing, fermentation, compression	Depending on the fuel in question, a variety of processes are included here. Regardless of the number of steps occurring for each fuel, it is the added step of processing the fuel for use that is documented.
Production	D	Electricity/Heat generation	This step is required any time electricity is generated and not used immediately or heat is not a passive or geothermal source.
Storage	E	Electricity/Heat/Gas storage	This step recognizes the reality of electricity storage for later use.
Transmission A	F	Crossing an international border	This step acknowledges the complexities of relying on international political stability and networks in energy supply. This step only traces the transmission of energy generated elsewhere, not the import of materials to generate locally or regionally. Each national border crossed is counted.
Transmission B	G	Outside one day's driving, within national borders*	This node recognizes jurisdictional boundaries within one country. Because this methodology is based on Canadian geography, vast distances are involved. Like in *Transportation A*, each provincial border is counted.
Conversion	H	Central voltage regulation/management	This step addresses the need for another layer of infrastructure in making energy accessible to residents.

The same data used to populate the example matrix in Figure 10 on page 54 is provided again below, but is now used to calculate the 'node score' for the neighbourhood.

Heat:

- 70 households with rooftop solar thermal collectors
- 530 households using natural gas-fed furnaces

Power:

- 70 households with rooftop solar for electricity
- 150 households using a neighbourhood solar array for electricity
- 380 households using energy from a power plant located 50km outside city limits with a fuel mix of 80% coal and 20% wind

The 'node scores' for this fictional example are shown on the following page.

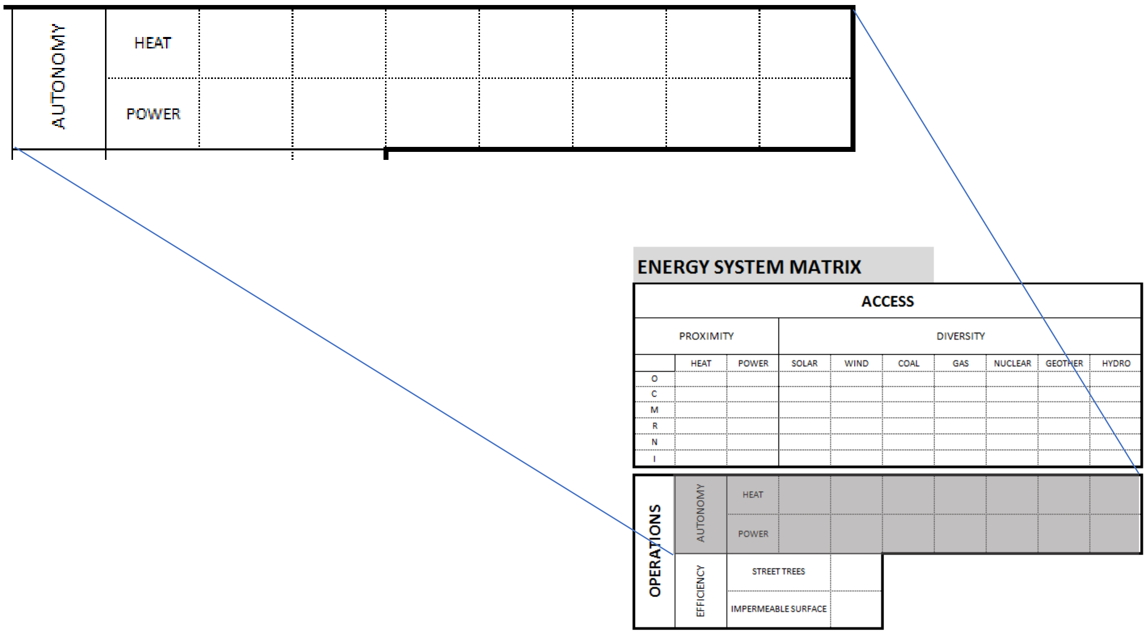
Solar Thermal Collectors: Production, Storage = **2 nodes** (DE)
Solar PV: Production, Storage, Conversion = **3 nodes** (DEH)
Wind: Production, Storage, Transmission B, Conversion = **4 nodes** (DEGH)
Coal: Extraction, Processing, Transmission B, Production, Storage, Transmission B, Conversion = **7 nodes** (ABCDEGH)
Gas: Extraction, Processing, Production, Storage, Transmission B = **5 nodes** (ACDEG)

Figure 13, below, demonstrates how to document the results using the fuel sources and end uses found in the *Diversity* metric. Figure 14, on the following page, highlights the section of the Energy System Matrix for inputting the results.

Figure 13 – Energy Node Scores

ACCESS										
PROXIMITY (%)			DIVERSITY (%)							
		HEAT	POWER	SOLAR	WIND	COAL	GAS	NUCLEAR	GEOTHER	HYDRO
O		12	12	H+P: 12						
C			25	P: 25						
M										
R		88	63		P: 12.6	P: 50.4	H: 88			
N										
I										
RATIONS	AUTONOMY	HEAT		2	/	/	5			
		POWER		3	4	7	/			

Figure 14 – Energy System Matrix, Operations Category, Autonomy Metric



On the following page, Table 3.9 provides a summary of all energy metrics described above, and the methods used to measure or assess and document the results. Within the table's three columns, *Metric*, *Resources*, and *Methods*, *Metric* explains the aspect being measured; *Resources* indicates how information is acquired; *Methods* outlines any relevant limitations or specifications in gathering the information.

Table 3.9 – Summary of Energy System Metrics

CATEGORY	METRIC		RESOURCES	METHODS
ACCESS	PROIMITY (ORIGINS)	Neighbourhood energy provision for A) heat and B) power.	-satellite imagery -internet research -utility provider information	- local energy production
	DIVERSITY (OPTIONS)	Variety of fuel sources used in the neighbourhood	- data from the Proximity metric (above) -satellite imagery - internet research -utility provider data and statistics	- the individual nature of household energy provision is difficult to access without violating the privacy of residents. Broad assumptions are made using utility provider website information regarding generating fuel sources when more specific information is not available.
OPERATIONS	EFFICIENCY (ENERGY USE)	Neighbourhood design elements affecting household consumption	-green infrastructure and developer information	- permeable surface area, street tree count, and neighbourhood covenants such as mandating Energy Star appliances etc
	AUTONOMY (COMPLEXITY)	Electricity supply chain	- the number of steps between generation and household consumption	-based on data uncovered in the Diversity and Proximity metrics - scores are tabulated using Table 3.7

3.1.3 Water

Below, Figure 15 illustrates the entire Water System Matrix.

Figure 15 – Water System Matrix

WATER SYSTEM MATRIX

ACCESS							
PROXIMITY					DIVERSITY		
SOURCE	M	R	N	I	POTABLE	NON-POT	BOTH
Groundwater (aquifer)							
Captured Rain (water tower/cistern)							
Retention (Dam/reservoir)							
Surface (river/lake)							
Desalination (Ocean/sea)							
Imported/Irrigated							

OEPRATIONS						
EFFICIENCY				AUTONOMY		
INITIATIVE	DOMESTIC	COMMERCIAL	PUBLIC	NUMBER OF HOUSEHOLDS	NODES	%
Low-flow faucets						
Xeriscaping						
Native Species planting						
Rain Capture (watering)						
Indoor Grey Water						
Industrial Grey Water						
Metering						
Topsoil						
Watering Days						
Mulching						
Storm water biofiltration						
Third pipe system						

The metrics in this section are designed to assess water consumption in the neighbourhood, specifically its source, use, and conservation. Prior to completing the water metrics, research on municipal water source(s) is required to uncover any programs or legislation in place affecting water conservation and consumption, as well as to understand the water treatment and the municipal water supply and associated infrastructure. Table 3.10, on the following page, provides definitions for some terminology used in this section. In North America, using potable water for domestic waste/sewage conveyance is commonplace, but this relationship is addressed later in the Waste Management section (Section 3.2.3). In Canada, municipalities and provinces address grey water differently, and research into local legislation and policies is required. Storm water is addressed as a hazard in the Shelter section (Section 3.2.1).

Table 3.10 – Glossary of Water Terminology

TERM	DEFINITION
Black Water	Water contaminated by human and/or industrial waste
Grey Water	Waste water generated in offices and households from sinks, showers, dishwashers, and washing machines, can also include captured rain water
Third Pipe System	Built infrastructure for non-potable water delivery, sourced from grey or storm water and destined for uses such as irrigation, industrial cooling, toilet flushing, or pre-treating via bio-filtration ponds.

Assessing the Water System: In developed countries, an independent neighbourhood water source is uncommon, though there are examples of neighbourhood grey water sources (van Roon 2007), and so while the food and energy systems can be supplemented with neighbourhood-based resources, potable household water is generally tied to a municipal system. These water metrics, therefore, assess a system extending outside the neighbourhood and even outside the municipality. Beginning with the *Access* category, the *Proximity* and *Diversity* metrics examine the source of the municipal water supply and its end uses, respectively. The *Operations* category examines water consumption/conservation within households and the neighbourhood, as well as the municipal water network's infrastructural legacy, using the *Efficiency* and *Autonomy* metrics, respectively.

3.1.3.1 Water Access

<u>Proximity</u>

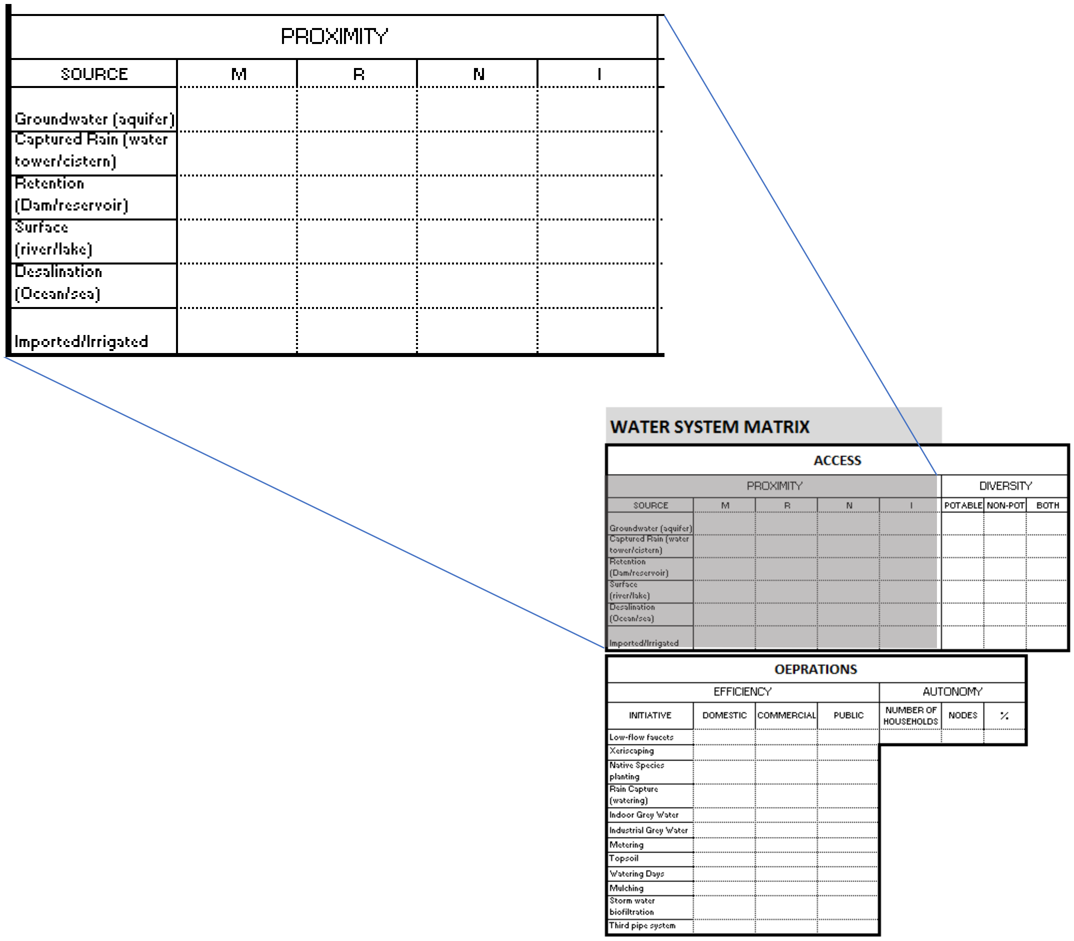
As with the other Supply Needs (Food and Energy), the *Proximity* metric examines water ***Distance*** in terms of the location of the source. Tracking the source provides information on residents' susceptibility to unpredictable water access, a growing concern with increasingly unpredictable weather and precipitation patterns (Sullivan 2011; Wong & Brown 2008). This metric reflects connections to outside networks and not actual distance water travels, so the following distance groups (see Table 3.11 below) are used: C (Community), M (Municipality), R (Regional), N (National), and I (International), with guidelines for classification also provided.

Table 3.11 – Distance Groups

SOURCE	DEFINITION	GUIDELINES
Community	Within the neighbourhood	Includes rain cisterns/water towers; local grey water source (wetland or rain; local springs or aquifer
Municipality	Within the municipality, outside the neighbourhood	Includes rain cisterns/water towers; municipal reservoir fed by a local river; water body or river within municipality; local springs or aquifer
Regional	Outside the municipality, within one day's return trip distance (6.5 hrs** driving)	Regional watershed allocation from glacier/snow melt; regional aquifers; dam or reservoir located outside municipality and shared by other regional jurisdictions; desalination plant located outside municipality
National	Outside one day's driving, within national borders	Regardless of source, water brought across jurisdictional boundaries within a country regardless of potability
International	Crossing an international border, regardless of distance	Regardless of source, water brought across international boundaries, regardless of potability

Results for this metric are documented by placing an ‘X’ in the cells of the highlighted section shown in Figure 16, below.

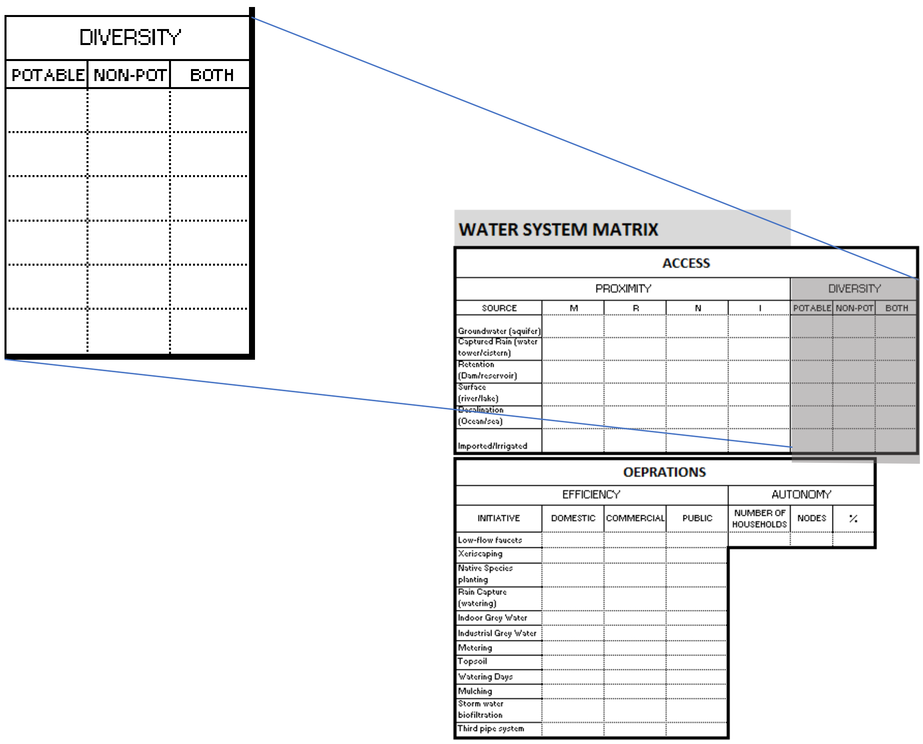
Figure 16 – Water System Matrix, Access Category, Proximity Metric



Diversity

The *Diverisity* metric examines water ***Options*** in terms of end uses. Tracking diversity of uses provides indirect information on resident vulnerability to water-related services, such as sewage treatment. To assess these options, the sources identified in the *Proximity* metric are assessed within a municipal policy or legislative context to uncover any separation of uses for water. Results are documented with an X in the appropriate cell in the highlighted section of the Water System Matrix shown in Figure 17, on the following page. For example, in Calgary, water is drawn from the Bow and Elbow Rivers running through the city and there is no grey water system for domestic flushing or industrial cooling – so an X is appropriate in the 'both' column because water use is not separated.

Figure 17 – Water System Matrix, Access Category, Diversity Metric



3.1.3.2 Water Operations

<u>Efficiency</u>

The *Efficiency* metric examines water ***Use*** by tracking water conservation initiatives at the household and neighbourhood level. In this research, 'water conservation' refers specifically to conserving **potable** water because of the energy and expense associated with its treatment and delivery. Urban water systems in Canada use potable water for non-potable uses like flushing, watering/irrigating, or industrial cooling. Without established grey water capture and delivery or 'dual reticulation' systems, other means to diminish (potable) water demand can be implemented using developer-established covenants in new communities outlining initiatives such as increased topsoil depth or rain barrels, for example; or as part of wider municipal policies, such as water metering. Decreasing demand is important because households requiring less treated water to function, will be better able to cope with a disruption to the potable water system, and this diminished demand resonates outside of the municipality since the majority of global water demand is related to agriculture (Howard & Bartram 2010). Furthermore, conservation initiatives are important because effective water resource management involves better governance, and is not exclusively tied to hydrological systems (Sullivan 2011), though recharging groundwater does remain an important contributing factor (Carmon et al. 1997). Groundwater recharge is addressed indirectly in the Energy section of this thesis, where the percentage of permeable to non-permeable surface area in a neighbourhood is tabulated.

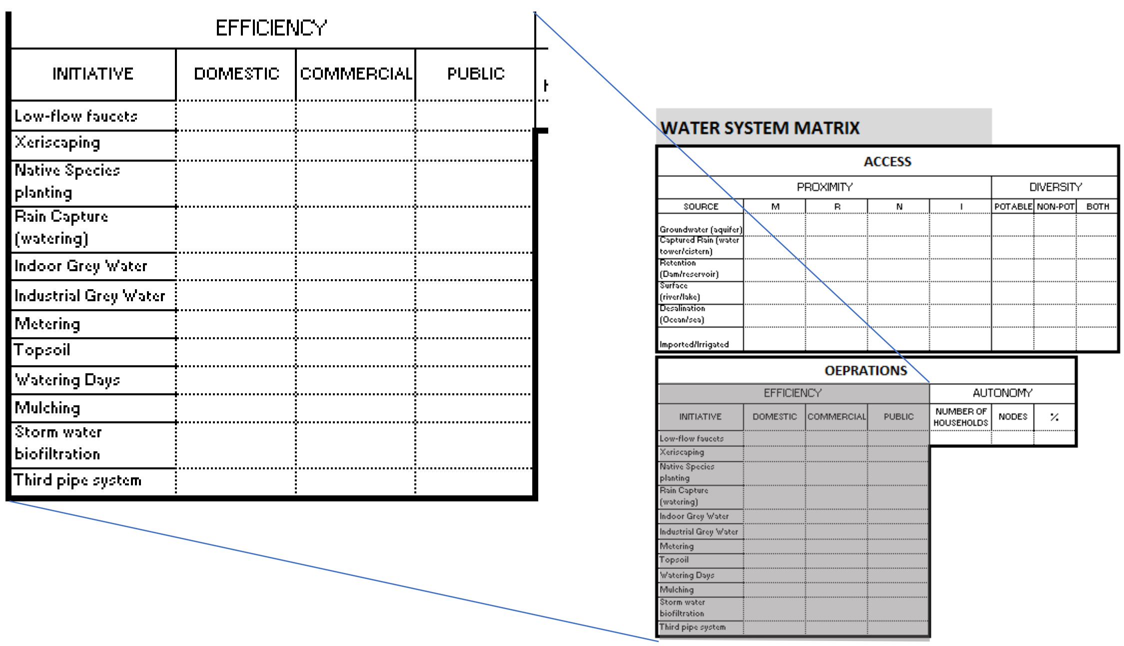
Table 3.12, on the following page, provides a list of potential policies or initiatives operating at the household and neighbourhood scale. Only official policies are documented here because participation in voluntary programs is difficult to track without a household survey. The policies listed in Table 3.12 are used in the Water System Matrix and fall into three areas: *Domestic*, *Commercial* or *Public* – and each policy can be present in none, one, two, or all three areas. Depending on the land use designations in the subject neighbourhood, these conservation initiatives can be significant. For example, a neighbourhood golf course using river water for irrigation, or in the case of a high degree of commercial development in a neighbourhood, household water access during a crisis can be significantly impacted by ‘forcing’ commercial water conservation with policies and legislation.

Table 3.12 – Water Conservation and Consumption

INITIATIVE/POLICY
Low-flow faucets/toilets
Xeriscaping
Native species planting
Rain Capture (watering)
Third pipe system
Metering
Increased top-soil depth requirements
Watering days
Mulching
Storm water bio-filtration
Constructed wetlands

Figure 18, below, highlights the appropriate section of the Water System Matrix for documenting the results. An ‘X’ is placed in all corresponding cells.

Figure 18 – Water System Matrix, Operations Category, Efficiency Metric



Autonomy

The *Autonomy* metric examines the ***Complexity*** of the water treatment network and the degree to which peripheral initiatives are integrated into the established system. Urban water systems in developed countries tend to be centralized networks rather than neighbourhood systems (Xu et al. 2008), and so tracing complexity within the dominant hierarchical system offers little in terms of new information. Because of this, *Complexity* here is viewed as incorporating supplementary initiatives or elements compatible with the existing system which diversify its operations and/or diminish its burden on the wider municipal system. These peripheral or supplementary systems supporting established networks, move cities towards more resilient and sustainable water management practices (Sullivan 2011; Wong & Brown 2008) by creating redundancy and increasing diversification. Table 3.13, below, lists strategies implemented in Australian neighbourhoods between 1990 and 2005 and summarized by Barton & Argue (2007). These are the basis for identifying any potential systems in the subject neighbourhood and focus on non-potable water capture and (re) use.

Table 3.13 – Integrated Urban Water Solutions

INITIATIVE	EXPLANATION	DESTINATION	USES	SCALE
Rooftop rain capture A	Capturing rain	Building	Non-potable on-site uses	Building
Rooftop rain capture B	Channeling rain	Wetland/catchment	Irrigation and biofiltration of storm water	Communal
Rooftop rain capture C	Channeling rain for use	Underground cistern or aquifer	-Groundwater recharge -Wastewater support -grey water supply	Communal
Road rain capture A	Bioswales / raingardens	Road side	Storm water treatment, passive irrigation, groundwater recharge	Immediate location
Road rain capture B	V-shaped road camber drainage	Underground cistern or aquifer	-Groundwater recharge -Wastewater treatment support -grey water supply	Communal
Other paved surface rain capture	Channeling water with culverts / trenches	Wetland/catchment	Irrigation and biofiltration of storm water	Communal

Using the same 'node score' system found in the Food and Energy sections, neighbourhood use or management of non-potable water (grey water, storm water, or wetlands) are tabulated. Unlike in Food and Energy where increasing complexity can undermine resilience, here 'complexity' supports resilience because of the implied redundancy, decentralization, and decreased energy input – as discussed in Section 1.1. The number of 'stops' water makes before leaving the neighbourhood to enter the municipal system or the natural water cycle are documented using Table 3.14, below.

Table 3.14 – Water Node Groups

PROCESS	CODE	EXPLANATION
Capturing A	A	On-site/building collected storm water as a source for non-potable indoor use
Capturing B	B	On-site/building collected storm water as a source for non-potable outdoor use
Capturing C	C	Neighbourhood storm water as a source for indoor non-potable use
Capturing D	D	Neighbourhood storm water as a source for outdoor non-potable use
Capturing E	E	Neighbourhood storm water as a supplement for sewage treatment (local or municipal)
Capturing F	F	Neighbourhood grey water system for indoor and outdoor non-potable use
Channeling A	G	Storm water channeled into municipal storm system
Channeling B	H	Grey water channeled into municipal third pipe system
Treating A	I	Bio-filtration/wetland for grey/storm water for release into natural water cycle
Treating B	J	Centralized municipal water system
Source A	K	Municipal grey water system for indoor and outdoor non-potable use
Using	L	Drinking, washing, flushing, cooling, cooking, watering

These nodes assume that a municipal mains system provides for potable water demands. An example of how to tabulate the water node score is provided below using the following fictional data for a neighbourhood of 600 households. In a case study, these data would have been uncovered as part of the *Access Proximity* and *Diversity* metrics.

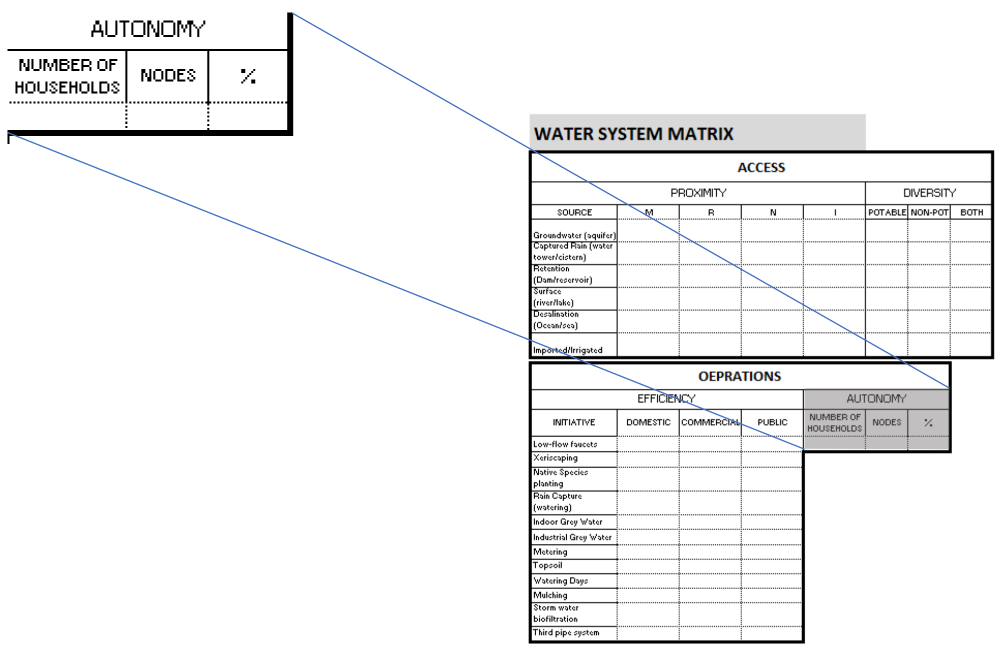
- 65 households connected to a decentralized storm water collection system. This system provides non-potable water to a small, local sewage treatment plant and uses city mains water for top up supply. It uses storm water for greenspace irrigation/bio-filtration. Grey water from the community is used in household toilets, with top up provided by municipal mains water.
- 85 households connected to a two-way municipal third pipe system using and collecting grey water.
- 450 households connected to a 'traditional' municipal mains water system using potable water for non-potable uses.

The 'node scores' for the above example are shown below, and are tabulated as a percentage of total neighbourhood households.

65 households (11%) have a score of **7 nodes** (CDEFIKL)
85 households (14%) have a score of **5 nodes** (GHJKL)
450 households (75%) have a score of **3 nodes** (GJL)

Figure 19, below, highlights the section of the Water System Matrix to document these results.

Figure 19 – Water System Matrix, Operations Category, Autonomy Metric



Below, Table 3.15 provides a summary of the metrics described above and the methods used to measure or assess and document the results. Within the table's three columns, *Metric*, *Resources*, and *Methods*, *Metric* explains the aspect being measured; *Resources* indicates how information is acquired; *Methods* outlines any relevant limitations or specifications in gathering the information.

Table 3.15 – Summary of Water System Metrics

CATEGORY	METRIC		RESOURCES	METHOD
ACCESS	PROIMITY (DISTANCE)	Neighbourhood water source	-watershed research, government websites	-all sources are tabulated-access is 'local' even if the source is not -source managed at a distance, however (like a dam falling in the R,N,I groups) is classified under the location of the dam.
	DIVERSITY (OPTIONS)	End use for water resources		-categorizes use as potable, non-potable, or both. -non-potable uses include indoor grey water systems, outdoor watering, and industrial cooling
OPERATIONS	EFFICIENCY (USE)	End-of-line conservation and consumption	-Municipal programs or legislation -Developer website	date of implementation… initiative must apply to at least 50% of households.
	AUTONOMY (COMPLEXITY)	Supplementary water systems supporting traditional water systems	- infrastructure established to exploit storm and grey water generated in the community	-using outlets/sources identified in Diversity

3.2 Supports

As discussed in Chapter 2, Section 2.3.1, basic needs within neighbourhoods are grouped into two types, either as *Supplies* or *Supports*. Support needs are part of the neighbourhood fabric and built form, and so include Shelter, Transportation, and Waste Management. How the Shelter, Transportation and Waste systems are examined individually is explained below in Sections 3.2.1, 3.2.2, and 3.2.3, respectively. Bike and/or walkshed mapping is used to gather information for each need, as explained in Section 3.1, a 600m distance is used to measure walking distance, while a 1.2 km distance is used for cycling.

3.2.1 Shelter

Below, Figure 20 illustrates the entire Shelter System Matrix.

Figure 20 – Shelter System Matrix

SHELTER SYSTEM MATRIX

ACCESS		
PROXIMITY		DIVERSITY
SHELTER	CAPACITY (%)	OVERLAP (%)
SHELTER A		
SHELTER B		
SHELTER C		

OPERATIONS					
AUTONOMY			EFFICIENCY		
VULNERABILITY	STRUCTURES (%)	NEIGHBOURHOOD	BUILDING VINTAGE	%	RATING (VL,L, M, H)
DROUGHT			PRE 1949		
HIGH WINDS			1950-1970		
EXTREME RAIN			1971-2011		
EXTREME HEAT			2012-2017		
STORM SURGE			2012-2017		
EXTREME COLD					
OVERLAND FLOODING					

The metrics in this section uncover information on the physical vulnerability of residents in terms of sheltering. As mentioned in Section 2.2 of Chapter 2, the term *shelter* can be ambiguous, and so this thesis uses two separate definitions: 1) referring to a short-stay dwelling during disruption (emergency or temporary shelter), and; 2) referring to the homes of residents. Here, the first definition is used in the *Access* metrics, and the latter definition is used in *Operations*. Prior to beginning this section, suitable locations for Emergency Shelter (ES) and Temporary Shelter (TS) must be identified. These are not required to be located within the subject neighbourhood, but for any located outside neighbourhood boundaries, but a minimum of 33% of neighbourhood households must fall within its walkshed for it to be considered as a viable option. This 33% threshold is based on the criteria used in Section 3.1.1 to establish basic access to a food outlet.

In the field of emergency planning, shelter locations are not generally chosen using the above criteria. They are usually established ahead of time and selection is based around the pre-positioning of supplies (Rawls & Turnquist 2010; Johnson 2007; Akkihal 2006) or evacuation routes (Xu et al. 2008). The two criteria described below do address some very basic ES/TS requirements and broadly accommodate a variety of climate change-related disruptions. This type of sheltering generally occurs in communal facilities such as schools, churches, or community centres/halls. Beyond the 33% threshold described earlier, facilities meeting the following criteria are considered acceptable:

a) They are not impacted by the disruption currently facing the community. For example, they are not located on a floodplain or floodway, or within the 150 m Evacuation Planning Zone (EPZ) buffer, used by Kongsomsaksakul et al. (2005).
b) They can accommodate many users with at least one large open, flexible space and an adequate number of public washrooms.

Assessing the Shelter System: With sheltering locations identified, the assessment begins using the format introduced in Table 2.2 from Chapter 2. Beginning with the *Access* category, the *Proximity* and *Diversity* metrics examine ES/TS's ability to accommodate residents in terms of location, as well as their capacity and if more than one option is available to residents, respectively. Using the 'home' definition of shelter, the *Operations* category examines individual households' relative energy efficiency, and then the appropriateness of structures to their local environment, through the *Efficiency* and *Autonomy* metrics, respectively.

3.2.1.1 Shelter Access

Proximity

For Support Needs, the *Proximity* metric examines shelter ***Distance*** in terms of resident travel in accessing ES/TS. This information highlights dependence on external resources, such as a vehicle, to seek assistance or meet other needs. To do this, a walkshed map of any identified neighbourhood shelters is completed and the number of households falling within each walkshed are counted. Households falling within the walkshed of more than one shelter are counted in all applicable walksheds. This metric is tabulated using estimated population as well as household numbers because shelter capacity is an important aspect of ES/TS assessment. And so this metric is a function of two interrelated aspects: the number of people 'close' to a shelter, and a shelter's capacity. In this way, 'proximity' is actually a reflection of the number of people/households within a walkshed who can also be accommodated. To calculate this, two steps are required:

1) The number of households within the walkshed is converted to an estimated number of people by assuming each household contains

2.5 residents, as per the Canadian average (Statistics Canada 2011).

2) Shelter capacity is tabulated based on two factors: a minimum space of $4m^2$ per person (Chou et al. 2013), and a minimum number of washrooms per person. The washroom ratio is based on provincial guidelines for temporary outdoor public events outlined in the Province of Manitoba's *Public Health Act* (Manitoba 2009). Tables 3.16 and 3.17, below, summarize these standards.

Table 3.16 – Occupancy **under** 3 hours

OCCUPANCY	TOILETS
1-50	2
51-100	4
101-200	6
201-300	8
301-400	10
401-500	12
501-600	14
601-700	16
701-800	18
801-900	20
901-1000	22
1000+	One additional toilet for every 100

Table 3.17 – Occupancy **over** 3 hours

OCCUPANCY	TOILETS
1-50	2
51-100	4 (6)
101-200	8
201-300	10
301-400	12
401-500	14
501-600	16
601-700	18
701-800	20
801-900	22
901-1000	24
1000+	One additional toilet for every 200

An example of how this metric is tabulated is provided below using a fictional neighbourhood of 600 households (1500 people[6]) with one local primary school for ES/TS operating as a neighbourhood cooling station during a heat wave, hosting residents for over three hours.

Walkshed information:

a. 120 households within the primary school's walkshed
b. 120 x 2.5 (household residents) = 300 people

Calculating the metric:

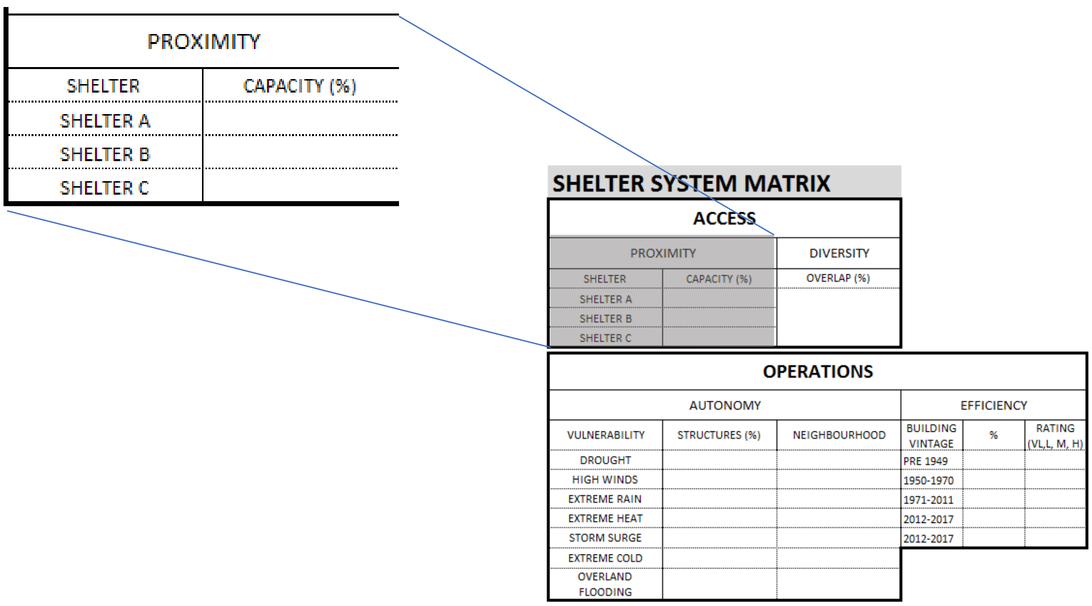
[6] 600 households x 2.5 residents per household = 1500 people

a. Primary school gymnasium area is 150 m^2 with 12 washrooms in the school.
b. 150 m^2/4 (m^2 per person) = 37 people
c. The school can therefore accommodate 37 of the 300 people living within the walkshed; the equivalent of 15 households (37/2.5 = 15 households)
d. 15 of 600 is 12% of the neighbhourhood's total households.

In the above example, "12%" is recorded in the Shelter System Matrix.

In a real-world application, public demand for shelters rarely reaches 100% as public sheltering is often seen as a last resort (Bolin & Stanford 1991). So having lower results for capacity or demand is not necessarily problematic. Figure 21, below, highlights the section of the Shelter System Matrix where the results of this metric are documented.

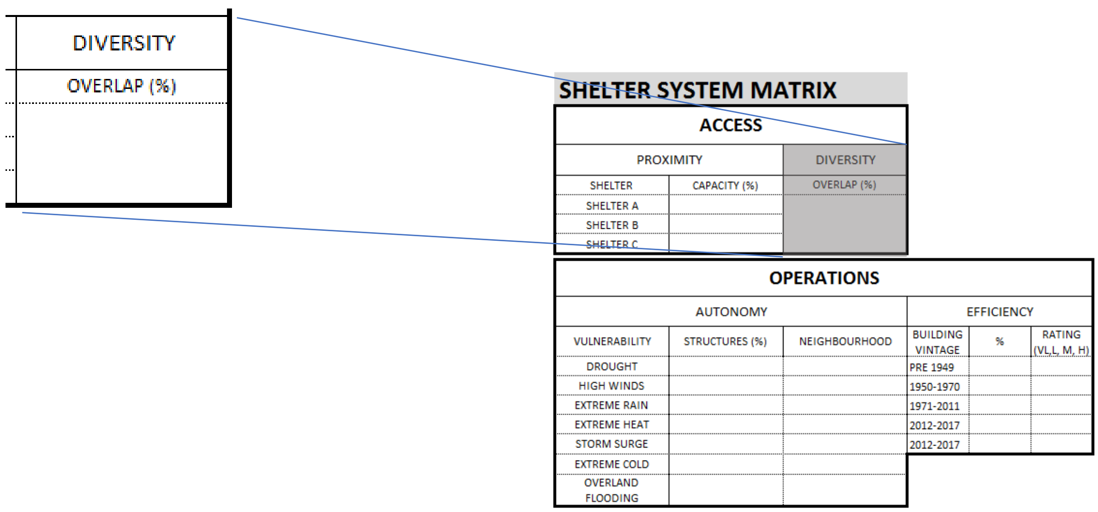
Figure 21 – Shelter System Matrix, Access Category, Proximity Metric



Diversity

The *Diversity* metric here examines shelter ***Options*** in terms of the number of residents having more than one sheltering choice. Depending on the disruption, not all shelters may be accessible or functional, and so documenting any sheltering redundancies is important. If only one shelter has been identified at the beginning of the *Access* category, then only completing a capacity assessement is required. If there is more than one sheltering option, the walkshed maps created for each shelter in the *Proximity* metric are overlapped, and households appearing in two or more walksheds are counted, and the results recorded as a percentage of total neighbourhood households. Figure 22, below, highlights the section of the Shelter System Matrix documenting the information gathered in this metric.

Figure 22 – Shelter System Matrix, Access Category, Diversity Metric



3.2.1.2 Shelter Operations

<u>Efficiency</u>

The *Efficiency* metric here examines shelter ***Use*** at the individual structure scale. Initiatives governing reduced consumption through public/neighbourhood-wide initiatives were addressed in Sections 3.1.2 (Energy) and 3.1.3 (Water), and so in this metric, energy consumption at the building scale is examined. In older neighbourhoods where redevelopment has occurred, tracking the number of efficient versus inefficient structures is difficult and so, when possible, redevelopment maps from the municipality are used to establish the construction age of structures. Construction age provides a relatively accurate measure of building energy consumption in Canada, and has been used by the Office of Energy Efficiency (OEE) and Natural Resources Canada (NRCan) to track national energy demand (Natural Resources Canada 2016). Though declining, in Canada, space heating still accounts for the majority of annual household energy consumption (Natural Resources Canada 2016), and so this *Efficiency* metric uses a combination of space heating and construction age to estimate energy consumption in shelters. Below, Table 3.18 provides a synopsis of energy consumption per m^2 by building vintage, along with the associated Energy Consumption Index (ECI) and EnerGuide Rating Scale (ERS) values when available. For reference, R2000 insulation, Next Gen R2000 insulation, and Net Zero Energy Homes (NZEH) ECIs are also provided.

Table 3.18 – Synopsis of Energy Consumption in Dwellings

YEAR OF CONSTRUCTION	ANNUAL SPACE HEATING ENERGY INDEX (MJ/m^2)	ENERGY CONSUMPTION INDEX	0-100 ENERGUIDE RATING SCALE[7]
Pre-1945	1150	.29[8]	
1946-1960	800	.22	
1961-1970	685	.19	53
1971-1980	675	.17	
1981-1990	500	.16	66
1991-2011	450	.14	75[9]
(2012-2017)[10]			80
(2012-2017)[11]			78
R2000	--	.11	80
Next Gen R2000	--	.07	86
NZEH	--	.035	88

Source: CanmetENERGY, n.d.

[7] Some values are approximate and extrapolated from data provided by CanmetEnergy (Parekh n.d.)
[8] Averaged between Energy Index value for 1920-1945 (2.7) and 1920 (3.15)
[9] Derived from the average ERS score for 1991-2009 (73) and the 2010-2011 ERS score (78)
[10] For Nova Scotia, Quebec, Ontario, Manitoba, and British Columbia
[11] For Alberta, Yukon, Nunavut, NWT, New Brunswick, and Newfoundland

Using the above information, each dwelling structure in the subject neighbourhood can be rated for efficiency according to its age. The province in which the municipality is located also impacts a dwelling's rating, and so provinces are divided into two groups in order to accommodate construction legislation differences between them. *Group A* provinces include: Nova Scotia, Quebec, Ontario, Manitoba, and British Columbia; and *Group B* provinces include: Alberta, Saskatchewan, Yukon, New Brunswick, PEI, Newfoundland, the Northwest Territories, and Nunavut. At time of writing, *Group A* provinces adhered to 2012 National Building Code (NBC) energy efficiency standards, and *Group B* provinces did not. The 2012 NBC's energy efficiency standards achieve ERS scores of 80/100 – equivalent to R2000 standards – in new construction. Table 3.19, below, illustrates the classification of dwellings according to age using the following efficiency categories: VL is *Very Low*; L is *Low*; M is *Medium*, and; H is *High*.

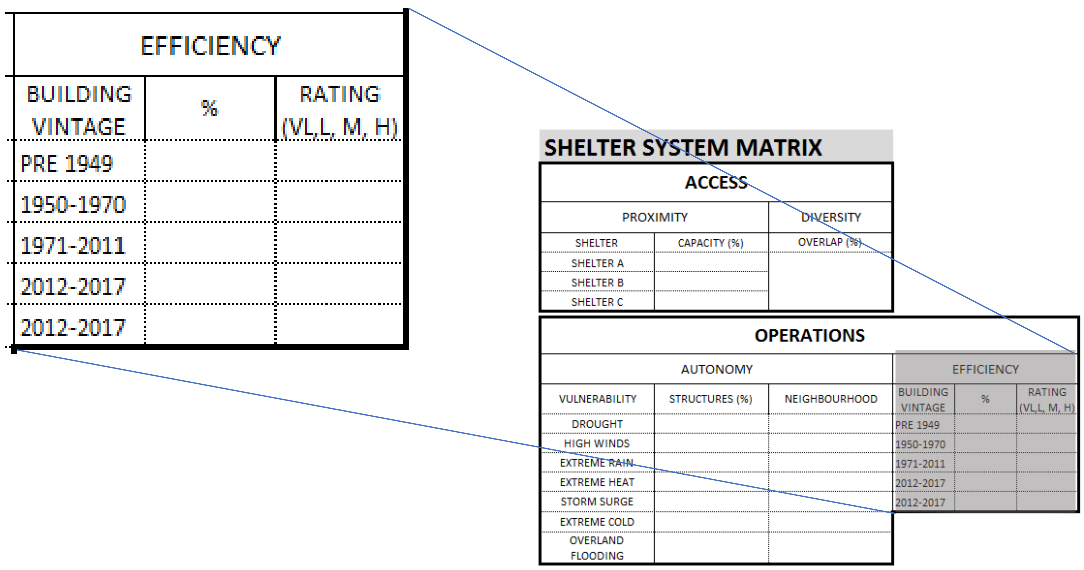
Table 3.19 – Construction Age and Efficiency Rating

A	CONSTRUCTION AGE	B
VL	PRE-1949	VL
L	1950-1970	L
M	1971-2011	M
H	2012-PRESENT	M
H	R2000	H
H	NET ZERO	H

For this metric, only dwellings are examined, not commercial or public buildings (emergency/temporary shelters), and for simplicity, single-family and multi-family buildings are assessed equally despite the increased efficiencies associated with multi-unit residential buildings (British Research Establishment 2006).

Depending on available municipal data, renovations to older structures may not be recognized using this method, resulting in a bias underestimating efficiency. Results of this metric are recorded as the number of neighbourhood structures falling within each Construction Age era and efficiency rating as a percentage of total neighbourhood dwelling structures as outlined in Table 3.19, on the previous page. Figure 23, below, highlights the section of the Shelter System Matrix documenting the information gathered in this section.

Figure 23 – Shelter System Matrix, Operations Category, Efficiency Metric



<u>Autonomy</u>

The *Autonomy* metric here examines shelter ***Design*** in terms of appropriateness to its location. This metric addresses the physical integrity of everyday shelters as being dependent not only on their design for specific local conditions, but also in terms of public/neighbourhood elements working to maintain shelter integrity. The information gathered in this metric provides insight into the degree to which a neighbourhoood's location is understood as important for maximizing shelter integrity during a disruption.

For example, in a neighbourhood located on a floodplain, neighbourhood features designed for guiding water flow, dry canals for example, are documented. Depending on the initiative, an on-site visit may be required to identify and document results. The age and history of the neighbourhood plays an important role here because of the unequal distribution of initiatives arising from infills or redevelopment occurring after any previous disruptions. Some initiatives listed below are not easily identifiable through observation, so date of disruption, resulting legislation affecting re-construction, and then also date of (re)construction, can be used in this metric. Initiatives addressing specific vulnerabilities are divided into two types: those dealing with structures, and those implemented at the neighbourhood scale. Tables 3.20 and 3.21 provide a list of vulnerability-focused solutions at the structure and neighbourhood scale, respectively. Depending on the vulnerabilities or extreme weather acting upon the neighbourhood, not all initiatives are required. The initiatives listed are based on the research summarized in Chapter 1, Tables 1.2, 1.3, and 1.4.

For Table 3.20, on the following page, results are documented as a percentage of total neighbourhood structures with location-appropriate architectural or design elements.

Table 3.20 - Vulnerability-focused **Structure** Design Elements and Strategies

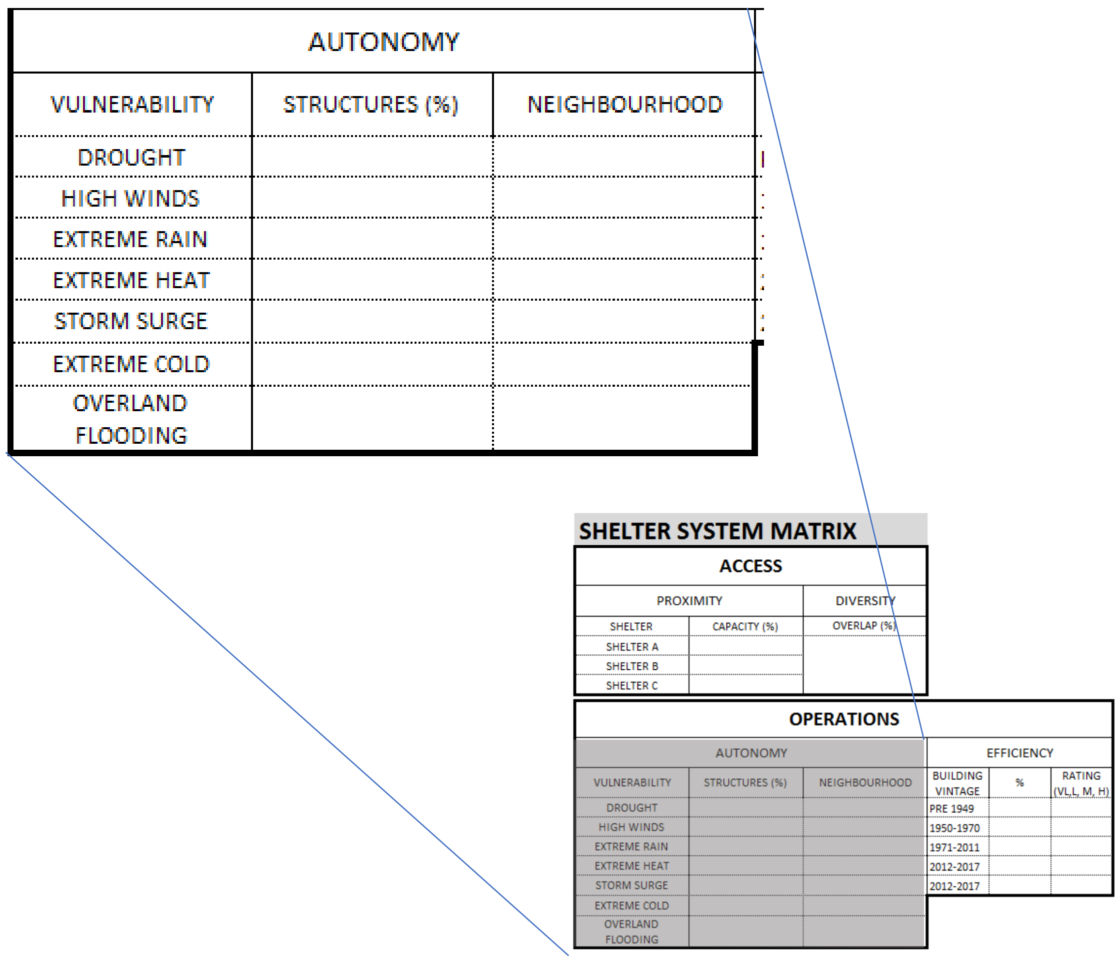
STRATEGY/ INITIATIVE	DROUGHT	HIGH WIND	ICE STORM	OVERLAND FLOODING	STORM SURGE	EXTREME RAIN	EXTREME HEAT	EXTREME HEAT
Elevated main floor				X	X	X		
Raised utility boxes				X	X	X		
Graded property				X		X		
Adaptive landscaping				X		X		
Bioswale/rain garden						X		
Permeable pavement						X		
Green roof						X	X	X
Vertical load construction		X			X			
Reinforce roof trusses		X			X			
Round construction		X						
Underground construction		X					X	X
Xeriscaping	X					X		
Rain harvesting	X					X		
Buried power lines		X	X					
Flow-through main floor				X	X	X		
Verandas/porches							X	
Natural Ventilation							X	
Mutual Shading							X	
Architectural Screens		X					X	
Thermal massing							X	X
Elevated insulation							X	X
Coastal retreat					X			

For Table 3.21, on the following page, because the efficacy of neighbourhood elements is difficult to quantify in terms of capacity or event size, only the *presence* of relevant strategies is documented by placing an X in the appropriate cell. Both results are documented in the highlighted section shown in Figure 24, on page 85.

Table 3.21 – Vulnerability-focused **Neighbourhood** Design Elements and Strategies

STRATEGY/ INITIATIVE	DROUGHT	HIGH WIND	ICE STORM	OVERLAND FLOODING	SEA LEVEL RISE	EXTREME RAIN	EXTREME HEAT	EXTREME COLD
Stream daylighting				X		X	X	
Wet/dry canals				X	X	X		
Water plazas				X		X	X	
Adaptive landscaping				X		X		
Submerge-able parks/paths				X	X	X		
Storm water pumps				X		X		
Floatable pathways				X	X	X		
Bioswales/raingardens				X		X		
Permeable pavement						X		
Rain harvesting	X					X		
Cisterns	X							
Buried power lines		X	X					
District Heating		X	X					X
Coastal Retreat					X			
Street channels				X	X	X		
Water retention 'art'	X							
Infiltration trenches						X		
Natural topography					X	X		
Planted wind breaks	X	X						
'Art' wind breaks		X						
Naturalized berms				X		X		
Embankments				X		X		
Levees and Canals				X	X			
Coastal reclamation					X			
Elevated promenades				X	X	X		
Street trees	X					X	X	
Water bodies	X					X	X	
Third pipe system	X							
Shade/sunscreen 'art'							X	
Solar access								X
Flood walls				X	X	X		

Figure 24 – Shelter System Matrix, Operations Category, Autonomy Metric



On the following page, Table 3.22 provides a summary of the Shelter metrics described above and the methods used to measure or assess and then document the results. Within the table's three columns, *Metric*, *Resources*, and *Methods*, *Metric* explains the aspect being measured; *Resources* indicates how information is acquired; *Methods* outlines any relevant limitations or specifications in gathering the information.

Table 3.22 – Summary of Shelter System Metrics

CATEGORY	METRIC		RESOURCES	METHODS
ACCESS	PROIMITY (DISTANCE)	Distance and capacity of emergency shelter to residents shelters identified at the beginning of this section. -capacity is tabulated as % of total	Walkshed maps for identified shelters and capacity.	-Uses emergency POPULATION, not by households
	DIVERSITY (OPTIONS)	Accessibility of multiple shelters by residents	Walkshed maps from the Proximity metric	Overlapping the walkshed maps to find households with redundant access
OPERATIONS	EFFICIENCY (ENERGY USE)	Energy use at the structure scale	Municipal construction age maps or developer and builder websites	Classification of space heating requirements according to building age
	AUTONOMY (DESIGN)	Inquiry on two levels about locational vulnerability initiatives: 1)structure 2)neighbourhood	Historical event vulnerability and any resulting legislation. Topographical or Flood maps etc	

3.2.2 Transportation

Below, Figure 25 illustrates the entire Transportation System Matrix.

Figure 25 – Transportation System Matrix

<table>
<tr><th colspan="10">TRANSPORTATION SYSTEM MATRIX</th></tr>
<tr><td></td><td colspan="5">ACCESS</td><td colspan="4">OPERATIONS</td></tr>
<tr><td></td><td colspan="4">PROXIMITY (%)</td><td>DIVERSITY</td><td colspan="4">AUTONOMY (%)</td></tr>
<tr><td>MODE</td><td>FOOD</td><td>CBD</td><td>TRANSIT</td><td>SCHOOL</td><td>OVERLAP</td><td>SIDEWALK</td><td>BIKE WAY</td><td>BIKE LANE</td><td>MUP</td></tr>
<tr><td>WALK</td><td></td><td></td><td></td><td></td><td></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>BIKE</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>PEDESTRIAN</td><td rowspan="2">PRD</td><td colspan="3" rowspan="2">EFFICIENCY</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>VEHICLE</td></tr>
</table>

The metrics in this section examine the impact street and path network play in accessing key destinations in or near the subject neighbourhood. To begin this section, key destinations are identified, namely: a central business district (CBD); a primary school or community centre; transit bus stops or a station, and a food outlet. Both 1.2 km bike and 600m walksheds are mapped in this section for all key destinations. To reiterate: A route is deemed 'walkable' if it meets the following two criteria: a) it includes a paved surface, no worn paths, and; b) it does not share space with vehicles – such a length of road without a sidewalk or a back lane. A bike-able route is assessed differently and includes research into local traffic laws and by-laws in terms of cycling on roads or on sidewalks.

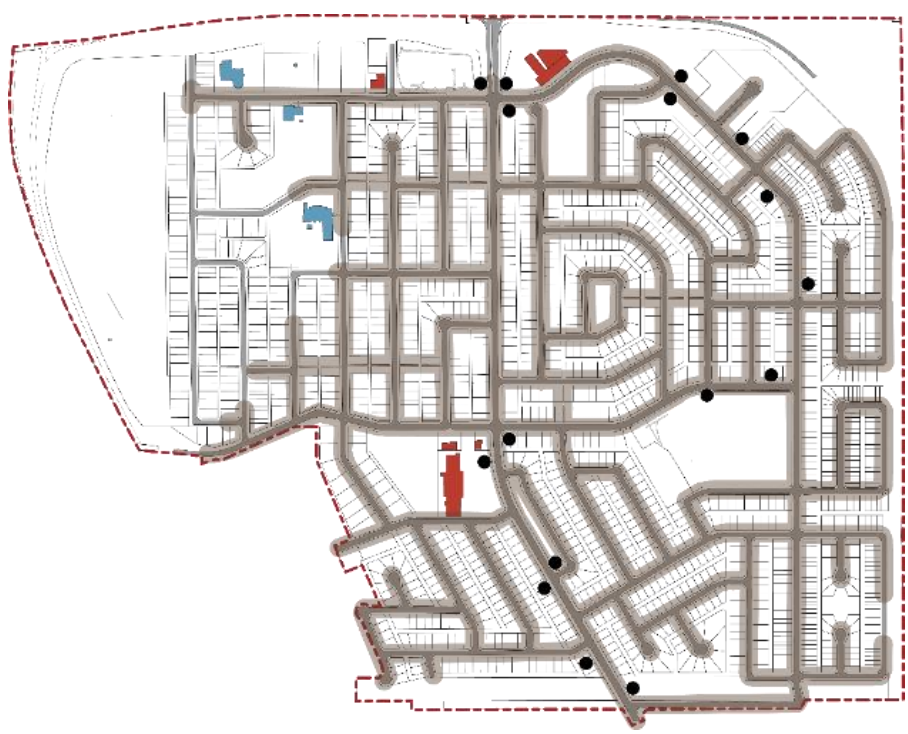
Assessing the Transportation System: Once all key destinations have been identified, the assessment begins and uses the structure introduced in Table 2.2 from Chapter 2. Beginning with the *Access* category, the *Proximity* and *Diversity* metrics examine the distances to key destinations and resident choice in using active modes of transportation, respectively. The *Operations* category examines travel effort, and available infrastructure related to transportation using the *Efficiency* and *Autonomy* metrics, respectively.

3.2.2.1 Transportation Access

Proximity

The *Proximity* metric examines transportation ***Distance*** within the neighbourhood, specifically the number of households close to multiple key destinations. Tracking this provides information on land use and amenity location, as well as forced reliance on motorized transportation because of excessive distances. On the following page, Table 3.23 illustrates neighbourhood walkshed maps for three key destinations. Once the shed map is created, the number of parcels located within the shed are counted with each dwelling unit in multi-family buildings counted separately. Acquiring multi-family unit numbers requires a site visit to confirm the amount in each building. All destinations are mapped for bicycle and walking access, with the exception of bus stops. The final number of households falling within bike and walksheds is recorded as a percentage of total households in the neighbourhood. Key destinations are shown on the maps with a 'star'.

Table 3.23 – Sample Key Destination walksheds

KEY DESTINATION	WALKSHED MAP
A Primary School	
B Transit Stops (a 'shed map is created for each bus stop)	

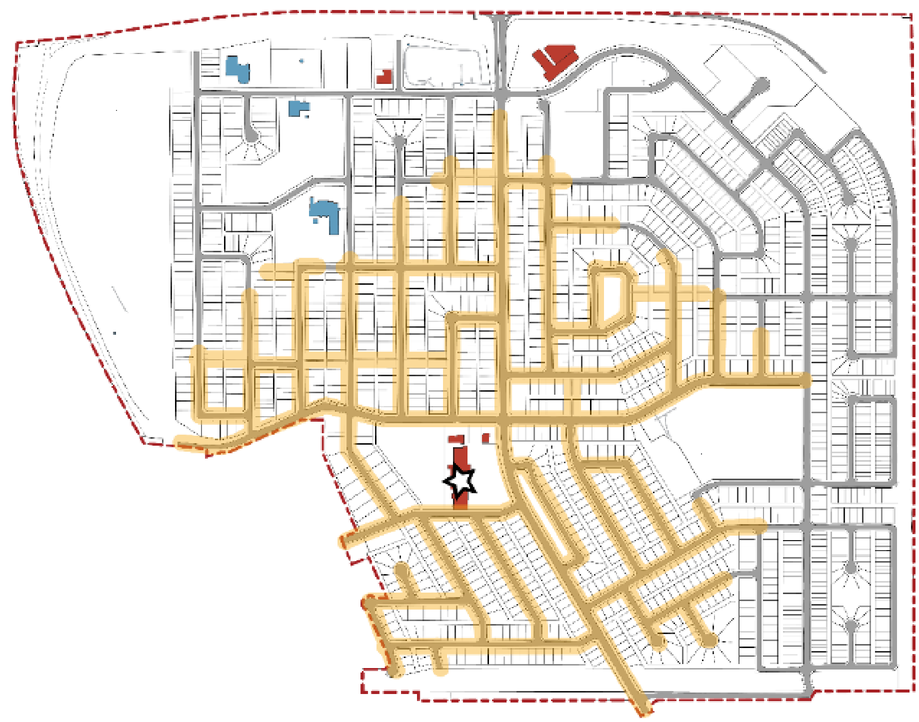
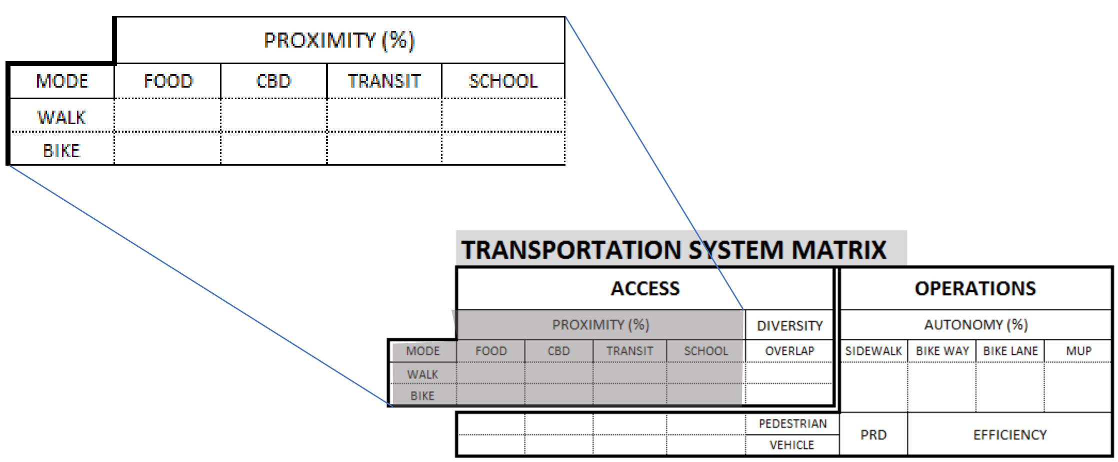
C Food Outlet	

Figure 26, below, highlights the section of the Transportation System Matrix documenting the information gathered in this metric.

Figure 26– Transportation System Matrix, Access Category, Proximity Metric



Diversity

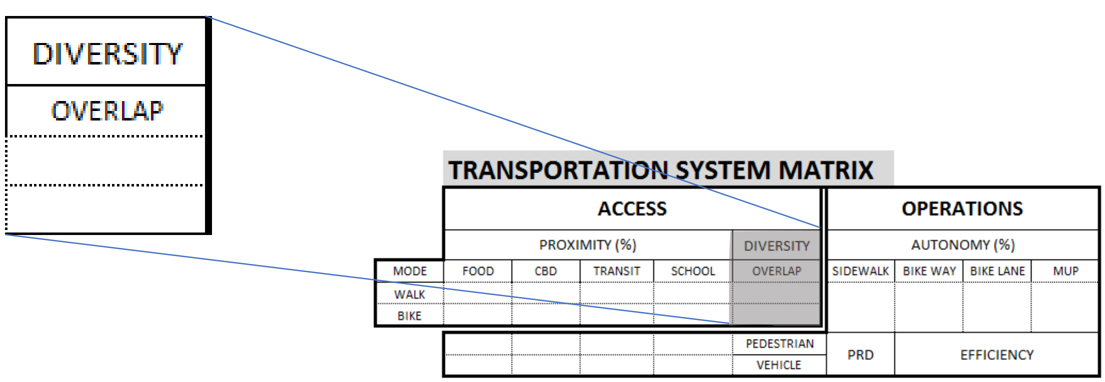
As in the other sections, the *Diversity* metric examines transportation ***Options*.** This metric assesses the extent to which using non-motorized vehicles is a choice for residents in accessing multiple key destinations. To do this, the shed maps created in the *Proximity* metric are overlapped, and land parcels/dwelling units falling simultaneously within all shed maps are identified. Parcels identified in this way illustrate which residents have access to multiple key destinations easily and without motorized transportation. The process is completed for both bike and walksheds. On the following page, Table 3.24 demonstrates the results using the walksheds from Table 3.23. The results are documented as a the number of households falling within these ‘overlap zones’ as a percentage of total neighbourhood households.

Table 3.24 – Sample Overlapping Walkshed Map

OVERLAPPING WALKSHED MAP	
Land parcels located within all three walksheds are shown in grey	

Figure 27, below, highlights the section of the Transportation System Matrix documenting the information gathered in this metric.

Figure 27 – Transportation System Matrix, Access Category, Diversity Metric



3.2.2.2 Transportation Operations

Efficiency

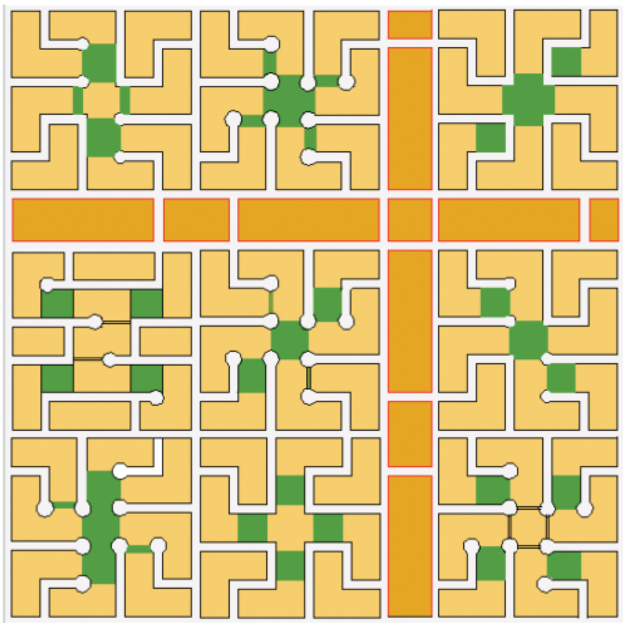
The *Efficiency* metric examines travel as it relates to transportation ***Use*** using a pedestrian connectivity measure called *Preferred Route Directness* (PRD) devised by Hess (1997). This tool measures efficiency in terms of time and effort by assessing the directness of routes to key destinations. The formula, shown in Equation 1, assesses route inefficiency by dividing route distance by geodedic (as the crow flies) distance – the closer the result is to 1, the more direct the route.

Equation 1

$$PRD = \frac{route\ distance}{geodedic\ distance}$$

In Hess' research, a maximum PRD of 1.2 is used to distinguish efficient from inefficient routes, but within this thesis, the PRDs of a motor vehicle's route are compared to the PRDs of a pedestrian's route from the same starting and end points. Identical vehicle and pedestrian PRDs to and from the same location indicate that pedestrian routes are likely built around sharing vehicular infrastructure (sidewalks next to roads and road intersections for connectivity), and therefore, that vehicle travel is prioritized. This emphasis on vehicle-based travel is important to note because it provides an indication of the vulnerability of residents to a disruption in road infrastructure or transportation fuel. The image in Figure 28, on the following page, taken from a Canadian Mortgage and Housing Corporation (CMHC) document from 2008, provides an example of a street layout where pedestrian travel is prioritized over vehicle travel, where roads (white) create driving distances that are indirect, and a pedestrian/bicycle greenway provides more direct acccess.

Figure 28 – Example of a Fused Grid Neighbourhood Road Network[12]



The steps required to complete this metric are outlined below. The distance measurement tool at Google Earth can be used in this metric.

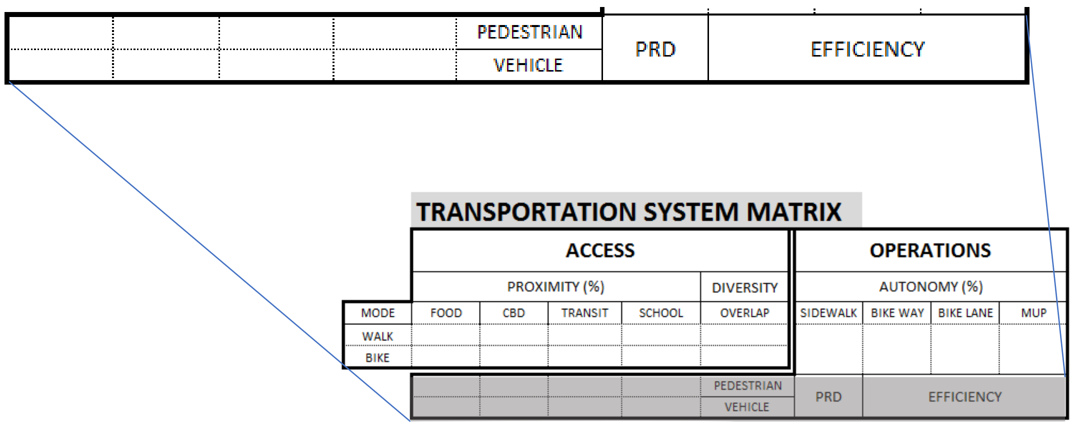
1. Using the already-created walkshed map of each key destination, three dwellings at the 600m edge of the walkshed are randomly selected
2. Walking route PRD for each dwelling to the key destination is calculated and an average between the three is taken
3. Driving route PRD for each dwelling to the key destination is calculated and an average between the three is taken

Resulting average PRD measurements for each transportation mode for each key destination are recorded. Only pedestrian and vehicle transportation modes are used here,

[12] CMHC, 2008, Research Highlight, Giving Pedestrians an Edge—Using Street Layout to Influence Transportation Choice

because bicycles can use walking infrastructure, such as MUPs, as well as vehicular infrastructure, such as roads. Below, Figure 29 highlights the section of the Transportation System Matrix documenting the information gathered in this metric.

Figure 29 – Transportation System Matrix, Operations Category, Efficiency Metric



<u>Autonomy</u>

For Support needs, the *Autonomy* metric examines transportation ***Design*** in terms of existing infrastructure related to cycling, walking, and BRT (Bus Rapd Transit) lanes, if applicable. As discussed in Section 1.1 of Chapter 1, an increased level of 'complexity' is desirable for resilience because it implies redundancy between modes. For example, if the roads surrounding a food outlet have flooded, the presence of an elevated walkway, though redundant when there is no flooding, provides important access to food for residents. Research on local biking by-laws is required for this measurement, as the legitimacy of bike travel on sidewalks varies between jurisdictions. Research by Bronson and Marshall (2014) suggests that the presence of infrastructure, as well as Low-Stress (LTS) transportation design elements (for example relative width/space, sharing, or vehicle speed) are key factors in affecting mode choice outside of private vehicles. While

Bronson and Marshall offer a finer grain analysis for variables affecting mode choice, they concluded that neighbourhood structure and layout not supporting active transportation before a disruption results in active modes less likely to be adopted after a disruption (p.2257).

In this metric, bike infrastructure is measured only as bike lanes and bike ways, even though cycling on roads is usually permitted. For pedestrians, a sidewalk on one side of the road provides basic access, so no distinction is made between distances with one or two sidewalks. Multi-user pathway (MUP) lengths are only counted if they are paved for pedestrians. For road lengths, cul-de-sacs are measured in a straight line in the middle of the road from the end of the cul-de-sac to the middle of the intersecting road. Table 3.25, below, summarizes the infrastructures examined here.

Table 3.25 – Glossary of Transportation Infrastructure

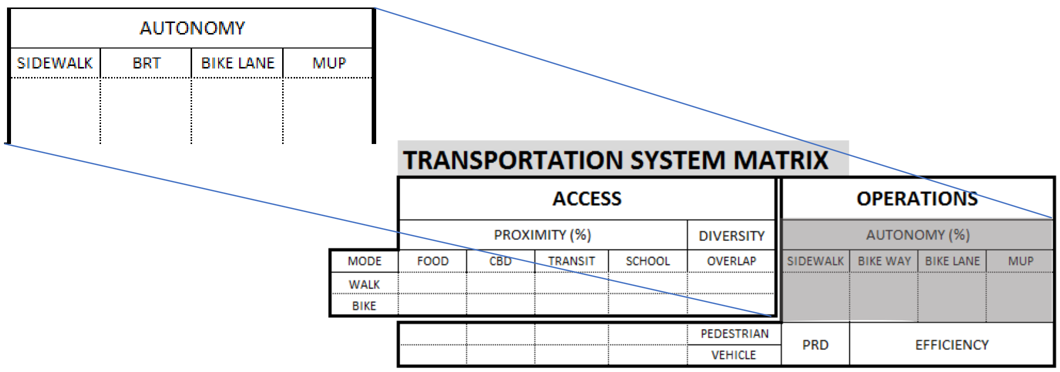
INFRASTRUCTURE	EXPLANATION
SIDEWALKS	On one or both sides of the road
BIKE LANE	Separate lane marked by paint or structures
BIKE WAY[13]	Designated route, no separation
MUP (Multi-user pathway)	Paved or gravel pathway for pedestrians and cyclists, respectively
BRT (Bus Rapid Transit)	Separate, transit-only lane.

Results for this metric are calculated by measuring the length of paved road within neighbourhood boundaries (not back lanes or parking lots) and the length of other modes' infrastructure including MUPs, bike lanes* (painted or separated), BRT lanes, and

[13] Designating a route as a bikeway can involve parking restrictions during peak travel times, and so requires local research in addition to measurement.

sidewalks. These lengths are expressed as a percentage of total neighbourhood road length. Figure 30, below, highlights the section of the Transportation System Matrix documenting the information gathered in this metric.

Figure 30 – Transportation System Matrix, Operations Category, Autonomy Metric



On the following page, Table 3.26 provides a summary of the metrics described in this section and the methods used to measure or assess and document the results. Within the table's three columns, *Metric*, *Resources*, and *Methods*, *Metric* explains the aspect being measured; *Resources* indicates how information is acquired; *Methods* outlines any relevant limitations or specifications in gathering the information.

Table 3.26 – Summary of Transportation System Metrics

CATEGORY	METRIC		RESOURCES	METHOD
ACCESS	PROIMITY (DISTANCE)	Distance to key destinations	Walk and bike-shed mapping for each destination.	600 m distance for walking 1.2 km distance for cycling Cycling distance to individual bus stops are not measured, only central transit stations are used.
	DIVERSITY (OPTIONS)	Household travel mode options	walk and bike shed maps created for all key destinations.	Overlapping the shed maps and identifying land parcels appearing in both.
OPERATIONS	EFFICIENCY (USE)	Route directness	PRD formula and distance measuring tool from Google Earth.	Based on walking, biking shed maps divided into 100m intervals.
	AUTONOMY (DESIGN)	Design and infrastructure	Measuring amount of infrastructure.	Distance measuring tool at Google Earth, internet research on municipal road designations/transit maps.

3.2.3 Waste Management

Below, Figure 31 illustrates the entire Waste Management System Matrix.

Figure 31 – Waste Management System Matrix

WASTE MANAGEMENT SYSTEM MATRIX

ACCESS				OPERATIONS										
DIVERSITY	PROXIMITY			AUTONOMY									EFFICIENCY	
WASTE STREAMS	O	C	M	WASTE HEAT	BIOGAS TRANSPO	BIOGAS COOKING	BIOGAS ELECTRIC	SEWAGE TREATMT	COMPOST / FERTILIZER	N/P WATER DOMESTIC	N/P WATER INDUSTRL	N/P WATER OUTDOOR	NO USES	DISCREPANCY
BLACKWATER														
GREY WATER														
GREEN														
REFUSE														

The metrics in this section assess waste management systems operating in the neighbourhood to uncover how it is collected and how it is processed or used once collected, if at all. To begin this section, waste is divided into one of four types: *Blackwater*; *Greywater*; *Green*, or; *Refuse*. Definitions for these terms, and others used in this section are provided below in Table 3.27. As discussed at the beginning of this chapter, Canadian urban municipalities use a water-borne system for removing and treating human waste. This is the case in most developed countries, though alternative, small-scale systems do exist with varying degrees of compatibility or interaction with established municipal systems.

Table 3.27 – Glossary of Terms for Waste Management

TERM	DEFINITION
Blackwater	Water contaminated by fecal matter or containing industrial toxins
Greywater	Effluent from domestic use (dishwater, shower water, washing machine
Green Waste	Organic waste from kitchens or yards
Refuse	Garbage destined for a landfill or incineration
Clivus Multrum	A waterless dry sanitation (DS) system developed in Sweden (Cordova & Knuth 2005)
DESAR	**D**ecentralized **S**anitation **A**nd **R**euse: this can refer to either a) a small, on-site independent system, catching black water and food waste and digesting it anaerobically on site, or; b) capturing grey and black water from a building and filtering out fecal matter to be either dried, removed, or sent into an existing sewer system. Remaining water is pre-treated and kept on site for non-potable or outdoor uses.

Assessing the Waste Management System: Because of the links to water supply, examining the human and food waste streams at both neighbourhood and municipal scales is necessary. Within this Waste Management section, the metrics are interrelated and require research into municipal policies and programs. The assessment uses the structure introduced in Table 2.2 from Chapter 2. Beginning with the *Access* category, the *Proximity* and *Diversity* metrics examine how waste is collected in terms of distance, and waste stream availability, respectively. The *Operations* category examines the organization of the identified streams in terms of added energy input, and secondary uses of waste, using the *Efficiency* and *Autonomy* metrics, respectively.

Within the Waste Management *Access* category, the *Diversity* (3.2.3.2) metric should be completed first, and the information gathered is then used for the *Proximity* metric.

3.2.3.1 Waste Management Access

Proximity

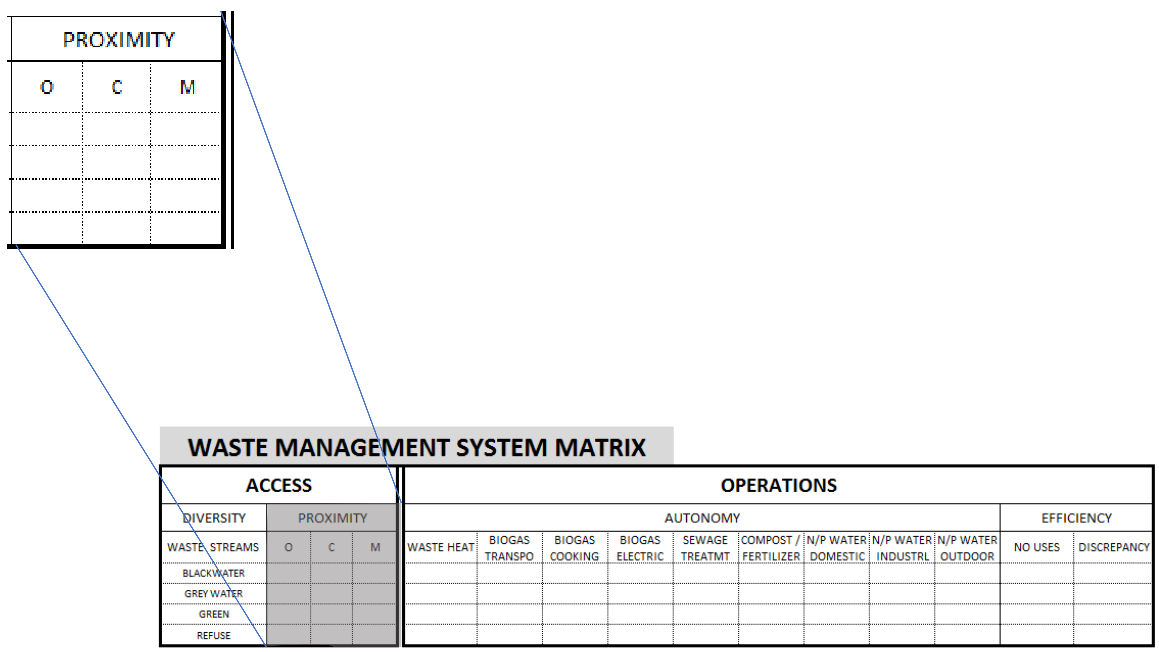
The *Proximity* metric examines waste management ***Distance*** and here this refers to how waste is collected. Tracking the distance waste travels for collection provides information on collection system organization in terms of (de)centralization. Much like for Supply Needs (Sections 3.1.1, 3.1.2, and 3.1.3), distance is assessed relatively rather than measured. For example, kitchen and yard organics can be collected at the individual household level, collected communally by the municipality, or semi-communally, that is, as groups of households. Using information gathered in the *Diversity* section, Table 3.28 on the following page, separates the different types of waste generated in the neighbourhood and examines the distances involved using the same Distance Groups used previuosly: O (On-site), C (Community), M (Municipal), and R (Regional).

Table 3.28 – Distance Groups for Waste Collection

DISTANCE GROUP	CODE	EXPLANATION
On-site	O	Collected at the individual household or business level. For multi-family or commercial buildings, this involves each unit collecting their waste and depositing it in a central location accessible only to residents of the building/complex. e.g. kitchen garbage
Community	C	Collected to a publically accessible location, or as part of a closed neighbourhood collection system accessed by residents through travel or infrastructure e.g. drop off community composting
Municipal	M	Collected using infrastructure extending outside the neighbourhood e.g. a municipal sewer system
Region[14]	R	Collected outside municipal boundaries e.g. a self-serve land fill

Results are placed in the highlighted section of the Waste Management System Matrix shown in Figure 32, below, and documented as the number of households participating in each system as a percentage of total households.

Figure 32 – Waste Management System Matrix, Access Category, Proximity Metric



[14] Region Distance Group is used primarily in the Operations Autonomy section to track location of a secondary use

Diversity

The *Diversity* metric examines waste management ***Options*** by documenting the number of waste streams present in the neighbourhood. These can be compatible with current infrastructural systems, programs such as curbside collection, or separate underground systems, and more than one system for each type of waste is possible. For example, if one multi-family complex has their own composting system, but the neighbourhood does not. Table 3.29, below, provides a summary of options and current technologies available for each waste stream and type.

Table 3.29 Waste Technologies by Stream

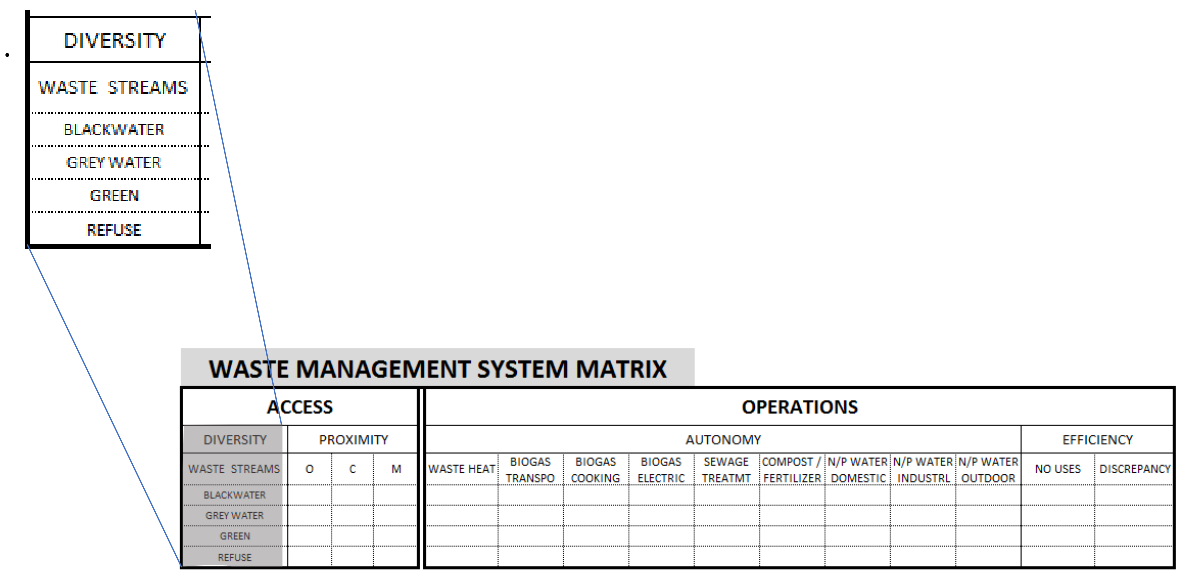
STREAM	INITATIVE TYPES
Black water	On-site DESAR
	On-site clivus multrum
	Community DESAR
	Municipal sewer
	Municipal stormwater/sewer[15]
Grey Water	On-site DESAR
	Community DESAR
	Third pipe collection
	Sewer
	Municipal stormwater/sewer
Green	Domestic compost collection/use
	On-site DESAR
	Community compost collection
	Municipal compost collection
Refuse	Community garbage collection
	Municipal garbage collection

Tracking the existence of these systems, which are often underground or within structures, begins with research into local legislative support for their implementation. If

[15] This initiative refers to older systems where sewer and storm water systems are merged, in Canada most of these merged systems began conversion to separate systems in the 1950s (http://www.calgary.ca/UEP/Water/Pages/Water-and-wastewater-systems/Storm-drainage-system/History.aspx#before)

these systems are not permitted, then no other research is necessary. The required information can be gathered through municipal websites, local building codes, legislation searches, or event promotional builder websites. Results are documented by listing the available waste streams in the Waste Management Matrix, and these are subsequently used in the *Proximity* metric (Section 3.2.3.1). The highlighted section in Figure 33, below, indicates where to document this information.

Figure 33 – Waste Management System Matrix, Access Category, Diversity Metric



3.2.3.2 Waste Management Operations

<u>Efficiency</u>

This metric uses information gathered in the *Operations Autonomy* metric below, and so should be completed after the *Autonomy* metric. The *Efficiency* metric here examines waste management in terms of conversion for eventual ***Use***. While the *Diversity* metric examined the systems available, this metric examines system functionality, specifically the conversion of waste collected and waste used, for example as fuel, biogas, or compost.

By cross-correlating information from the *Proximity* and *Autonomy* metrics, the discrepancy between where waste is collected and where/how it is converted for use is documented. Tracking this discrepancy provides information on relative efficiency in waste processing as well as reliance on external systems such as transportation or centralized municipal infrastructure. For example, on-site composting for on-site use, requires little input, infrastructure, or transportation, whereas on-site compost collection requiring pick-up by the municipality, maintains much higher energy input. This discrepancy is recorded by documenting the number of 'steps' between collection and eventual use (if any), similar to the 'node' system used in the Food and Energy sections (Sections 3.1.1 and 3.1.2). Here, the steps/nodes are consistent however, and are summarized below in Table 3.30, below, using the Distance Groups from Table 3.28 in Section 3.2.3.1, *Access Proximity* metric.

Table 3.30 – Discrepancy Between Waste Collection and Waste Use

		SCALE OF COLLECTION			
		On-site	Community	Municipality	Region
SCALE OF USE	On-site	0	1	2	3
	Community	1	0	1	2
	Municipality	2	1	0	1
	Region	3	2	1	0

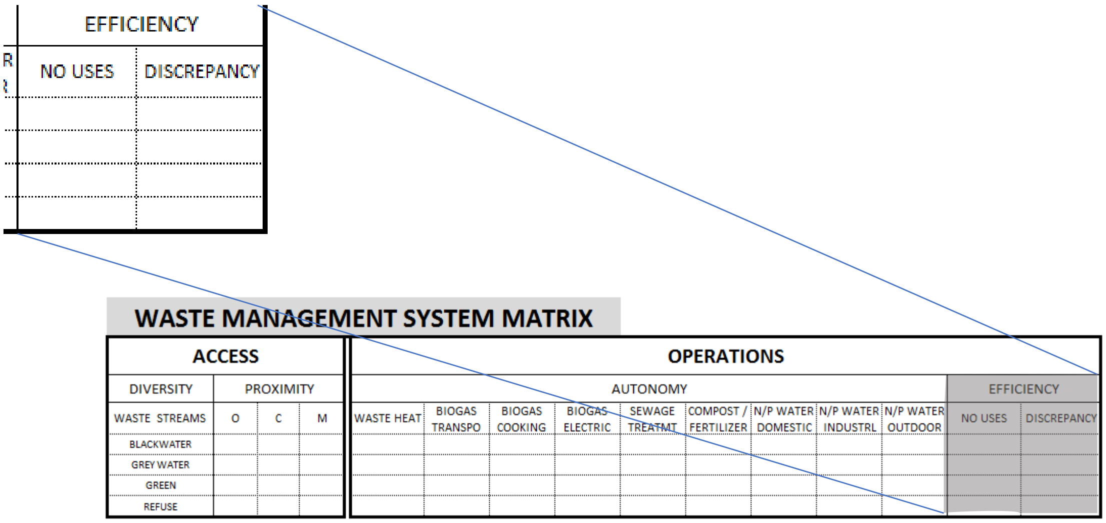
Filling in this section requires research into neighbourhood association and municipal programs and policies regarding waste management. Figure 34, on the following page, provides an example of how discrepancies are recorded using information already gathered for the *Access Proximity* and *Operations Autonomy* metrics. In the example below, four waste streams are present in the sample neighbourhood. The Black and Grey Water systems are managed by municipal infrastructure (M) and Black Water is tapped for waste heat in the subject neighbourhood (C). Using Table 3.30, the discrepancy between municipal <u>collection</u> and neighbourhood <u>use</u> is ‘1’. Grey Water is collected municipally (M) and deployed for non-potable domestic use in neighbourhood households (O), resulting in a discrepancy of ‘2’. Green Waste and organics, as well as regular Refuse, are collected ‘curbside’ (O) by a municipal fleet of trucks. Green Waste is used by the Municipality for compost in parks (M), and Refuse is burned for city electricity (M).

Figure 34 – Waste Management Efficiency Tabulation Example

ACCESS				OPERATIONS										
DIVERSITY	PROXIMITY			DESIGN									EFFICIENCY	
WASTE STREAMS	O	C	M	WASTE HEAT	BIOGAS TRANSPO	BIOGAS COOKING	BIOGAS ELECTRIC	SEWAGE TREATMT	COMPOST / FERTILIZER	N/P WATER DOMESTIC	N/P WATER INDUSTRL	N/P WATER OUTDOOR	NO USES	DISCREPANCY
BLACKWATER			100	C										1
GREY WATER			100							O				2
GREEN	100								M					2
REFUSE	100						M							2

The highlighted section in Figure 35, on the following page, indicates where to document this information.

Figure 35 - Waste Management System Matrix, Access Category, Efficiency Metric



<u>Autonomy</u>

For the *Operations* category, the *Autonomy* metric assesses waste management system ***Design***, in order to uncover any secondary uses for waste, after it is collected, such as biogas, electricity, or heat. A waste system designed to exploit waste as a resource to support other needs, potentially decreases the demand for external inputs into other systems. While these systems may not run entirely on waste by-products, per se, having diminished the demand for fuels to operate these systems, or by supplying local sources for these systems' functioning increases their flexibility. This has implications not only for efficient use of infrastructural resources, but also climate change mitigation and GHG emissions reduction.

Furthermore, local systems using both local and external resources increase a system's redundancy, and therefore, its resilience. The contents for this metric are based on technology and strategies deployed in urban communities in developed countries including: Västra Hamnen in Malmö, Sweden (Anderson 2014; Austin 2009); Vauban in

Freiburg, Germany (Otterpohl et al. 2003); New Haven Village in Adelaide, Australia (Barton & Argue 2007), and; Southeast False Creek in Vancouver, Canada (Alexander 2000; Kear 2007). Below, Table 3.31 summarizes initiatives from these neighbourhoods and potential secondary uses for waste are marked with a X. While none of the above communities address all aspects of waste management in a closed loop, they do provide examples of different strategies and technologies available and compatible with contemporary urban living in a developed country.

Table 3.31 – Waste Management and Secondary Uses

SECONDARY USE	BLACK WATER	GREY WATER	GREEN	REFUSE
Waste heat	X		X	X
Bio gas (transportation)	X		X	
Bio gas (cooking)	X			
Bio gas (electricity)	X		X	X
Sewage Treatment		X		
Compost/Fertilizer	X		X	
Non-potable water (domestic)		X		
Non-potable water (industrial)		X		
Non-potable water (outdoor/public)		X		

Using the waste streams identified in the *Access* category in this section, any secondary uses are uncovered and documented in the appropriate cell using the distance categories: O (On-site); C (Community), M (Municipality), and; R (Region) to track the scale of waste by-product use. This is marked in the highlighted section shown in Figure 37, on page 109. An example of how to use this metric is provided in Figure 36, also on page 109, and based on an example taken from Barton & Argue (2007) along with information gathered at the City Port of Adelaide Enfield municipal website[16]:

[16] www.portenf.sa.gov.au

> North Haven is a neighbourhood of approximately 400 households in the suburb of Osbourne in the City Port of Adelaide Enfield, Australia. A 65-household development (New Haven Village) has its own separate neighbourhood waste water system. There is a small sewage treatment facility, using domestic grey water and some storm water to support its processes, and in turn, grey water is produced at the facility for non-potable domestic uses, both indoor (flushing) and outdoor (watering). All residences in the municipality of City Port have a municipal kitchen waste collection ‘green bin’ and a refuse collection program by weekly curb-side pickup by City vehicles, though yard waste is not collected. The City uses the collected green waste for municipal composting/fertilizing, garbage/refuse is sent to the landfill with no secondary uses.

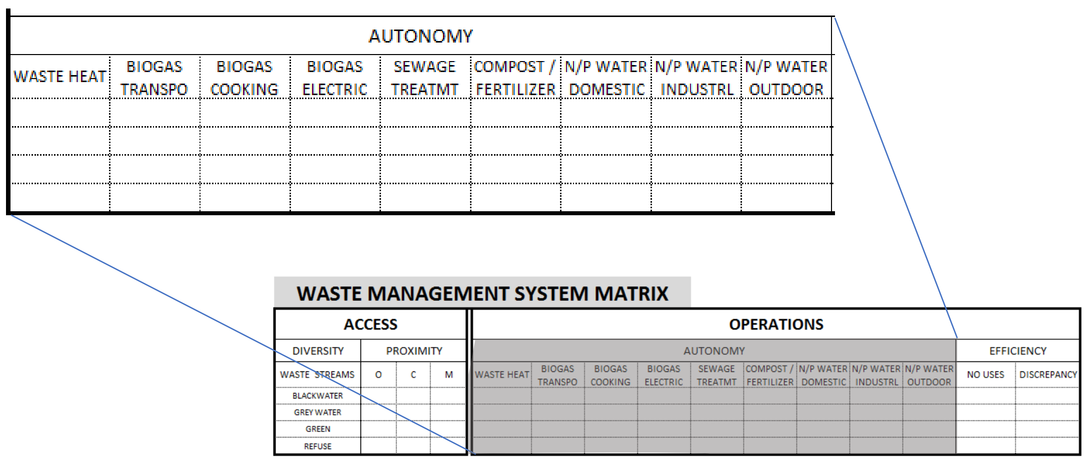
The systems in New Haven Village operate within the wider neighbourhood of North Haven, and so within the *Access Diversity* metric, two waste streams for Blackwater are used. The number of households tied to each system, as a percentage of total neighbourhood households, is documented in the *Access Proximity* metric and tracks the scale of waste collection. The *Operations Design* metric documents the scale that waste is used by using abbreviations for On-site (O), Community (C), Municipal (M), and Regional (R) distance categories. With the above example, Blackwater produced in New Haven Village is locally treated, and so in the Sewage Treatment column, Blackwater A receives a ‘C’, for Community in the matrix. Conversely, kitchen organics are collected by households (O) but used as fertilizer by the City (M). All un-applicable uses are eliminated from the matrix.

Figure 36 – Waste Management Operations Autonomy Example

ACCESS				OPERATIONS					
DIVERSITY	PROXIMITY			AUTONOMY				EFFICIENCY	
WASTE STREAMS	O	C	M	SEWAGE TREATMT	COMPOST / FERTILIZER	N/P WATER DOMESTIC	N/P WATER OUTDOOR	NO USES	DISCREPANCY
BLACKWATER A		16%		C					0
BLACKWATER B			84%					X	3
GREEN	100%				M				2
GREY WATER		16%		C		C	C		0
REFUSE	100%							X	3

Results are marked in the highlighted section shown in Figure 37, below.

Figure 37 – Waste Management System Matrix, Operations Category, Autonomy Metric



On the following page, Table 3.32 provides a summary of the metrics described in this section and the methods used to measure or assess and document the results. Within the table's three columns, *Metric*, *Resources*, and *Methods*, *Metric* explains the aspect being measured; *Resources* indicates how information is acquired; *Methods* outlines any relevant limitations or specifications in gathering the information.

Table 3.32 – Summary of Waste Management System Metrics

CATEGORY	METRIC		RESOURCES	METHOD
ACCESS	PROIMITY (DISTANCE)	Collection point for each waste stream	Municipal websites	Research on infrastructure or services provided
	DIVERSITY (OPTIONS)	Number of waste streams	Municipal website research	Research on infrastructure or services provided
OPERATIONS	EFFICIENCY (ENERGY USE)	Spatial difference between waste collection points and uses (if any)	Using information from proximity metric and autonomy metric	Number of 'distance groups' between collection and use
	AUTONOMY (DESIGN)	Secondary uses for waste	Municipal/ community association website research	Research on alternative energy production, waste management practices… can use information gathered in Energy metrics if applicable

CHAPTER 4

This chapter applies the methodology outlined in Chapter 3 to two neighbourhoods in southern Alberta (Drake Landing, Okotoks, and; Sunnyside, Calgary) using the matrices in each Need. A summary matrix at the beginning of each case study provides an overview of the results of all six matrices, and results are discussed. A synopsis of the data used to fill the matrices are found in the Appendices A and B at the end of chapter.

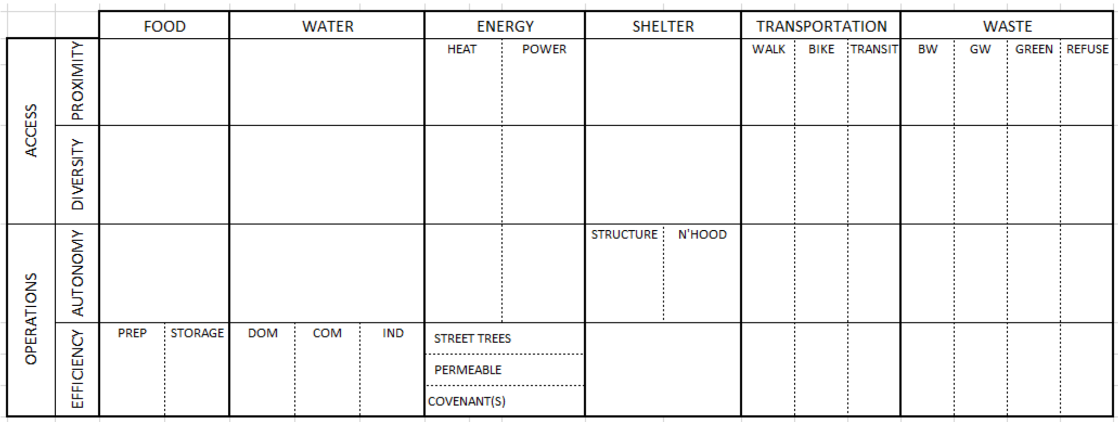
4 Collecting Information

Prior to beginning of any of the assessment metrics, certain tools or facts are required:

- the population size and area size in m^2
- the number of dwelling units (households)
- a satellite map of the neighbourhood
- transit route(s) information
- common types of household fuels used in the region (for heating and electricity)
- utility service provider information (generation and delivery)
- food-related programs or initiatives operating in the neighbourhood (for example: CSA drop off point, food programs, community gardens)
- design and construction-related programs or initiatives in the neighbourhood (neighbourhood covenants, developer initiatives, and standards etc.).
- geographical information (flood maps, topography etc.)
- climatic information (weather and extreme weather)
- age of the development or access to a redevelopment date map
- local water information: source, processes, infrastructure (both green and grey)

Because "resilience" involves both mitigation and adaptation, the information gathered is interpreted through both lenses. While not all neighbourhood Need Systems maintain an influence on both mitigation and adaptation simultaneously, they are all potentially impacted by neighbourhood locational and weather hazards in the municipality and/or within Alberta and Canada. Results of the methodology proposed in Chapter 3 can be summarized using the matrix shown in Figure 38, on the following page.

Figure 38 – Summary Matrix



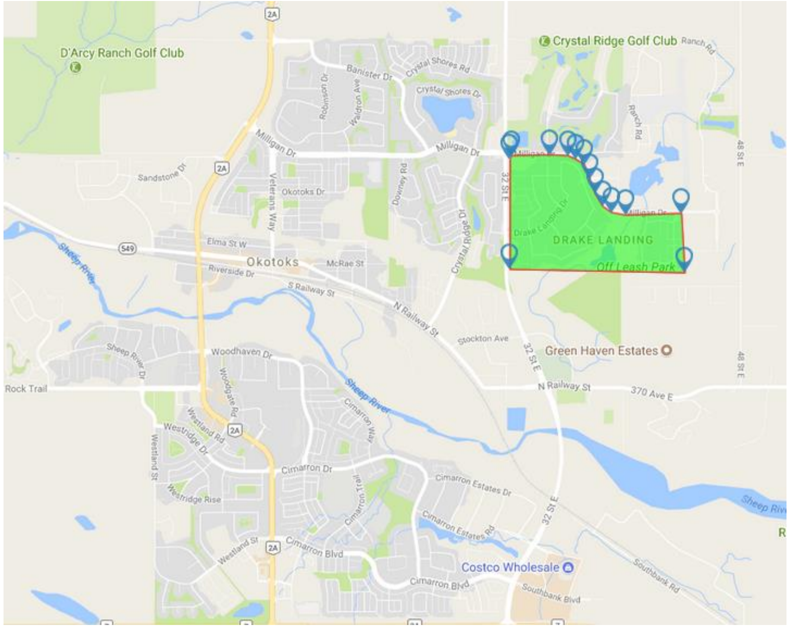
4.1 Case Study: Drake Landing, Okotoks, Alberta, Canada

Okotoks is a small city in Alberta, located 18 km south of Calgary with a population of 29,000 in 2016 (okotoks.ca). Below, Figure 39 locates Okotoks within the rest of Canada, and Figures 40 and 41, illustrate the study area within the town of Okotoks.

Figure 39 - Okotoks, Alberta

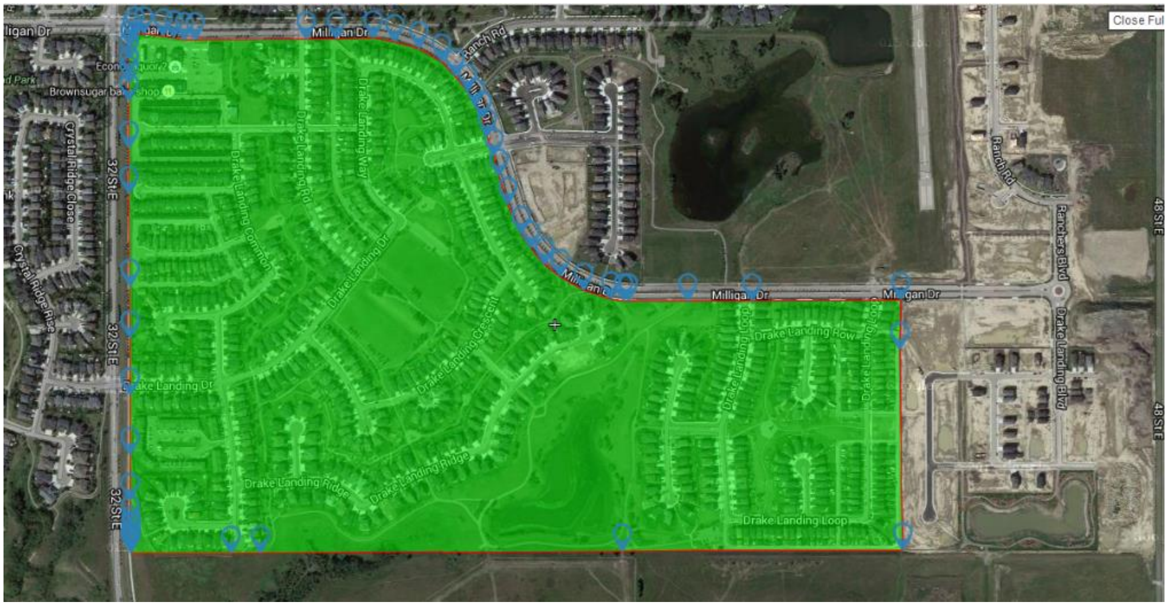
Google Maps, 2013.

Figure 40 – Drake Landing in Okotoks



Google Maps, 2013.

Figure 41 – Drake Landing



Google Maps, 2013.

Drake Landing and its associated green spaces and storm water retention pond covers an area of 697,853.445 m^2 and contains 796 Households[17]

Below, Table 4.1 outlines the specific extreme weather events impacting Drake Landing and illustrates the links between these events on resident basic needs examined in this thesis. These projected impacts are based on extreme weather events summarized in, but not limited to, Tables 1.2 – 1.4 in Chapter 1 as well as the information summarized in Section 2.2 of Chapter 2. Impacts range from immediate impacts such as the destruction of infrastructure, to secondary impacts, including disruptions to transportation of goods.

Table 4.1 - Drake Landing Extreme Weather and Neighbourhood Hazards[18]

NEED SYSTEM	ICE STORM	DROUGHT	EXTREME RAIN	EXTREME WIND	HAIL	EXTREME HEAT/COLD
Food	X	X		X	X	X
Energy	X			X	X	
Water		X	X			
Shelter	X		X	X		X
Transportation	X		X	X		
Waste Mgmt		X	X			

FOOD in Drake Landing

The results of the food metrics are summarized in Figure 42, on the following page. The Food System Matrix has been altered to include specific references and information relating to Drake Landing, Okotoks, and Alberta. Explanation of the data collected to fill the Food System Matrix is provided in Appendix A-1 at the end of this thesis.

[17] At time of writing, Drake Landing was still under construction. The total area, and total number of households excludes the unfinished area on the far east (right) of the site, see Figure 41

[18] (Lemmen et al. 2008; Etkin & Brun 2001)

Figure 42 – Drake Landing Food System Matrix

FOOD SYSTEM MATRIX

	OPERATIONS													ACCESS								
	EFFICIENCY (%)		AUTONOMY											DIVERSITY		PROXIMITY (%)						
	STORAGE	PREP	LENTILS	BEEF	CANOLA OIL	COW MILK	RICE	BARLEY	WHEAT	APPLES	WINTER SQUASH	CARROTS	BROCCOLI	OUT	IN	I	N	R	M	C	O	
ELECTRICITY	100	35	/	/	/	/	/	/	/	/	1	1	1		x					/	5	NEIGHBOURHOOD
GAS	0	65	/	4	4	5	6	/	5	5	6	6	6	x		36	27	18	/	/	/	COSTCO
OTHER	/	/	5	4	4	5	6	5	4	5	6	6	6	x		36	36	27	/	/	/	SAVE ON FOODS
			/	4	5	5	6	5	4	5	6	5	6	x		27	54	9	/	/	/	CHRISTINES

On a household basis, data collected for Drake Landing's Food System Matrix reveals a high dependence on vehicle transportation for accessing food. According the USDA's definition, Drake Landing is located in a *Food Desert*, a situation worsened by a lack of municipal transit. This dependence on vehicular transportation occurs simultaneously at a larger scale because key foods available at nearby outlets are majority sourced from national or international producers. One outlet, *Save on Foods*, sources a larger portion of regional food than the others, demonstrating that more regional food is possible. *Save on Foods* has a more balanced spread of food sources between regional, national and international.

Food storage is vulnerable because of the nature of electrical generation and distribution not only in Drake Landing, but in Alberta. With no homes in the neighbourhood producing electrical power, the entire area is vulnerable to a disruption in the Grid. Approximately 65% of the households use gas-fired ranges for food preparation. This has implications for climate change mitigation (see the Energy discussion below), but maintains no real vulnerability in terms of extreme weather events common in the area.

<u>ENERGY in Drake Landing</u>

The results of the energy metrics are summarized below in Figure 43. The Energy System Matrix has been altered to include specific references and information relating to Drake Landing, Okotoks, and Alberta. Explanations of the data collected to fill the Energy System Matrix is provided in Appendix A-2 at the end of this thesis.

Figure 43 – Drake Landing Energy System Matrix

ACCESS								
PROXIMITY (%)			DIVERSITY (%)					
	HEAT	POWER	SOLAR	WIND	COAL	GAS	BIOMASS	HYDRO
C	6		H-6					
M								
R	94	100		P: 5	P: 51	H: 94 P: 39	P: 3	P: 2

OPERATIONS			SOLAR	WIND	COAL	GAS	BIOMASS	HYDRO
	AUTONOMY	HEAT	3			5		
		POWER	4	4	5	5	4	4
	EFFICIENCY (%)	STREET TREES	1.5					
		PERMEABLE SURFACE	56					

In terms of adaptation, Drake Landing benefits from having domestic electrical delivery infrastructure underground, however, its supply is dependent on long-distance, above-ground transmission – infrastructure inherently vulnerable to the extreme weather in the region.

The majority (over 85%) of the electricity supply (heat and power combined), is derived from fossil fuel sources – this is problematic in terms of mitigation in any neighbourhood. While natural gas power plants are being constructed to diminish the use of coal in Alberta[19], natural gas and its associated processing is not the emission-free product (Brandt et al. 2014) as it is often presented[20]. Natural gas use is somewhat diminished in the neighbourhood because 6% (52) of the homes are tied into a neighbourhood Borehole Thermal Energy Storage (BTES) system, thereby eliminating the need for gas-fired furnaces. Additional solar thermal collectors on these homes are used to heat water. These BTES-connected homes lack the same vulnerability to extreme cold that other homes in the neighbourhood possess in the event of disruptions to natural gas supply infrastructure. They also have been built to the R2000 insulation standard, unlike the rest of the homes.

In terms of consumption, Drake Landing could deploy strategies to reduce energy consumption – thereby diminishing GHG emissions and mitigating further environmental damage and subsequently decreasing the need to implement further adaptation measures. For example, the lack of deciduous street trees, covering only 1.5% of neighbourhood road length, increases UHI in summer, resulting in increased energy demand for air conditioners. Anecdotally, according to the developer, all 52 of the BTES homes have added air conditioners. Drake Landing does succeed in maintaining significant amounts of green space to help mitigate UHI and even exceeds the German Green Council's 50% guideline, however, there are other opportunities for decreasing UHI: for example, the

[19] https://www.alberta.ca/climate-coal-electricity.asp

[20] http://www.energy.alberta.ca/NaturalGas/723.asp frames Natural Gas as the 'cleanest' energy source available.

paved back lanes, wide enough for two vehicles abreast, eliminate the opportunity not only for small vegetation patches, but also because the paving further increases the ambient temperatures in the area. While this is a positive attribute in winter, it only functions when there is direct solar penetration to the asphalt and not through snow.

WATER in Drake Landing

The results of the metrics are summarized below in Figure 44. The Water System Matrix has been altered to include specific references and information relating to Drake Landing, Okotoks, and Alberta. Explanations of the data collected to fill the Water System Matrix is provided in Appendix A-3 at the end of this thesis.

Figure 44 – Drake Landing Water System Matrix

WATER SYSTEM MATRIX

ACCESS							
PROXIMITY					DIVERSITY		
SOURCE	M	R	N	I	POTABLE	NON-POT	BOTH
Surface (river)	X						X

OEPRATIONS						
EFFICIENCY				AUTONOMY		
INITIATIVE	DOMESTIC	COMMERCIAL	PUBLIC	NUMBER OF HOUSEHOLDS	NODES	%
Low-flow faucets	X	X		796	4	100
Metering	X					
Topsoil	X					
Mulching			X			
Storm water biofiltration			X			

In an area prone to drought, water availability, and specifically its conservation, is increasingly important. Because the vast majority of water is used for agriculture rather than in cities (Howard & Bartram 2010), increasing the available volume of water in an agricultural province, is important. Water conservation initiatives in Drake Landing are minimal. In Alberta, rain is considered property of the provincial government, and so harnessing storm water in significant quantity to offset non-potable needs is not permitted.

SHELTER in Drake Landing

The results of the shelter metrics are summarized below in Figure 45. The Shelter System Matrix has been customized to include specific references and information relating to Drake Landing, Okotoks, and Alberta. Explanations of the data collected to fill the Shelter System Matrix is provided in Appendix A-4 at the end of this thesis.

Figure 45 – Drake Landing Shelter System Matrix

SHELTER SYSTEM MATRIX

ACCESS		
PROXIMITY		DIVERSITY
SHELTER	CAPACITY (%)	OVERLAP (%)
NO SHELTERS IDENTIFIED		

OPERATIONS					
AUTONOMY			EFFICIENCY		
VULNERABILITY	STRUCTURES (%)	NEIGHBOURHOOD	BUILDING VINTAGE	%	RATING (VL,L, M, H)
DROUGHT		X	PRE 1949		
HIGH WINDS			1950-1970		
EXTREME RAIN			1971-2011	94%	M
EXTREME HEAT			2012-2017		
EXTREME COLD	6%		R-2000	6%	H
OVERLAND FLOODING					

During a disruption, emergency or temporary shelter is largely inaccessible to most residents on foot. Given the potential weather vulnerabilities, the lack of public shelter options is problematic, especially because most of the homes are not built or designed with these disruptions/hazards in mind. The nearest large communal building (Gibson Morris School) can be used as an emergency shelter, but because of its location, vulnerable residents (that is, those who cannot drive: the very young, the very old, the injured and/or disabled and their caregivers) are unable to access it easily.

For individual structures, all dwellings have been designed in a typical suburban fashion, with little attention paid to increasing their passive design using a variety of architectural features or strategies, such as mutual shading, on-site solar power generation, grey water use, etc. This results in dwellings that are completely dependent on outside systems to operate. While 6% of the homes are insulated to a R2000 standard, the remaining 94%, are not, rendering them completely dependent on the integrity of natural gas lines and supply. There is a lack of redundancy, and therefore resiliency, to their heating systems.

TRANSPORTATION in Drake Landing

The results of the transportation metrics are summarized on the following page in Figure 46. The Transportation System Matrix has been altered to include specific references and information relating to Drake Landing, Okotoks, and Alberta. Explanations of the data collected to fill the Transportation System Matrix is provided in Appendix A-5 at the end of this thesis.

Figure 46 – Drake Landing Transportation System Matrix

TRANSPORTATION SYSTEM MATRIX

	ACCESS					OPERATIONS			
	PROXIMITY (%)				DIVERSITY	AUTONOMY			
MODE	FOOD	CBD	TRANSIT	SCHOOL	OVERLAP	SIDEWALK	BRT	BIKE LANE	MUP
WALK				0.5		100			30
BIKE				43					
					PEDESTRIAN	PRD	EFFICIENCY		
					VEHICLE				

Travel within the neighbourhood is relatively efficient because of the small size of the area, but the road network layout itself is inefficient. Travel is largely dominated by private vehicles, with MUPs used primarily for recreation, evidenced by their lack of destination-oriented layout and meandering routes. This is exacerbated by the fact that there is little to walk or cycle to in terms of key destinations, except for the primary school in the adjacent neighbourhood, and even this is quite far with only 0.5% of households falling within a 600m walkshed. There is no transit available in Okotoks, and no dedicated biking infrastructure outside of the MUP network in the neighbourhood. For the most part, residents are required to drive everywhere, rendering them vulnerable in a variety of ways to any disruptions in transportation fuel supply and/or roadway integrity.

<u>WASTE MANAGEMENT in Drake Landing</u>

The results of the waste management metrics are summarized on the following page in Figure 47. The Waste Management System Matrix has been altered to include specific references and information relating to Drake Landing, Okotoks, and Alberta. Explanations of the data collected to fill the Waste Management System Matrix is provided in Appendix A-6 at the end of this thesis.

Figure 47 – Drake Landing Waste Management System Matrix

WASTE MANAGEMENT SYSTEM MATRIX						
ACCESS				OPERATIONS		
DIVERSITY	PROXIMITY			AUTONOMY	EFFICIENCY	
WASTE STREAMS	O	C	M	COMPOST / FERTILIZER	NO USES	DISCREPANCY
BLACKWATER			100	R		1
GREEN	100			R		3
REFUSE	100				X	

The systems in place in Drake Landing are largely designed for compatibility with older established infrastructure. Sewage is dealt with at the household level as part of a municipal, water-borne, sewage network and there is weekly garbage collection destined for the municipal landfill. Green and organic waste is either dealt with by individual households as either as compost or refuse and collected privately, kept on site, picked up with garbage, or dropped off at a central location in the neighbourhood.

<u>Summary</u>

The results of all the matrices for Drake Landing are provided in the summary matrix in Figure 48, on the following page. Presented is a summary of quantitative and qualitative information, based on the discussions within each need system. An attempt has been made to ensure neutrality in the results, and present them as factually as possible, allowing them to be interpreted depending on the hazard or vulnerability under examination.

Figure 48 – Drake Landing Summary Matrix

		FOOD	ENERGY		WATER	SHELTER	TRANSPORTATION		WASTE	
			HEAT	POWER			WALK	BIKE	BW	REFUSE
ACCESS	PROXIMITY	VEHICLE DEPENDENT	94% GAS DOMINATED	REGIONAL/ LONG DISTANCE	MUNICIPAL SOURCE	NO ES/TS	MINIMAL/NO DESTINATIONS	43% FOR ONE DESTINATION	M	O
	DIVERSITY	NO OUTLETS	94% FOSSIL FUEL DOMINATED	DIVERSE BUT FOSSIL FUEL DOMINATED (see Appendix B)	POTABLE AND NON-POTABLE	NO ES/TS	NO OVERLAP	NO OVERLAP	2 STREAMS	
OPERATIONS	AUTONOMY	REGIONAL AND NATIONAL TRANSPORTATION DEPENDENT	94% COMPLEX NETWORK DOMINATED	COMPLEX NETWORKS	4 NODES	MINIMAL/NO AUTONOMY	SIDEWALKS EVERYWHERE + 30% MUPS	NO ON-ROAD INFRASTRUCTURE OR DESIGNATION + 30% MUPS	FEW/NO USES	
	EFFICIENCY	PREP: GAS Dependent; STORAGE: GRID Dependent	1.5% STREET TREES / 56% PERMEABLE		MINIMAL/SOME LEGISLATED CONSERVATION	6% HIGH EFFICIENCY	VEHICLE-DOMINATED STREET NETWORK		1	X

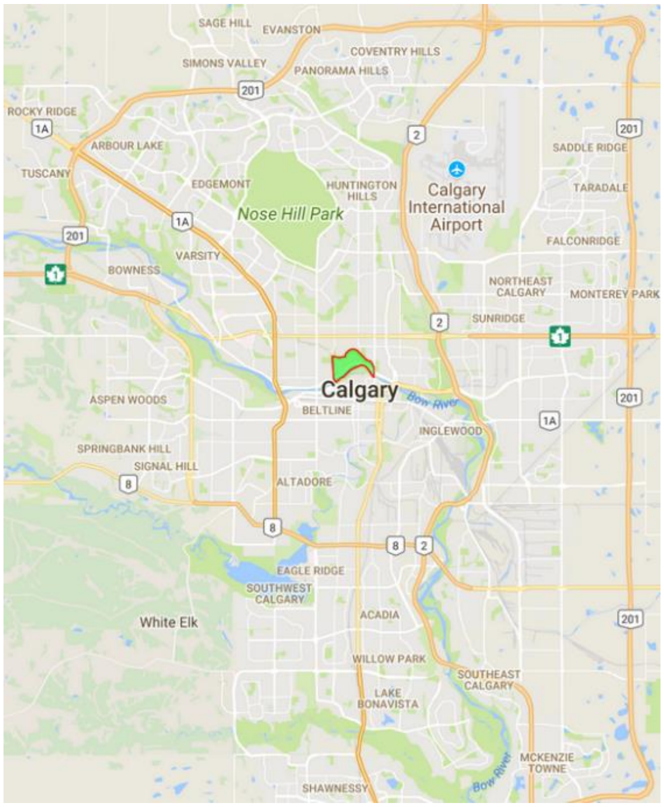
4.2 Case Study: Sunnyside, Calgary, Alberta, Canada

Calgary is a city of over 1 million people (calgary.ca), located in the southern half of Alberta. Below, Figure 49 locates Calgary within the rest of Canada, and Figures 50 and 51, illustrate the study area within the city of Calgary.

Figure 49 - Calgary, Alberta

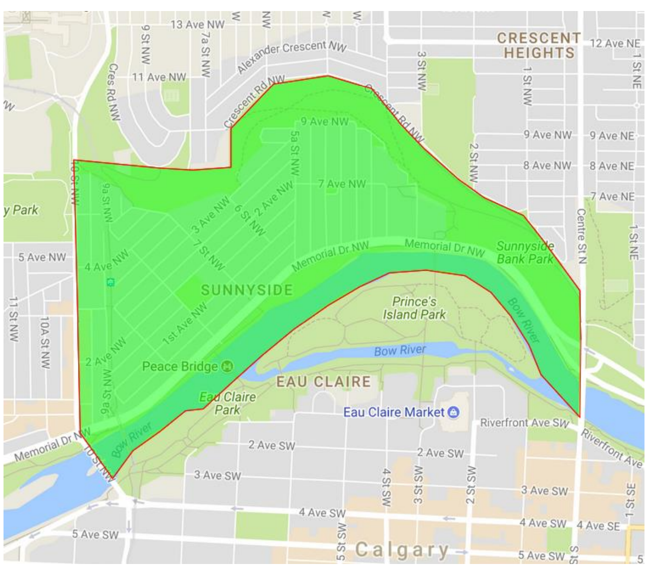
Google Maps, 2013.

Figure 50 – Sunnyside in Calgary



Google Maps, 2013.

Figure 51 – Sunnyside



Google Maps, 2013.

Sunnyside contains 2591 households and covers an area of 1,019,726.762 m^2 including all associated green areas but excluding the Bow River. Neighbourhood boundaries include the river, but for the purposes of the case study, its surface area has been excluded.

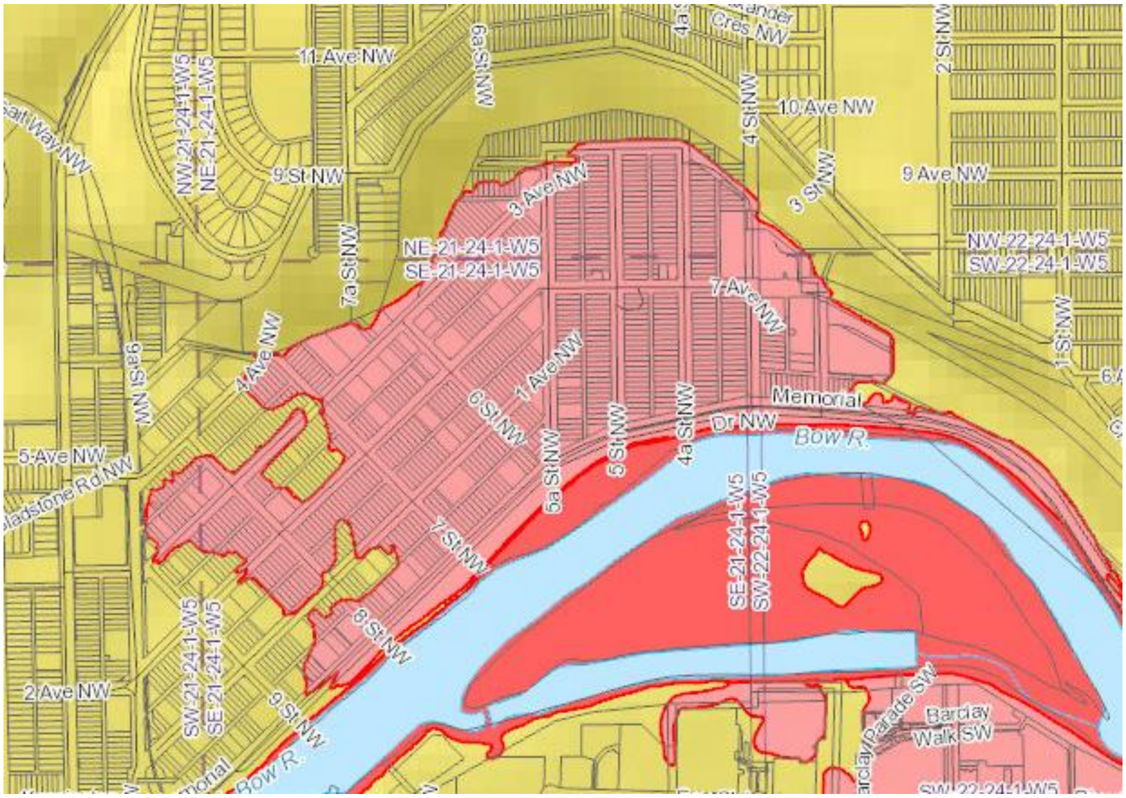
Below, Table 4.2 outlines the specific extreme weather events impacting Sunnyside and illustrates the links between these events on resident basic needs examined in this thesis. These projected impacts are based on extreme weather events summarized in Tables 1.2 – 1.4 in Chapter 1 as well as the information summarized in Section 2.2 of Chapter 2. Furthermore, Sunnyside is located on a floodplain and is vulnerable to flooding from the nearby Bow River. Figure 52, on the following page, indicates the extent of the floodable area. Potential impacts range from the immediate, such as the destruction of infrastructure and buildings, to the secondary, including disruptions to transportation of goods.

Table 4.2 - Sunnyside Extreme Weather and Neighbourhood Hazards[21]

NEED SYSTEM	ICE STORM	DROUGHT	EXTREME RAIN	EXTREME WIND	HAIL	EXTREME HEAT/COLD	OVERLAND FLOODING
Food	X	X		X	X	X	X
Energy	X			X	X		X
Water		X	X				X
Shelter	X		X	X		X	X
Transportation	X		X	X			X
Waste Mgmt		X	X				X

[21] (Lemmen et al. 2008; Etkin & Brun 2001)

Figure 52 – Flood map of Sunnyside, Calgary[22]



<u>FOOD in Sunnyside</u>

The results of the food metrics are summarized on the following page in the matrix shown in Figure 53. The Food System Matrix has been altered to include specific references and information relating to Sunnyside, Calgary, and Alberta. Explanations of the data collected to fill the Food System Matrix is provided in Appendix B-1 at the end of this thesis.

[22] http://maps.srd.alberta.ca/floodhazard/.

Figure 53 – Sunnyside Food System Matrix

FOOD SYSTEM MATRIX

OPERATIONS														ACCESS								
EFFICIENCY (%)			AUTONOMY											DIVERSITY		PROXIMITY (%)						
	STORAGE	PREP	LENTILS	BEEF	CANOLA OIL	COW MILK	RICE	BARLEY	WHEAT	APPLES	WINTER SQUASH	CARROTS	BROCCOLI	OUT	IN	I	N	R	M	C	O	
ELECTRICITY	100	96								1	1	1	1		X					1.4	0.5	NEIGHBOURHOOD
GAS		4		5	6	6	6		6	5	4	5	5		X	36	27	18	0			SAFEWAY
			4	3	3	3	6	5	3	4	4	3			X	18	9	64	0			SUNNYSIDE MARKET

On a household basis, Sunnyside's Food System Matrix reveals that food is accessible to most residents because there are two community gardens serving 37 households, 14 backyard vegetable plots, and two food outlets located within neighbourhood boundaries. Furthermore, long-distance transportation for externally produced food is less common at one food outlet (Sunnyside Market), because they source a large portion of Key Foods from local and regional suppliers. Food storage is vulnerable because of the nature of electrical generation and distribution not only in Sunnyside, but in Alberta (see Section 3.1.2). Google satellite imagery reveals five households producing electrical power (one condominium with four units and one single-family home), and so the entire neighbourhood's food storage capacity is vulnerable to a disruption in the electrical grid. Food preparation is vulnerable because of the dominance of electric ranges in the neighbourhood. The methodology used to calculate this is outlined in Appendix B-1.

ENERGY in Sunnyside

The results of the energy metrics are summarized below in the matrix shown in Figure 54. The Energy System Matrix has been altered to include specific references and information relating to Sunnyside, Calgary, and Alberta. Explanations of the data collected to fill the Energy System Matrix is provided in Appendix B-2 at the end of this thesis.

Figure 54 – Sunnyside Energy System Matrix

ENERGY SYSTEM MATRIX

ACCESS								
	PROXIMITY (%)		DIVERSITY (%)					
	HEAT	POWER	SOLAR	WIND	COAL	GAS	BIOMASS	HYDRO
O		0.1	P: 0.1					
R	100	99.9		P:5	P:51	H: 100 P: 39	P:3	P:2

OPERATIONS								
	AUTONOMY	HEAT				5		
		POWER	2	4	7	5	4	4
	EFFICIENCY (%)	STREET TREES	84					
		PERMEABLE SURFACE	54					

In terms of adaptation, Sunnyside's energy system is vulnerable on two important fronts: 1) neighbourhood electrical distribution uses above-ground power lines, and this local supply is also dependent on above-ground, long-distance transmission – infrastructure inherently vulnerable to the extreme weather, such as high winds and hail and ice storms, identified in this region. Conversely, above-ground power lines are less vulnerable to overland flooding.

Almost 100% of the electricity supply (heat and power combined), is derived from fossil fuel sources – this is problematic in terms of climate change mitigation in any neighbourhood. While natural gas power plants are being constructed to diminish the use of coal in Alberta[23], natural gas and its associated processing is not the emission-free product (Brandt et al. 2014) as it is often presented[24]. With only five households using solar PV panels for electricity, even assuming these panels provide for all electrical needs, access to electricity is extremely vulnerable, especially given the power lines.

In terms of energy consumption and conservation, Sunnyside exhibits many positive attributes and strategies. Despite the prevalence of paved back lanes, UHI is curtailed because of the number of street trees in the area, covering 84% of neighbourhood road length, resulting in decreased energy use/demand from air conditioners during the summer or extreme heat. Furthermore, that 54% of the surface area is permeable – the large green space/bluff on the north side of the neighbourhood accounts for much of this permeability – despite the large amount of paved surface parking for many of the apartment blocks, also supports UHI mitigation.

WATER in Sunnyside

The results of the water metrics are summarized on the following page in Figure 55. The Water System Matrix has been altered to include specific references and information relating to Sunnyside, Calgary, and Alberta. Explanations of the data collected to fill the Water System Matrix is provided in Appendix B-3 at the end of this thesis.

[23] https://www.alberta.ca/climate-coal-electricity.asp
[24] http://www.energy.alberta.ca/NaturalGas/723.asp frames Natural Gas as the 'cleanest' energy source available.

Figure 55 – Sunnyside Water System Matrix

WATER SYSTEM MATRIX

ACCESS							
	PROXIMITY				DIVERSITY		
	M	R	N	I	POTABLE	NON-POT	BOTH
Surface (river)	X						X

OEPRATIONS						
	EFFICIENCY			AUTONOMY		
	DOMESTIC	COMMERCIAL	PUBLIC	NUMBER OF HOUSEHOLDS	NODES	%
Low-flow faucets	X	X	X	2591	3	100
River/Stream water (watering)			X			
Metering	X	X				

In an area prone to drought, water availability, and specifically its conservation, is increasingly important. Domestic water consumption rates in Calgary are the highest in Canada (Schepers 2010), and the only legislated water conservation initiatives in Sunnyside apply to the whole of Calgary also. Water metering became mandatory in all new construction, commercial and domestic, in 2002, and retrofitting older facilities reached 79% by 2006 (Schepers 2010). It is assumed therefore, that all the properties in Sunnyside are metered at time of writing (2017). Low-flow faucets and toilets became part of Calgary City Bylaws in 2015, and so using a date of construction (DOC) dataset provided by the City of Calgary, use of low-flow faucets and toilets can only be confirmed for 143 households in Sunnyside. In Alberta, rain is considered the property of the provincial government, and so harnessing storm water in significant quantity to offset non-potable needs is not permitted. Domestic grey water systems for toilets or outdoor use is not permitted in Calgary.

SHELTER in Sunnyside

The results of the shelter metrics are summarized below in Figure 56. The Shelter System Matrix has been altered to include specific references and information relating to Sunnyside, Calgary, and Alberta. Explanations of the data collected to fill the Shelter System Matrix is provided in Appendix B-4 at the end of this thesis.

Figure 56 – Sunnyside Shelter System Matrix

SHELTER SYSTEM MATRIX

ACCESS		
PROXIMITY		DIVERSITY
SHELTER	CAPACITY (%)	OVERLAP
SUNNYSIDE SCHOOL	3.5%	7%
CURLING RINK	100%	

OPERATIONS					
AUTONOMY			EFFICIENCY		
VULNERABILITY	STRUCTURES (%)	NEIGHBOURHOOD	BUILDING VINTAGE	%	RATING (VL,L, M, H)
DROUGHT			PRE 1949	35	VL
HIGH WINDS			1950-1970	10	L
EXTREME RAIN			1971-2011	46	M
EXTREME HEAT			2012-2017	8	M
EXTREME COLD			2012-2017	0.1	H
OVERLAND FLOODING	4.2	X			

Sunnyside is an older neighbourhood with significant amounts of redevelopment, and so there is considerable variety in the age of the residential structures. According to City of Calgary data, almost half of the neighbourhood’s current domestic building stock was constructed/renovated between 1971-2011 – an era not widely recognized for energy efficiency. This has implications for climate change mitigation, because while most of the homes in Alberta use natural gas-fired furnaces, as already mentioned in the Energy section, natural gas is not as clean burning as it was once believed. Furthermore, because of the inefficiency of these buildings, they require additional amounts of fuel for heating.

During a disruption, what little Emergency and Temporary shelter available, cannot accommodate most of the residents. Even more problematic is that both possible shelters are located at low topographical points in the neighbourhood, and are themselves vulnerable to the most likely hazard in the area, overland flooding. In 2014, the City of Calgary, as a response to the 2013 flood, implemented legislation directed at new construction in the neighbourhood, but because most structures pre-date this legislation, resident shelters remain vulnerable, increasing the potential demand for emergency sheltering. Furthermore, the storm water lift stations are not yet operational, two are under development, and two are planned in the next few years, and outside of these pieces of infrastructure, Sunnyside has no neighbourhood-wide initiatives designed to accommodate overland flooding, such as dry canals etc.

TRANSPORTATION in Sunnyside

The results of the transportation metrics are summarized on the following page in Figure 57. The Transportation System Matrix has been altered to include specific references and information relating to Sunnyside, Calgary, and Alberta. Explanations of the data collected to fill the Transportation System Matrix is provided in Appendix B-5 at the end of this thesis.

Figure 57 – Sunnyside Transportation System Matrix

TRANSPORTATION SYSTEM MATRIX

	ACCESS					OPERATIONS			
	PROXIMITY (%)				DIVERSITY	AUTONOMY (%)			
MODE	FOOD	CBD	TRANSIT	SCHOOL	OVERLAP	SIDEWALK	BIKE WAY	BIKE LANE	MUP
WALK	71	54	99	88	54	98.5	14	9.5	42.5
BIKE	100	93	95	100	93				
	1.23	1.26	1.5	1.23	PEDESTRIAN	PRD	EFFICIENCY		
	1.22	1.35	1.37	1.22	VEHICLE				

Because of its size and land-use designations, residents of Sunnyside can access a variety of non-motorized transportation. The two larger roads (10th St and 2nd Ave NW) have transit and either a bike lane or bike way, as well as sidewalks on both sides of the road. Key destinations are all easily accessible on foot and the pedestrian cut through over the C-Train tracks supports non-vehicular connectivity, for the most part however, the PRD scores indicate that the neighbourhood has been designed around vehicle mobility. The redundancy built into this network provides multiple options in case of disruption, but again, this is to support vehicular traffic. If these routes were to become unpassable for vehicles, this does not guarantee access for pedestrians or bikes. In general, Sunnyside residents could easily manage a disruption to transportation fuel supply even with some indirect route options.

WASTE MANAGEMENT in Sunnyside

The results of the waste management metrics are summarized in Figure 58, on the following page. The Waste Management System Matrix has been altered to include specific references and information relating to Sunnyside, Calgary, and Alberta.

Explanations of the data collected to fill the Waste Management System Matrix is provided in Appendix B-6 at the end of this thesis.

Figure 58 – Sunnyside Waste Management System Matrix

WASTE MANAGEMENT SYSTEM MATRIX

ACCESS				OPERATIONS		
DIVERSITY	PROXIMITY			AUTONOMY	EFFICIENCY	
WASTE STREAMS	O	C	M	COMPOST / FERTILIZER	NO USES	DISCREPANCY
BLACKWATER			100	R		1
GREEN	100			M		2
REFUSE	100				X	

The three waste streams in Sunnyside are a product of compatibility with older established systems, either as human waste removal, or even green and refuse removal. Sewage is dealt with through the established municipal system entering each household. Green Waste and Refuse are collected by each household or building and picked up through a curbside collection, again by City of Calgary Waste and Recycling Services.

In terms of re-use, through a program called *Calgro*, the City of Calgary provides decontaminated and nutrient-rich biosolids extracted from the blackwater/wastewater treatment plant processes, for regional agricultural use. Treated water is returned to the Bow River. Green waste and organics collected by the City are composted and sold in bulk to private compost or landscaping companies[25]. Currently there is no municipal means to exploit refuse as a resource.

[25] http://www.calgary.ca/UEP/WRS/Pages/Recycling-information/Residential-services/Green-cart/compost-facility-composting-process.aspx

Summary

The results of all the matrices for Sunnyside are provided in the summary matrix in Figure 59, below. This composite matrix provides a quantitative and qualitative summary of the information gathered within each need system. An attempt has been made to ensure neutrality in the results, and present them without bias, allowing them to be used as a basis to understand ramifications associated with different likely hazards or disruptions.

Figure 59 – Sunnyside Summary Matrix

		FOOD	ENERGY		WATER	SHELTER	TRANSPORTATION		WASTE		
			HEAT	POWER			WALK	BIKE	BW	GREEN	REFUSE
ACCESS	PROXIMITY	VEHICLE INDEPENDENT	100% GAS DOMINATED	REGIONAL/ LONG DISTANCE	MUNICIPAL SOURCE	NO ES/TS	LARGE PORTION OF DESTINATIONS	ALMOST ALL DESTINATIONS	M	O	O
ACCESS	DIVERSITY	TWO OUTLETS, TWO COMMUNITY GARDENS, MANY PRIVATE GARDENS	100% FOSSIL FUEL DOMINATED	DIVERSE BUT FOSSIL FUEL DOMINATED (see Appendix H)	POTABLE AND NON-POTABLE	INADEQUATE ES/TS	OVER 50% WITH OPTIONS		3 STREAMS		
OPERATIONS	AUTONOMY	PREDOMINANTLY REGIONAL AND SOME (INTER)NATIONAL TRANSPORTATION DEPENDENT	94% COMPLEX NETWORK DOMINATED	COMPLEX NETWORKS	3 NODES	VERY LITTLE (4.2%) STRUCTURAL AUTONOMY	SIDEWALKS ALMOST EVERYWHERE + 42.5% MUPS	BIKES ACCOMMODATED ON TWO MAIN ROADS + 42.5% MUPS	FEW USES		
OPERATIONS	EFFICIENCY	PREP: GRID Dependent; STORAGE: GRID Dependent	84% STREET TREES; 54% PERMEABLE		SOME RECENT LEGISLATED CONSERVATION	DOMINANTED BY INEFFIECIENT STRUCTURES	VEHICLE DOMINATED BUT PEDESTRIAN-FRIENDLY		INEFFICIENT COLLECTION AND USE		

CHAPTER 5

This chapter discusses the relevance of the proposed assessment methodology and its application or relevance for the study neighbourhoods is highlighted. Areas for refinement are indicated, along with additional compatible parameters. Opportunities for further research are discussed.

5. Conclusion

This thesis presents a methodology examining neighbourhood functionality with a view to providing insight on a neighbourhood's resilience to climate change extreme weather. Functionality, and therefore dysfunctionality, are understood as residents' capacity to satisfy their Basic Needs. Using a series of four metrics for each of the six Basic Needs identified by Sarlo et al. (2001) for a Canadian household, the methodology is designed to extract information relevant to urban resilience, both for mitigation and adaptation to climate change. Metrics are based on resilience assessments and studies found in academic literature on sustainability, landscape urbanism, urban resilience, urban design, mobility, resource conservation, and best practices in the developed world.

5.1 Objectives of the Assessment Methodology

The proposed methodology is developed to provide a systematic means to assess neighbourhoods across Canada regardless of their geo-climatic location. Room exists within each metric for customization according to local circumstances, technology, and laws, such as heating fuel or building regulations. This flexibility allows for greater nuance and accuracy in the final discussion within each Need Matrix. While the intent of the metrics ultimately centers on improving or supporting climate change resilience to extreme weather events, the results of the metrics are intended to provide an unbiased window into neighbourhood functionality, and therefore results are intended to be 'neutral'. Several resilience assessment methodologies currently exist, and while this proposed methodology does not replace them, it does compliment them, and results or metrics can also be used to examine neighbourhood functionality in relation to other issues such as walkability, food security, or health. The value of this assessment framework lies in its usability and accessibility for community groups or neighbourhood associations. It has the capacity to highlight strengths and weaknesses and helps educate residents on the various forces operating within the area. The information contained in a summary metric further reinforces the need to address all developments with extreme weather and safety of residents in mind, rather than merely using zoning and land use changes to guide development.

Beyond this, the metrics can be used independently or in different combinations to guide decision-making in specific areas. There is much research on the WEF (Water Energy Food) nexus, and the overlaps contained in the metrics, and specifically because these are all 'Supply' Needs, their interaction can be an alternate focus – with an additional economic, poverty, accessibility lens applied on top… results can be helpful in supporting this

5.1.1 Case Study Analysis

The case study neighbourhoods were selected to provide some overlapping similarities, but also some significant differences. Drake Landing in Okotoks serves as a proxy for new suburban development, while Sunnyside in Calgary represents an older, gentrifying community under constant re-development pressures. Because they are both located in southern Alberta, these neighbourhoods are subject to similar extreme weather events. They differ however because their respective development ages are several decades apart, and Sunnyside has the added vulnerability of its location within a government-identified flood way for the Bow River.

The resulting analyses of each case study neighbourhood were not entirely surprising, but they did provide information on areas for improvement. For example, food in Drake Landing is not only difficult to acquire on foot or by bike for residents, but the food outlets that are available, source their food from far afield. Meanwhile, Sunnyside is subject to the same market forces dictating food production and availability, and the *Safeway* in the Sunnyside reflects a similar sourcing pattern as the outlets in Okotoks. The *Sunnyside Market*, however, sources a greater percentage of key foods from local producers – though at a price difference. This dependence on long-distance travel for food can have negative and positive effects, depending on the identified disruptions: extreme weather affecting far-away crops, or their transportation, or local drought affecting local availability. No region is immune to disruption entirely, but redundancy and variety become increasingly important in supporting a more resilient system overall. The City of Okotoks could encourage food security and increase food resilience in Drake Landing with land use designation that accounts for identified vulnerabilities.

5.2 Recommendations

The methodology would benefit from several improvements:

1) Mapping and measuring could be formalized and more accurate using software such as ArcGIS or LIDAR. This would save time, though it may increase costs. Many of the mapping techniques suggested and deployed in the case studies relied on measurements made using the distance measurement tool at Google Earth or other free online tools.

2) A third case study from elsewhere in Canada with different extreme weather pressures would provide greater variety to results and further test the effectiveness of the methodology. Using a neighbourhood designed prior to private motorized vehicular transportation would have been beneficial, especially in the Transportation section.

3) Partnering with municipalities to acquire accurate data or information regarding energy consumption, building permits, or actual number of residents in each household, would increase the depth of information.

4) Resident surveys on energy efficiency, appliances, personal conservation strategies, travel behaviour etc. would add missing information and eliminate the need for assumptions regarding purchasing patterns, or appliance use.

5.3 Opportunities for Future Research

The assessment framework presented here offers a baseline snapshot of a defined area. There are opportunities however to explore the concepts and metrics more deeply and also to use the results.

1) Introducing a temporal element to the metrics. For example, canopy sizes increase over time, but this ‘potential’ is not included within the metrics.

2) Additional information addressing the interconnectivity of the systems Refining the metrics to include aspects such as system and network design, especially in energy, water, road layout, or waste infrastructure, to recognize network redundancy as a supportive element in creating resilience. Beyond this, an additional layer of analysis addressing sociological needs, economics, culture etc.

would expand the methodology into other areas of resilience beyond the (infra)structural and logistical.

3) Independent or bespoke combinations of each metric can also be used to position future research. There is an ever-expanding body of literature on the WEF Nexus (Water Energy Food) and more recently the HTF Nexus (Housing Transportation Food) opening the door for other pairings or linkages.

4) An additional layer or lens is also applicable in terms of barriers for residents, such as language, accessibility, disability, poverty. Much like in point 3 above, these can be applied over all metrics, or only those identified as targets for intervention or examination.

5) These metrics and the information contained within them can be used as tools unto themselves outside of academia. Currently there is no baseline standard for neighbourhood design elements like permeable surface area, or percentage of households falling within a 10-minute walk of a food outlet. This information is laid bare in the metrics and provides the opportunity to establish minimum requirements for a variety of neighbourhood design elements, something which supports the development of targets in development or redevelopment targets.

6) Inter-neighbourhood relationships and systems also offer an opportunity for exploration, especially in new developments. The consequences and benefits of doubling-up or sharing systems, elements, or resources offer a glimpse into taking this assessment to larger areas and including other scales beyond single

neighbourhoods, especially if dealing with some of the Need groups such as WEF or HTF.

7) Data modelling algorithms for each Need also provide an entirely different realm of possible research as spatial networks can be quantified for variables. This has the potential to operate at multiple scales or with all or just some of the Need systems.

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APPENDICES

Appendix A Drake Landing Data

APPENDIX A-1 – DRAKE LANDING FOOD DATA

According to Drake Landing's developer, United Communities, 65% of new home buyers chose gas ranges over electric ones.

APPENDIX A-2 – DRAKE LANDING ENERGY DATA

Access – Proximity (Origins – Generation)

- 6% households (52) homes are part of an NRCan-initiated experiment with a BTES system

Access – Diversity (Options – Fuel Sources)

- Fuel source mix follows provincial AESO mix from December 2015[26]
  - Coal: 51%
  - Natural Gas: 39%
  - Hydro: 2%
  - Wind: 5%
  - Biomass: 3%
  - Other (includes Solar, Fuel Oil and Waste Heat): 0% (insignificant)

Operations – Efficiency (End Use – Consumption/Conservation)

Table A.1 – Energy Conservation Aspect Measurements

ASPECT	DRAKE LANDING	RESULTS
Street tree coverage	Road length in DL: 12,400 m (excluding paved back alleys) 226 street trees on both sides Road length with trees on both sides: 198.24m	1.5%
Impermeable surface area	Total Area: 697,853.445 m² (less the storm lake (21,146.027 m²) = 676,707.418 m²) Green public space area: 374,197.193 m² Total Paved Surface Area: 176,532.906 m² Broken down as follows: - Roads + Back Lanes + parking lots: 105,660.378 m² - Pathways: 21,092.528 m² - 10 Driveways: average = 65.5 m² on 730 households (less 36 townhouse units) = 49,780 m² Roofing area (average from 20 structures): 174.4 x 720 (less 16 semi-det structures) = 125,568 m² + townhouses: 2593.135 m² + semi-detacheds: 2119.79 m² Roofing total: 130,280.925 m²	Total greenspace/permeable (public and private): 391,039.613 m² **(56% of total area)** Total paved space/impermeable (public and private): 306,813.831 m² **(44% of total area)**

[26] http://www.energy.alberta.ca/Electricity/682.asp

APPENDIX A-3 – DRAKE LANDING WATER DATA

Operations – Efficiency (End Use – Consumption/Conservation)

Domestic:

- Increased topsoil depth, low-flow appliances required by United Communities and are outlined on the company website: http://www.drakeunited.com/architectural_guidelines.bpsx

APPENDIX A-4 – DRAKE LANDING SHELTER DATA

Access – Diversity (Options – Sheltering Redundancy)

Operations – Efficiency (Energy Use – Structure Age)

- 6% of Drake Landing = High Efficiency. The homes in the BTES experiment were insulated to R2000 standards (McDowell & Thornton 2008)

APPENDIX A-5 – DRAKE LANDING TRANSPORTATION DATA

Access – Proximity (Distance – Key Destinations)

Table A.2 – Key Destination Walkshed Maps for Drake Landing

KEY DESTINATION	DRAKE LANDING WALKSHED MAPS	% of HOUSEHOLDS
Primary School		0.5%
Transit Stops	N/A	
Food Outlet	N/A	
CBD	N/A	

Table A.3 – Key Destination Bike-shed Maps for Drake Landing

KEY DESTINATION	DRAKE LANDING BIKE-SHED MAPS	% of HOUSEHOLDS
p e r a t i o n s – Primary School		43%
Transit Stops	N/A	
Food Outlet	N/A	
CBD	N/A	

Autonomy (Design – Infrastructure)

Table A.4 – Drake Landing Infrastructure

INFRASTRUCTURE	LENGTH	% of ROAD
ROAD	12,400m	100%
SIDEWALKS 1 side	10,989m	88%
SIDEWALKS 2 sides	1370m	11%
NO SIDEWALKS	41m	0.3%
BIKE LANE	N/A	-
BIKE WAY[27]	N/A	-
MUP (Multi-user pathway)	2184.13m	17.5%
BRT (Bus Rapid Transit)	N/A	-

APPENDIX A-6 – DRAKE LANDING WASTE MANAGEMENT DATA

Access – Proximity (Distance – Collection)

Operations – Efficiency (Energy Use – Discrepancy)

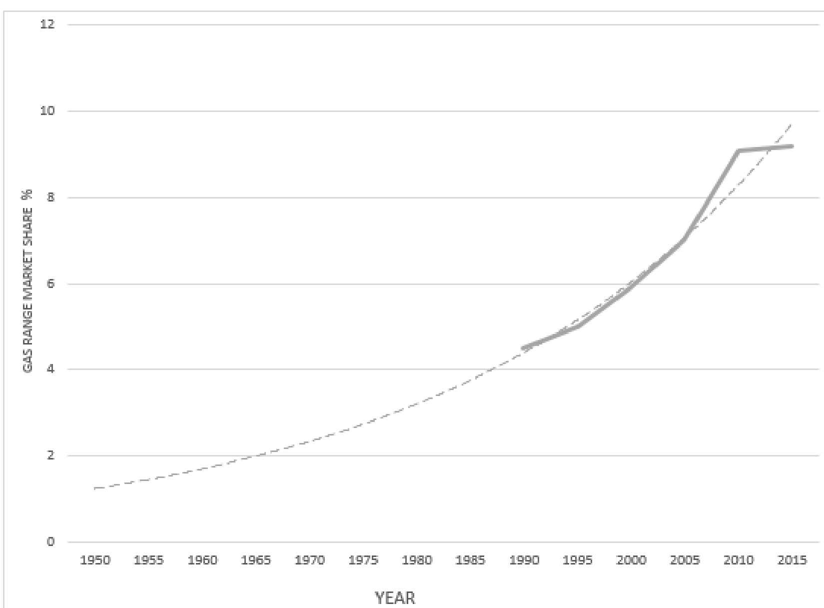
Information for both metrics available on the municipal website: www.okotoks.ca

[27] Designating a route as a bikeway can involve parking restrictions during peak travel times, and so requires local research in addition to measurement.

APPENDIX B-1 – SUNNYSIDE FOOD DATA

Information on the number of households relying on electric versus gas ranges is difficult to acquire, and so assumptions are necessary. According to a 1965 Dominion Bureau of Statistics report, 13% of all non-combination cooking ranges[28] sold in Canada that year, were gas (Dominion Bureau of Statistics 1965). A telephone conversation with United Communities, the developer of Drake Landing, revealed that 65% of new homebuyers in Drake Landing in 2007 chose gas ranges for their kitchen. A subsequent telephone conversation with S.M. the Inspiration Studio Manager for Brookfield Developments and 25-year veteran of the home renovation and building industry, revealed that gas ranges account for approximately 90% of cooking ranges installed in new or renovated kitchens in the past 10 years. This information indicates a rapidly increasing rate of gas range use over time, with the highest levels recorded in the last decade or so. Available government data on gas range use is limited to 1990-2015, and this is shown by the solid line in Figure 60, below. A dotted, exponential trend line has been extrapolated using the government data along with the recent consumer information from two developers. This trend line provides the basis for estimating gas range market penetration for Sunnyside, according to year of construction/renovation, and is summarized in Table B.1, on the following page.

Figure B.1 – Gas Range Market Share in Canada, 1950-2015



[28] A combination range uses two sources of fuel. During that era in Canada, combinations were usually Gas and a solid fuel (wood/coal/oil) or Electric and a solid fuel (wood/coal/oil), but not usually a Gas and Electric combination.

Table B.1 –Estimated Breakdown of Gas Range Use by Building Construction Era

ERA	TOTAL HOUSEHOLDS	GAS RANGE USE % BY ERA	SUNNYSIDE HOUSEHOLDS WITH GAS RANGES
Pre-1950	51	1	.51
1950-1954	96	1.2	1.15
1955-1959	17	1.5	.25
1960-1964	92	1.7	1.56
1965-1969	348	2	6.96
1970-1974	497	2.2	10.93
1975-1979	447	2.9	12.96
1980-1984	85	3.1	2.57
1985-1989	35	3.9	1.36
1990-1994	58	4.5	2.61
1995-1999	68	5	3.4
2000-2004	325	5.9	19.17
2005-2009	54	7	3.78
2010-2014	275	9.1	25
2015-present	143	9.2	13.15
TOTAL	**2591**	**--**	**105.36**

The results of Table B.1 indicate that approximately 105 households (4%) in Sunnyside rely on gas ranges for food preparation, but the reality is likely higher. On-line research, into two recent and large condo developments, reveals that all the units (almost 200 in total) have been fitted with gas ranges, but these were constructed after 2015, but this does support the assertion that gas range use is increasing.

APPENDIX B-2 – SUNNYSIDE ENERGY DATA

Access – Proximity (Origins – Generation)

- 0.2% (5) of households with solar power according to satellite imagery from Google Earth

Access – Diversity (Options – Fuel Sources)

- Fuel source mix follows provincial AESO mix from December 2015
  - Coal: 51%
  - Natural Gas: 39%
  - Hydro: 2%
  - Wind: 5%
  - Biomass: 3%
  - Other (includes Solar, Fuel Oil, and Waste Heat): 0% (insignificant)

Operations – Efficiency (Use – Consumption/Conservation)

Table B.2 – Energy Conservation Aspect Measurements

ASPECT	SUNNYSIDE	RESULTS
Street tree coverage	Road length in Sunnyside: 10, 419 m (excluding paved back alleys) Road length with trees on both sides: 8714.78m	84%
Impermeable surface area	Total Area: 842,475.97 m² (excludes river surface area) Total Paved Surface Area: 385,413.45 m² Broken down as follows: - Roads + Back Lanes + parking lots[29]: 123,989 + 24,132.64 + 68,096.32 m² - Pathways: 17,881.29 m² - Building footprint (average from 20 structures of each type): 158,290.6 m² - multi-family buildings: 586.8 m² x 112 = 65,721.6 m² - single family + semi-detached: 107.3 m² x 562 = 60,302.6 m² - single family + semi-detached garages: 45 m² x 562 = 25,290 m² Townhouses: 6,976.4 m²	Total paved surface area **(46% of total area)**

APPENDIX B-3 – SUNNYSIDE WATER DATA

Operations – Efficiency (End Use – Consumption/Conservation)

Domestic:

- Low-flow faucets/toilets – required after 2015[30] (City of Calgary 2015) = 143 households, 5%
- Metering (Schepers 2010)

Commercial:

- Metering (Schepers 2010)

Public:

- Four planned storm water lift stations, two currently under construction for 2018[31]

[29] Includes paved parking lots, commercial buildings' and school footprints, and any other paved surfaces such as plazas etc. The map used is provided on the following page.
[30] http://lub.calgary.ca/ Part VII, Div 16 (1)
[31] https://engage.calgary.ca/SunnysideLS

APPENDIX B-4 – SUNNYSIDE SHELTER DATA

Access – Proximity (Distance – ES/TS)

School:

1. Calculating maximum demand:

a. 2254 household falling within a 600m walkshed of the school
b. 2254 households x 2.5 people per household = 5635 people requiring shelter

2. Calculating capacity:

School building data is difficult to acquire for security reasons, so capacity is estimated using the following information:

- School toilet count established using two data points:
  1) by estimating the number of staff and students based on classes and grades listed on the school website:
    - 183 occupants: 7 teachers, 170 students[32], 6 support staff (Principal, Vice-Principal, Secretary, Librarian, Music Teacher, Custodian)

  2) using the occupant count to establish the associated workplace washroom guideline for the Province of Alberta
    - 7 toilets[33] = 101-200 people under and over 3 hours

= accommodates 3.5% of the walkshed population

Rink:

1. Calculating maximum demand:

a. 299 household falling within a 600m walkshed of the curling rink
b. 299 households x 2.5 people per household = 748 people requiring shelter

2. Calculating shelter capacity:

Winter (Sept – Apr)

a. Rink facility space is 6562 m^2 with 15 toilets[34].
b. 6562 m^2/4 (m^2 per person) = 1640 people
c. 1640/6468 = 25% of neighbourhood residents
d. 15 toilets = 501-600 under 3 hours; 401-500 over 3 hours

[32] Using average class sizes as reported by Alberta Teachers Association Local 38 in http://www.metronews.ca/news/calgary/2016/02/21/calgary-class-sizes-too-high-at-every-grade-level.html
[33] http://laws.justice.gc.ca/eng/regulations/SOR-86-304/page-18.html#docCont
[34] Information provided by K.Stubbs, Program and Events Coordinator at the Calgary Curling Club

Summer (May – Aug)

a. Rink facility space is 8512 m^2 with 15 toilets
b. 8512 m^2/4 (m^2 per person) = 2128 people
c. 2128/6468 = 33% of neighbourhood residents
d. 15 toilets = 501-600 under 3 hours; 401-500 over 3 hours

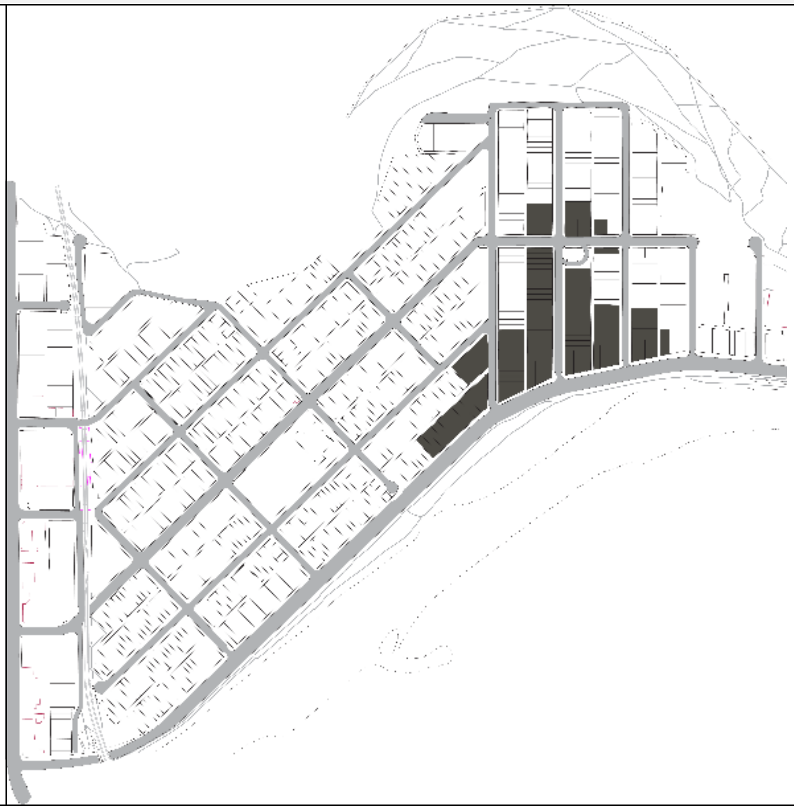
<u>= accommodates 100% of the walkshed population throughout the year</u>

Access – Diversity (Options – Sheltering Redundancy)

- **school and rink both located on floodplain** see floodmap on page 120 of this thesis

- 7% of households (180) within walkshed of both the rink and the school – 450 people

Table B.3 – Overlapping Parcels from Rink and School Walksheds

OVERLAP MAP		
CALGARY CURLING RINK + SUNNYSIDE PRIMARY SCHOOL		7% (450 people)

Operations – Autonomy (Complexity – Networks)

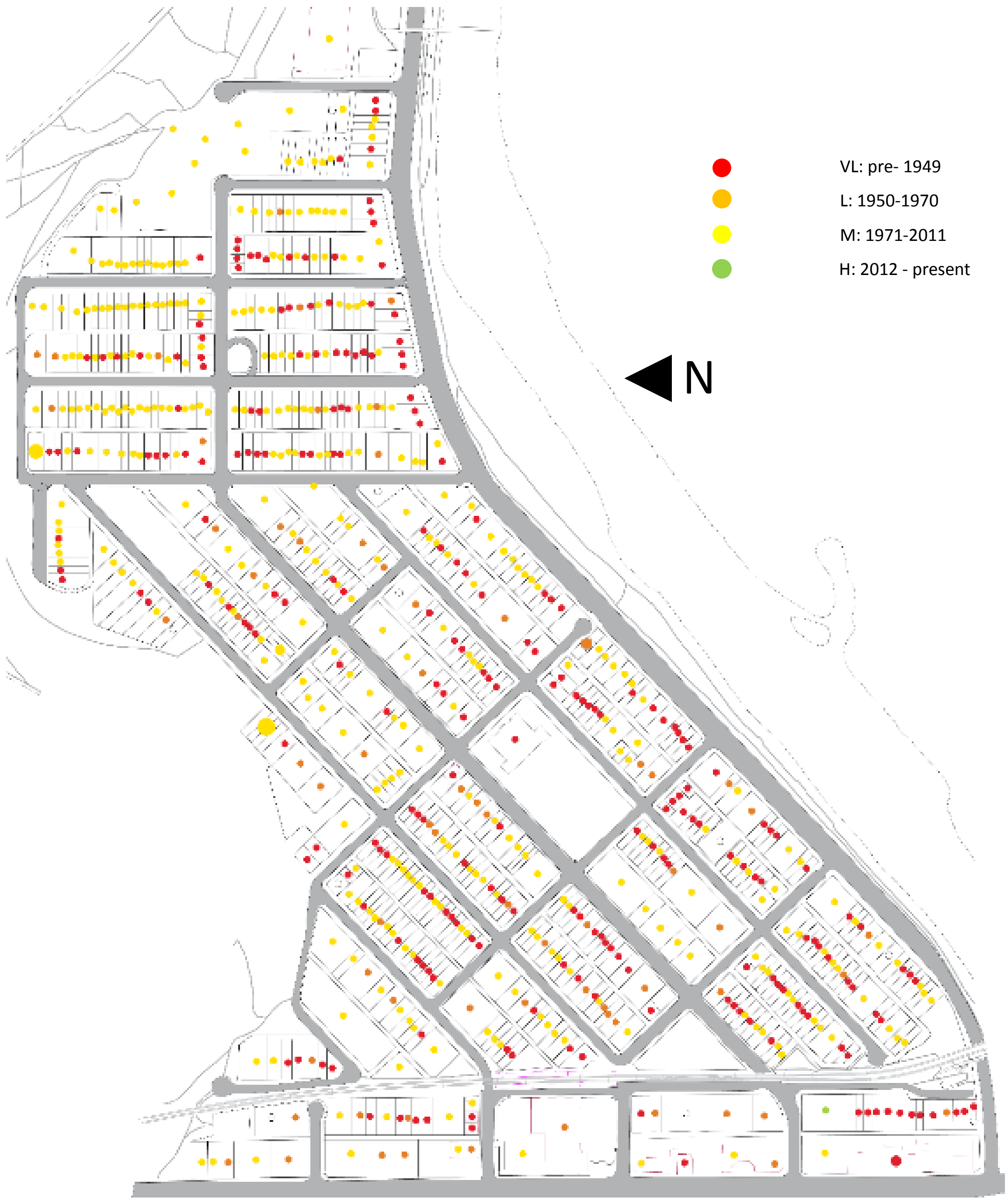
After the 2013 flood, the Calgary Land use Bylaw was amended in 2014 to include building regulations for new construction/renovation in flood-prone areas[35]. 31 structures

[35] http://lub.calgary.ca/ Part III, Div 3, 60 (1)

in Sunnyside were constructed between 2014 and the present, accounting for 4.2% of neighbourhood residential buildings

Operations – Efficiency

Figure B.1 – Sunnyside Heating Efficiency Map[36]



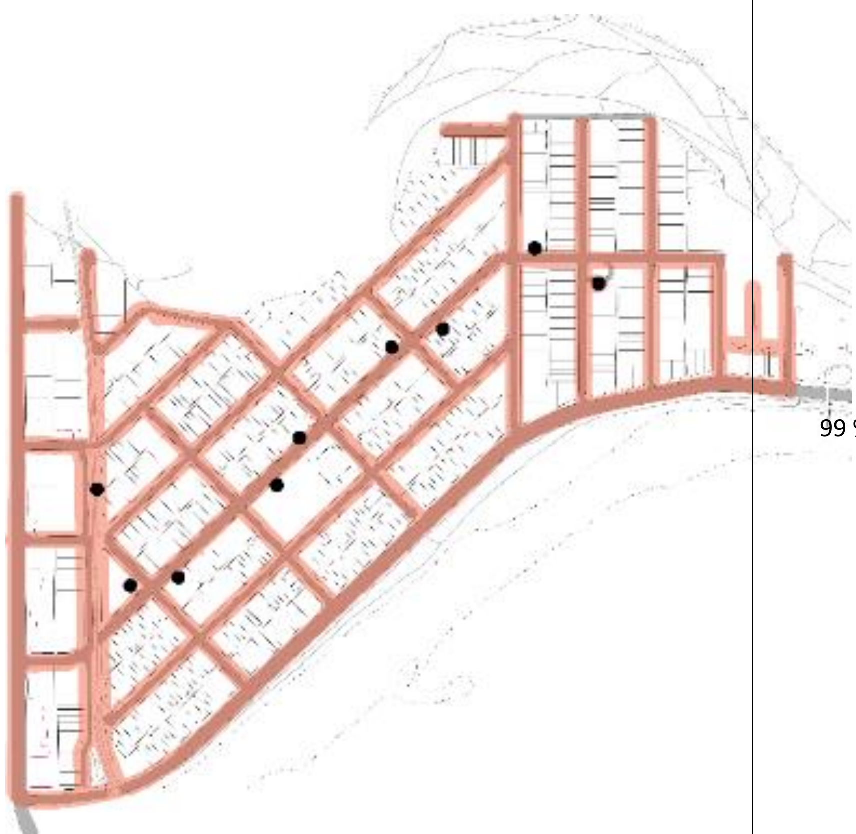
[36] Based on building construction age courtesy of City of Calgary Open Data Archive, 2017

APPENDIX B-5 – SUNNYSIDE TRANSPORTATION DATA

Access – Proximity (Distance – Key Destinations)

Table B.4 – Key Destination Sunnyside Walkshed Maps

KEY DESTINATION	SUNNYSIDE WALKSHED MAPS	% of HOUSEHOLDS
Sunnyside Primary School		88 %

KEY DESTINATION	SUNNYSIDE WALKSHED MAPS	% of HOUSEHOLDS
Transit Stops (Bus)		99 %

KEY DESTINATION	SUNNYSIDE WALKSHED MAPS	% of HOUSEHOLDS
FOOD (Safeway + Sunnyside Market)		71 %

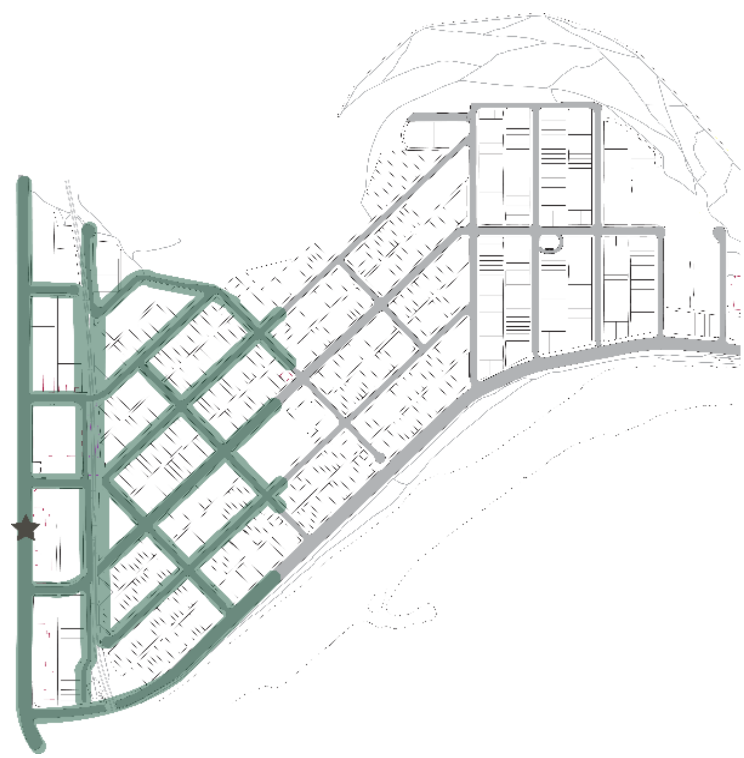
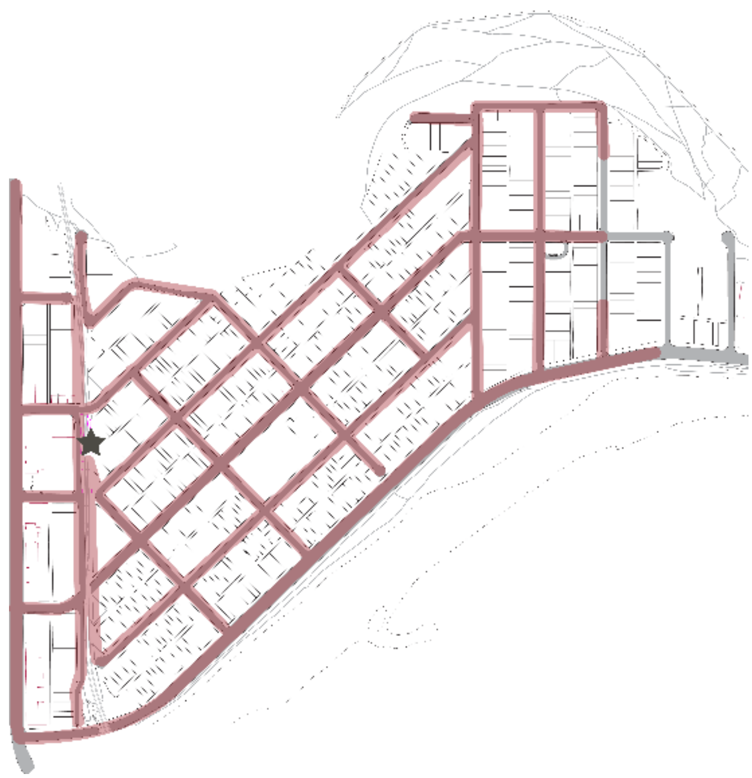
KEY DESTINATION	SUNNYSIDE WALKSHED MAPS	% of HOUSEHOLDS
Central Business District		54%

Table B.5 – Key Destination Sunnyside Bike-shed Maps

KEY DESTINATION	SUNNYSIDE BIKE-SHED MAPS	% of HOUSEHOLDS
Sunnyside Primary School		100 %

KEY DESTINATION	SUNNYSIDE BIKE-SHED MAPS	% of HOUSEHOLDS
C Train Station		95 %

KEY DESTINATION	SUNNYSIDE BIKE-SHED MAPS	% of HOUSEHOLDS
FOOD (Safeway + Sunnyside Market)		98 %

KEY DESTINATION	SUNNYSIDE BIKE-SHED MAPS	% of HOUSEHOLDS
Central Business District		93%

Access – Diversity (Options – Transportation Mode Choice)

Table B.6a – Overlapping Key Destination Walkshed Map

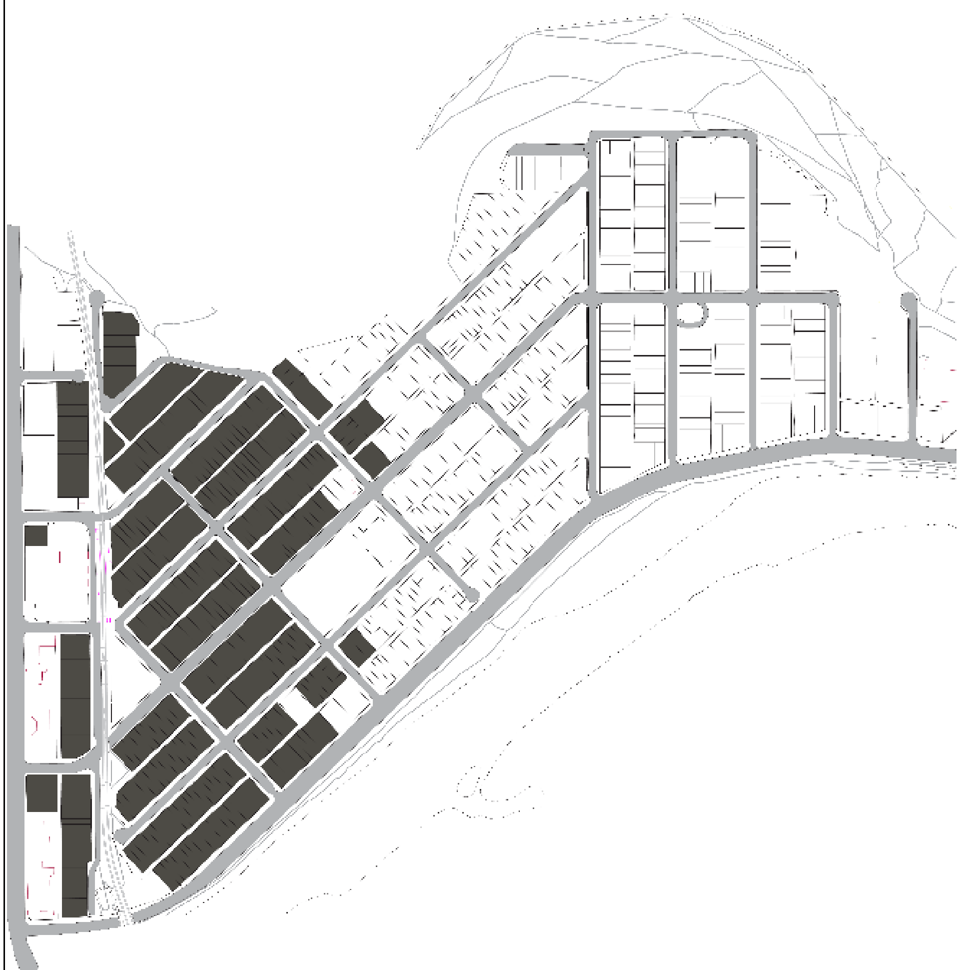
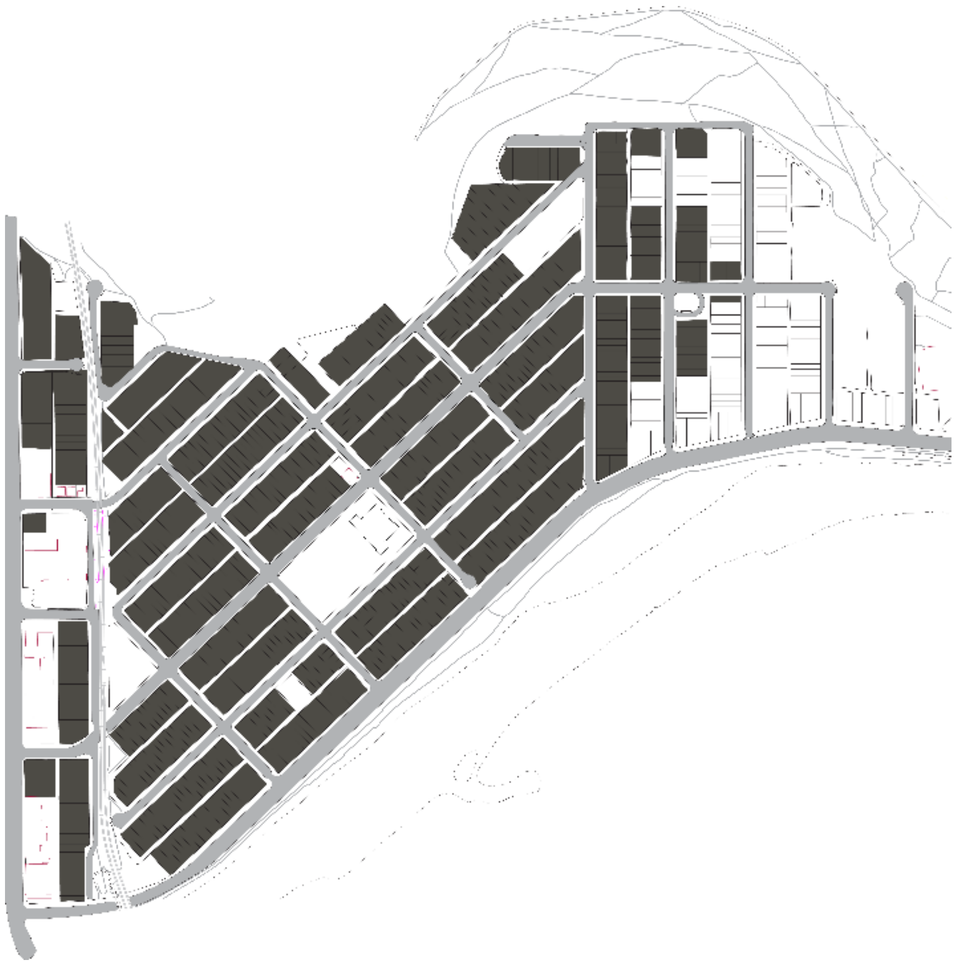
OVERLAP WALKSHED MAP	% of HOUSEHOLDS
	54 %

Table B.6b – Overlapping Key Destination Bike-shed Map

OVERLAP BIKE-SHED MAP	% of HOUSEHOLDS
	93%

Operations – Autonomy (Design – Infrastructure)

Table B.7– Sunnyside Infrastructure

INFRASTRUCTURE	LENGTH	% of ROAD
ROAD	10,419 m	100%
SIDEWALKS 1 or 2 sides	8,856 m	98.5%
NO SIDEWALKS	190m	1.5%
BIKE LANE	959 m	9.5%
BIKE WAY[37]	1,494 m	14%
MUP (Multi-user pathway)	4,440.43 m	42.5%
BRT (Bus Rapid Transit)	N/A	--

[37] Based on a City of Calgary map available at https://maps.calgary.ca/pathwaysandBikeways/

Operations – Efficiency (Use – PRD)

Table B.8 – Random PRDs to Key Destinations

KEY DESTINATION	PEDESTRIAN PRD	PEDESTRIAN AVERAGE PRD	VEHICLE PRD	VEHICLE AVERAGE PRD
CBD	1.11	1.26	1.35	1.35
	1.5		1.5	
	1.19		1.19	
FOOD	1.02	1.24	2.23	1.65
	1.38		1.73	
	1.32		.97	
TRAIN	1.51	1.5	1.15	1.37
	1.5		1.43	
	1.54		1.53	
SCHOOL	1.17	1.23	1.17	1.22
	1.23		1.23	
	1.3		1.28	

APPENDIX B-6 – SUNNYSIDE WASTE MANAGEMENT DATA

Access – Proximity (Distance – Collection)

Information acquired at municipal website: www.calgary.ca

Operations – Efficiency (Energy Use – Discrepancy)

- Blackwater: 3 (Regional[38])
- Green: + 2 (Municipal)
- Refuse: None + 2 (Municipal)

[38] http://www.calgary.ca/UEP/Water/Pages/Biosolids/Farming-with-biosolids.aspx