Cascading Failure in Critical Infrastructure:

An Actor-Network Analysis of the 1998 Ice Storm in Ottawa

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Abstract

An ice storm in January 1998 initiated a cascading failure across several of Ottawa's critical infrastructure systems, leaving +50,000 people without electricity or heat for prolonged periods as emergency managers struggled, and often failed, to grasp the extent of the disaster and initiate a successful coordinated response. Actor-Network Theory (ANT) in collaboration with risk and vulnerability principles is used to unpack the complexities that contributed to this disaster and explore how Ontario's 2008 Provincial Emergency Response Plan (PERP) might have altered outcomes. ANT revealed electrical and transportation failures were initially isolated but days three through five in the Storm were characterized by failures transcending the resilience of several infrastructure systems as well as emergency programs, resulting in system-wide, cascading severe disruptions and failures to all infrastructure systems other than sanitation and water. This thesis also concludes conditions conducive to a cascading failure persist and that PERP (2008) would not adequately prevent the reoccurrence of cascading infrastructure failure during a prolonged ice storm.

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ANT	Actor-Network Theory
CI	Critical Infrastructure
EMO	Emergency Management Ontario
EMU	Emergency Measures Unit
MCSCS	Ministry of Community Safety & Correctional Services
MCSS	Ministry of Community & Social Services
MOA	Ministry of Agriculture
MOE	Ministry of the Environment
MOH	Ministry of Health
MOHLTC	Ministry of Health & Long-term Care
MNR	Ministry of Natural Resources
MTO	Ministry of Transportation
NCR	National Capital Region
OPP	Ontario Provincial Police
PAR	Pressure and Release Model
RMOC	Regional Municipality of Ottawa-Carleton
PERP	Provincial Emergency Response Plan
SoVI	Social Vulnerability Index

Chapter 1: Introduction

1.1 The Context – Emergence & Importance of Cascading Failures

One of the biggest challenges confronting governments today is the ongoing threat of disaster. As cities in the developed world continue to construct and depend upon highly complex and fragile infrastructure systems, the social and economic costs of disaster become an ever greater risk. Hurricane Katrina in The United States, the Fukushima Daiichi nuclear disaster in Japan, and Hurricane Sandy in New York are recent examples of some of the most costly disasters. Canada has its own examples such as the 1998 Ice Storm in which a week-long bout of freezing rain had devastating social and economic consequences for cities in central Canada such as Ottawa, Kingston, and Montreal. Although very few lives were lost in the Storm[1] in comparison to other disasters, the Storm damaged a significant portion of eastern Ontario's and southwestern Quebec's electricity grids, amounting to one of the most expensive disasters in Canadian history. By the end of the Storm an unprecedented amount of freezing rain accumulated across Ontario and Quebec including: 75mm in Kingston, 105mm in Cornwall, 85mm in Ottawa, and 100mm in Montreal (Lecomte et al., 1998). A study conducted by Lecomte et al. (1998) several months after the Storm provides a detailed breakdown of this Storm's economic toll. In Canada, over 1 million people in Quebec and Ontario lost power during the Storm and several thousand kilometres of power lines and telephone cables were completely destroyed. Over 1000 transmission towers were brought down by the sheer weight of the accumulated ice and nearly a quarter of them were worth $100,000 each. 30,000 wooden utility poles at a cost of $3,000 each were also destroyed. The total cost of repairs for

[1] 42 deaths in total are attributed to the 1998 Ice Storm, 28 of which occurred in Canada and 14 within the United States (Lecomte, 1998).

Ontario and Quebec's electrical infrastructure alone was $1 billion dollars. Canadian insured losses for the Storm were the largest in Canadian history through to 1998 with over 84,000 claims in Ontario alone.

For Canadians, the disaster has been given the name the *1998 Ice Storm* but this popular moniker can also be misleading. In eastern Ontario, the event began with a serious ice storm that would eventually conclude with a series of cascading failures which, aided by a severely damaged electrical transmission and distribution system and a poorly coordinated provincial response, swept across the region's CI network. Ultimately, the 1998 Ice Storm was a series of separate disasters consisting of ice accumulated roads, extensive power blackouts, and widespread communication infrastructure failures that could each, on their own, warrant a provincial emergency response. However, the 1998 Ice Storm was also an example of how the relationship between the built human environment and the natural environment is one of benefits and disastrous outcomes.

In an increasingly urbanized planet, cities have become a complex and ever changing assemblage of parts. Modern cities, which are comprised of a diverse blend of technology, infrastructure, and people among other things, have approached a level of complexity that makes them comparable to any ecosystem. These cities require a constant input of energy in order to function; cities communicate across oceans and land with other cities in an increasingly globalized world; and, much like any ecosystem, a city is vulnerable to hazards and subjected to harm either brought on by itself and its components or by the larger environment it is a part of. Broadly speaking, both humans and the environment are two very important parts of this assemblage. The former is the creator and user of cities; the latter is where these cities belong to and operate in. But what often go largely unnoticed are the vast, highly interconnected, fragile, and increasingly complex array of infrastructure systems that have the important task of acting as a link to how people interact with the environment and with each other.

Stephen Graham (2010) writes about infrastructure systems as being “immobilized in space, they continually bring into being the mobilities and circulations of the city and the world” (Graham, 2010, p.1). Infrastructures are a means to store ideas and knowledge and to communicate these ideas and knowledge across the planet; infrastructures supply clean water for drinking and remove waste water from homes; and through a network of roadways and transit nodes, infrastructures allow people to travel over great distances and at greater speeds than previously possible. Herman and Ausubel (1988) wrote that “Cities are the summation and densest expressions of infrastructure, or, more accurately, a set of infrastructures, working sometimes in harmony, sometimes with frustrating discord, to provide us with shelter, contact, energy, water and means to meet other human needs” (Herman et al., 1988, p.1). With over fifty percent of the global population living and working in cities, it has never been more important to understand the nature of these systems. Little (2010) wrote that a greater understanding of these systems involves looking at the “measures necessary to ensure that the flow of services provided continues unimpeded in the face of a broad range of natural and manmade hazards” (Little, 2010, p.27). As cities and regions become increasingly sophisticated in their infrastructure make-up, the interaction with Earth’s natural processes becomes more complex, exposing new vulnerabilities and risks. When the flow of services is interrupted the risk to society can come in the form of injury or death, considerable monetary costs, and/or damage to the environment. With the growing interconnectedness of modern infrastructure systems, the potential for the occurrence of a cascading failure across multiple infrastructures becomes a significant threat for societies that are dependent upon a continued flow of service. When society and governments are positioned in such a way that a single failure in a CI is enough to warrant an emergency response, it is crucial that there be an attempt to understand how cascading failures occur and what their presence means to the discussion on hazards and disasters.

1.2 Purpose of this Thesis & Specific Research Questions

Geographers have had a longstanding tradition in hazards research providing fundamental perspectives that help understand and explain the phenomenon of hazards and disasters (White, 1945; Hewitt, 1983 & 1997; Burton, Kates, & White, 1983; Alexander, 1993; & Blaikie et al., 2004). Geographers' inclusion of a unique human-environment perspective into the hazards discussion has led to important research that has since aided governments in implementing policy and strategy to help mitigate and adapt to the threat of disaster (Tobin & Montz, 1997; Kates, 2011). Using a geographic perspective on hazards, this thesis examines the 1998 Ice Storm as a case study for exploring how a cascading failure in critical infrastructure has altered the hazard landscape and influenced disaster. Modern disasters in the developed world have become increasingly complex, involving a tangled web of social, technological, and environmental factors. The challenge is in portraying a complete picture of disaster without neglecting the crucial links that exist between society, the technology it uses, and the environment with which it operates. While the 1998 Ice Storm provides an example from which to work, Actor-Network Theory (ANT) as developed by Latour (1987, 1999 & 2005) and

Callon (1986 & 1991) offers a means for organising this example into one scope of study while also providing useful insights into how geographers might be able to use ANT to conduct new hazards research.

It is within the foundations of a geographic perspective and through the use of ANT, that the primary goal of this thesis is to demonstrate how an extreme weather phenomenon intersects with the built-environment to create a complex hazard event initiated by the occurrence of a cascading failure. In doing so, this thesis argues that the modern built-environment is constructed and used in such a way that emphasizes the growing complexity of hazardous threats, impacting how society experiences catastrophe while also reinforcing geography's longstanding view that disaster itself is largely a social phenomenon. To contribute to the future of hazards research in geography, it is the intent herein to demonstrate how ANT and the concept of a cascading failure can provide useful insights for conducting new hazards research. This thesis asks three key questions that will aid in achieving the aforementioned goal: What conditions conducive to a cascading failure are present prior to the occurrence of an extreme weather event? How effective are emergency practices in Ontario in responding to a cascading failure across CI? And finally, what does cascading failure offer to hazards research in geography?

1.3 Scope of Thesis

This thesis utilizes the events of the 1998 Ice Storm and the subsequent provincial emergency response in eastern Ontario to demonstrate how cascading failure occurs and what the consequences of such a failure might be. The research is focused primarily on the City of Ottawa and to a lesser extent eastern Ontario. Figure 1.0 shows the entire Ottawa-Carleton region with the political jurisdictions that existed during the 1998 Ice Storm, with the focus area of this thesis outlined in red. Ottawa has been selected because it was one of several large cities adversely impacted by the Ice Storm. Areas immediately outside of the City of Ottawa, such as Nepean or Kanata, appear throughout this thesis, and are used in order to draw upon specific examples but no in-depth analysis is conducted for these areas. As a point of study, it is preferable to choose a city as opposed to a neighboring rural region since urban areas typically have high concentrations of built infrastructure whose services are depended upon by a relatively large population. Lastly, it is important to clarify that the Ice Storm disaster appears to have had a much greater impact in Quebec, and in particular Montreal; however, this region is beyond the scope of study and will not be discussed within this thesis.

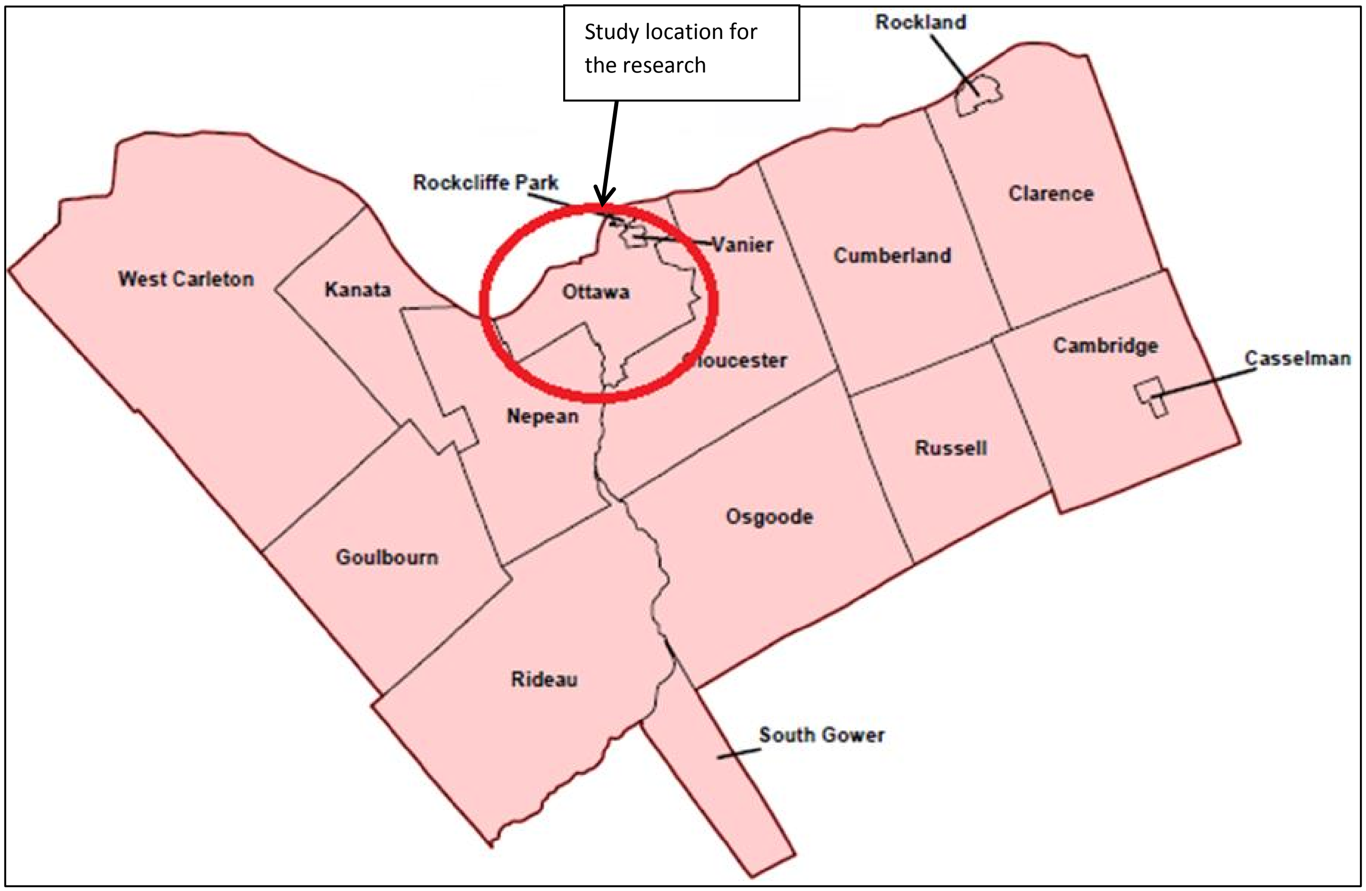


Figure 1.0 Map of Ottawa and surrounding municipalities affected by the 1998 Ice Storm with focus of study circled in red Source: HRSDC (2014).

One of the criticisms of ANT is that it creates an infinite network of relationships. For example, a single actor such as Ottawa's electricity infrastructure can be broken down into smaller actors that may include Ottawa Hydro, the mechanical parts made up of power lines and utility poles, and/or the end-users of electricity in Ottawa. Between each of these actors are intermediaries (i.e. actions, beliefs, knowledge, money, etc.)[2] that bind actors together; and between these intermediaries are other actors and intermediaries. The point being that as long as actors can be networks and vice-a-versa, the assemblage of actors in a network is theoretically infinite. In regards to cascading failures, this leads to an endless array of tracings of the failure. To limit this, this thesis will focus only on the failure as it occurs through several primary CI actors – namely electrical, transportation, and communication. Certain elements of the failure are chosen for discussion over others based solely on the context and relationship of influence; for example, the challenge of finding fuel for generators is discussed in the context of those actors that have an influence over the infrastructure (i.e. hydro repair crews, road crews, etc.). This is not intended to negate the role of other actors or intermediaries, but to limit the study to a more practical length.

1.4 Thesis Organization

This thesis is organised in such a way that conveys the events of the 1998 Ice Storm through a geographic perspective. To help identify how a cascading failure occurred, each chapter links together various aspects of the Storm with concepts derived from hazards geography literature. Chapter 2 provides a literature review that lays the theoretical foundation from which cascading failure and ANT are used throughout this thesis. The chapter

[2] Actors and intermediaries are discussed in greater detail in Chapter 2 and Chapter 4 of this thesis.

begins with a description of the evolution of hazards research in geography from hazards as being an ‘act of God’ toward broader and deeper concepts of risk and vulnerability. The chapter then describes the important transition from a single hazard event such as an ice storm towards a more complex view with consideration given to the social, technological, and environmental components of hazards and disasters. The chapter finishes with a review of how ANT can be used to organize the complexity within hazards research and how this theory intersects with cascading failure so that crucial connections can be made between different social and non-social components in the hazard landscape.

Chapter 3 presents the research data gathered about the 1998 Ice Storm into a day-by-day narrative account of the Storm. This chapter provides the history of the Ice Storm from January 5 to January 15 with strict focus on tracing the sequence that links actors (i.e. various infrastructures, people, and environmental factors) together. Since much of the data presented in Chapter 3 comes from print media it is important to acknowledge that there are benefits and challenges to this source material. Although newspapers do not have the same rigour and recognition as other source material such as peer-reviewed papers and official government reports, they can provide a detailed and personalised account of the societal impacts of an event (i.e. power outages, road closures, deaths and injuries, etc.). Chang et al. (2007) wrote that newspapers “provide snapshot records of situations across many points in time, such as on a daily basis throughout the duration of [a] disaster” (Chang, 2007, p. 345). Also, many of these reports come from media that operated in Ottawa at the time of the Storm and are themselves actors within the Ice Storm. In accordance with ANT principles, media reports are viable for tracing events during the Storm.

Chapter 4 is an analysis of the Ice Storm. This chapter is largely analytical and focuses on how ANT is used to locate and analyse the cascading failure that occurred in Ottawa's CI. This chapter addresses the question of how ANT shows that the conditions conducive to a cascading failure were present prior to the freezing rain and makes the argument that such conditions did exist. This chapter also utilizes a series of graphs, developed by the writer of this thesis, that measure the degree of disruption in each CI, both in isolation and in a single interconnected network. The purpose of these graphs is to show how the presence of an ice storm intersects with Ottawa's CIs and at what points in the network a cascading failure occurs.

Chapter 5 takes what is discussed in the previous chapter and applies it to emergency management practices in Ontario. This involves looking at what may occur today if an ice storm of similar or greater force impacted Ottawa's CI and how Ontario's 2008 Provincial Emergency Response Plan (PERP) might alter events. The focus of this chapter remains on cascading failure in CI, and informed speculation is used to determine where in the failure the PERP (2008) might better or worsen the cascading failure. Policy recommendations are made with regards to how ANT and cascading failure can inform future emergency planning in Ontario. Finally, Chapter 6 concludes with a summary description of key observations and arguments made within specific chapters. This chapter also discusses the limitations of this study, as well as implications for future research. Chapter 6 finishes with a discussion on what ANT and cascading failure can contribute to hazards geography research, where ideas intersect, and where they may contradict.

Chapter 2: Intellectual Roots for Cascading Failure Research

2.1 The Evolution of Hazards Research in Geography

Geographers have for many decades concerned themselves with natural hazards (i.e. White, 1945; Hewitt, 1983 & 1997; Burton et al., 1993; Blaikie et al., 2004; Tobin & Montz, 2011). Today, hazards research in geography recognizes the social causation of disaster while utilizing concepts such as *risk* and *vulnerability*, each with broad-themed characteristics, to help explain and mitigate disaster (Tobin & Montz, 2011). However, prior to geographers' recognition and adoption of these concepts as important social components of disaster, research within the field of hazards and disasters took a much different approach.

Early research (i.e. Goldthwait, 1928; Everett, 1913; Halstead 1900) put emphasis on understanding characteristics of the natural processes associated with catastrophe (Tobin & Montz, 2011). Popular belief in the early portions of the twentieth century placed responsibility for a natural disaster solely on nature in the form of an uncontrollable natural event such as a flood, tornado, or earthquake, while generally ignoring any human or social influence within a catastrophic event. Although these early investigations have since helped to contribute to a better understanding of the spatial distribution (Joerg, 1912), and to a lesser degree impacts (Lemons, 1942) and mitigation (Reed, 1916) of Earth's natural processes, earlier hazards research in geography is mostly descriptive rather than analytical (Tobin & Montz, 2011). The 'root causes' of disaster, which Blaikie et al. (2004) argue includes a human or societal dimension, were largely excluded in hazards geography research until Gilbert F. White's publication of *Human Adjustment to Floods* (1945).

Viewing disaster as a 'problem of nature' changed in the mid-1940s when White's (1945) research addressed disaster as a social problem. It is in this work that White famously writes: "Floods are 'acts of God', but flood losses are largely an act of man" (White, 1945, p2). Although White had not yet directly formulated any concept of vulnerability - a concept that has since been used to help identify and explain human involvement in disaster - his work does promote a wider acceptance within the hazards research community in which blame on disaster expands from a response in nature to a response in human action. As a result, a new tradition in hazards research led by White and his students at the University of Chicago during the 1950s and 1960s looked to apply geographic knowledge, techniques, and skills against the complexity of the social and environmental issues associated with natural hazards and disasters to help solve the practical problems experienced by communities threatened by natural disaster (Tobin & Montz, 2011). Many geographers (i.e. Mitchell, 1990; Cutter, 2001) credit White as initiating both the crucial research directions and fundamental methodological approaches that continue to inform current thinking about hazards. It is from this point that hazards research in geography tended to theme around case-specific (and often location-specific) or micro-management approaches to the disaster problem resulting in significant changes to hazards policy in such places as the United States.

Despite the success and wide adoption of White's approach to hazards in both research and in policy, it has since been criticized as lacking a sound theoretical foundation – a consequence of being overly concerned with case studies of disasters in which there are inherently unique spatial and temporal characteristics (i.e. Hewitt, 1983 & 1997; Alexander, 1997; Blaikie et al., 2004; and Tobin & Montz, 2011). Without a strong theoretical foundation, knowledge gained through research from one disaster scenario was not easily transferable or relevant to the often unique and multilayered contextual (i.e. spatial, temporal, organizational, environmental, sociocultural, economic, and/or political) characteristics found throughout separate disaster scenarios (i.e. Mitchell et al., 1989). Mitchell et al. (1989) write that "It is very difficult to derive broadly applicable conclusions from studies of specific natural disasters, because contexts are likely to vary" (Mitchell et al., 1989, p. 406). In this sense, each natural hazard is strongly modified by the environmental, sociocultural, economic, and political contexts in which it occurs (Mitchell et al., 1989). Alexander (1997) suggests that context provides researchers with a potential unifying concept, but this, of course, presents a challenge for research in which the disaster context is itself broadened and connections must be made between different contextual aspects. Alexander (1997) writes:

> *One of the most fundamental and potentially unifying concepts is that of context, as it offers a basis for analysing disaster in relation to current developments and preoccupations, and with respect to their variation from place to place... one might add the socio-economic context of vulnerability and coping mechanisms, the political context of motivation to implement disaster prevention, mitigation, and preparedness measures, and the environmental context of disasters. All of these influence the pattern of disasters and help account for changes* (Alexander, 1997, p.299-300).

This idea of 'context' emphasises that research in hazards and disasters is highly inter-disciplinary involving social, natural, and technological phenomenon to be considered in both theoretical and applied concepts (see Tobin & Montz, 2011; Alexander, 1997). This requires a shift in hazards and disaster research away from earlier narrow perspectives largely focused on the relationship between nature and calamity towards a much deeper and complex inter-disciplinary involvement that considers the relationship between nature and society, thus creating a position better aimed at understanding and preventing disaster. In the past, popular research on hazards tended to focus on the cognitive aspects of human behavior as they related to either the creation or mitigation of extreme events (i.e. Burton, Kates & White, 1993). Such methodologies promoted the idea that exposure to hazards was largely the result of bad decision making. However, departing from this line of thinking, Hewitt (1983) argued that bad decision making was not entirely sufficient when explaining how and why disaster occurs. He argued that vulnerabilities are manifested through a lack of choice generated by certain social and economic conditions that place people in dangerous places. As Alexander (1997) points out, the result of Hewitt's radical critique is that there is a growing "tendency to regard disasters as caused more by the social conditions they affect than by the geophysical agents that precipitate them" (Alexander, 1997, p. 289). Armed with this new perspective, geographers have been able to broaden their view of both the causes and consequences of hazards and in doing so establish a more complete definition of disaster within the context of vulnerability. Blaikie et al. (2004) write that, "Disasters are a result of the interaction of both [vulnerability and hazard]; there cannot be a disaster if there are hazards but vulnerability is (theoretically) nil, or if there is a vulnerable population but no hazard event" (Blaikie et al., 2004, p. 49). They argue that "A disaster occurs when a significant number of vulnerable people experience a hazard and suffer severe damage and/or disruption of their livelihood system in such a way that recovery is unlikely without external aid" (Blaikie et al., 2004, p. 50). In this sense, vulnerability encapsulates the social processes associated with disaster.

Following work done by Hewitt, authors such as Cutter (1993), Kasperson et al., (1988), Mitchell et al., (1989), Palm (1990), and Tobin & Montz (1997) were beginning to develop conceptual models and integrative frameworks that served to weaken the tension between theory and practice. For example, work had been done that would allow social models to be incorporated into technical risk assessments used in analysing risk events (i.e. Kasperson et al., 1988). Such works also helped in expanding both the range of factors recognized as contributing to hazardousness (i.e. characteristics of risk and vulnerability) as well as the tools and techniques used for analysis (Tobin & Montz, 2011). As a result, hazards research in geography moved away from developing a simple theoretical framework based on limited case-studies, towards an interdisciplinary approach that organizes the subject of hazards and disasters around unifying concepts of risk and vulnerability (Tobin & Montz, 2011). Doing so has allowed geographers to acknowledge the unique social and physical characteristics of each disaster scenario (mapped out through an examination of a group's vulnerability), while also being able to make the larger generalizations more suited to the needs of interdisciplinary research. In this way, it can be better to characterize disaster though generalization as opposed to uniqueness.

Although geographers have since accepted that a degree of vulnerability within a population acts to influence disastrous outcomes, it has taken time and substantial effort on the part of geographers to formulate this concept and its underlying characteristics as well as its relation to the concept of *risk*. Indeed, there is still no unified and agreed upon definition of vulnerability. For example, Cutter (1996) identified 18 distinct definitions of the term in the context of hazards and disasters. Despite the many varied definitions, Cutter finds three distinct themes in vulnerability studies: vulnerability as risk/hazard exposure; vulnerability as social response; and vulnerability of places (Cutter, 1996, p. 530). Blaikie et al. (2004) offer up a commonplace meaning for vulnerability stating that it "includes being prone to or susceptible to damage or injury" (Blaikie et al., 2004, p.11). This fundamental meaning is consistent within other research on vulnerability (i.e. Cutter, 1996; Schröter et al., 2005; and Yarnal, 2007). Blaikie et al.'s work in *At Risk: Natural Hazards, People's Vulnerability and Disasters* (2004), was a successful attempt at refining vulnerability's common meaning in relation to natural hazards. They define vulnerability as:

> *The characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard (an extreme natural event or process). It involves a combination of factors that determine the degree to which someone's life, livelihood, property and other assets are put at risk by a discrete and identifiable event (or series or 'cascade' of such events) in nature and in society (Blaikie et al., 2004, p. 11).*

Since vulnerability's inclusion into hazards and disaster research, geographers (most notably Hewitt, 1997; Blaikie et al., 2004) have been able to explain why natural hazards have such disastrous outcomes on highly vulnerable populations where poverty, racial inequality, and lack of political freedom persist. However, there is still little discussion as to why disaster still occurs in less vulnerable regions, including portions of the United States and Canada, where lack of economic and political freedoms are not as prevalent. The answer may be found in the idea that vulnerability does not make up the entire disaster equation, and that Earth's natural processes still play an important role in a disastrous outcome. Blaikie et al., (2004) write:

> *It is plainly wrong to ignore the role of hazards themselves in generating disasters… Likewise, we are not suggesting that vulnerability is always the result of exploitation or inequality (just as it is not equivalent to poverty). It is integrally linked with the hazard events to which people are exposed (Blaikie et al., 2004, p. 35).*

The idea that vulnerability is not always an outcome of exploitation, inequality, and/or poverty explains why disasters can also occur in wealthier countries and regions that enjoy a relatively high degree of freedom and equality. These vulnerable traits still exist in pockets throughout wealthier countries and are highly visible in certain areas; yet, there must also be other factors that influence disaster, and these factors include the exposure to hazard. Regardless, it is still the premise behind vulnerability that those most vulnerable tend to be most negatively impacted by disaster.

Due to the interdisciplinary nature of research in hazards and disasters, the term vulnerability is itself at risk of overuse (Blaikie et al., 2004). Engineers use vulnerability to describe risks to mechanical components and the built-environment through such things as infrastructure vulnerability assessments. For example, the Public Infrastructure Engineering Vulnerability Committee is an organization whose goal is to determine and mitigate the engineering vulnerability of Canadian public infrastructure to the impacts and risks of current and future climate (PIEVC, 2007). The term has been extended beyond just people to things such as infrastructure and the economy, but Blaikie et al. (2004) limits their use of the concept to just people; things such as infrastructure, economies, natural hazards, and regions are not considered vulnerable. Instead the authors use such terms as susceptible, unsafe, fragile, hazardous, or hazard-prone to describe these things. For example, an infrastructure system (i.e. an electrical grid) is not vulnerable, but can be susceptible, fragile, or unsafe; thus, infrastructure is fragile and susceptible to disruption or damage that in turn can have an impact on people's vulnerability. In this sense, the term *vulnerability* used by Blaikie et al. (2004) is best described as a *social vulnerability*.

Hazards and vulnerability are certainly crucial components to the disaster equation; however, risk is also an important component in the disaster equation – an idea that has not been ignored by geographers. Geographers (Blaikie et al., 2004 and Burton et al., 1993) have expressed disaster through a conceptual equation where:

Risk = hazard x vulnerability

In this sense, the intersection between hazard and vulnerability create risks to vulnerable people exposed to hazards. However, there has been a certain degree of confusion within the literature between the terms risk and vulnerability. Timmerman (1981) shows risk as an active concept in which 'risks are taken'; whereas, vulnerability is a more passive concept in that it 'merely exists' (Alexander, 1997, p. 291). In this sense, risks are voluntarily entered into and can thus be avoided; whereas, vulnerability is to be endured (Alexander, 1997). However, Hewitt's (1983) critique shows that some social, political, and economic restrictions can often hinder individual and/or community decision making, thus eliminating or limiting control over risk. Smith (1996) argues that risk is better viewed as a product of both a hazard (the physical agent and its impact) and overall vulnerability (the susceptibility to damage or injury). This coincides with Blaikie et al.'s (2004) use of the term *risk* in their Pressure and Release (PAR) model.

The PAR model is based on the idea that disasters are explained by tracing the connections that link the impacts of hazards on people with "a series of social factors and processes that generate vulnerability" (Blaikie et al., 2004, p.52). The PAR model is comparable to a nutcracker in that vulnerabilities create pressure on one side and hazards put pressure on the other. People or societies are situated at a point between these two pressure points; when the pressure becomes too great the point in-between breaks in the form of disaster. The PAR model is a useful organising framework for “outlining a hierarchy of causal factors that together constitute the pre-conditions for disaster” (Blaikie et al., 2004, p. 87). Blaikie at al. (2004) present the PAR model in such a way that focus is on the challenges often faced in the developing world. Limited accesses to resources, severe environmental degradation, or inadequate and unprotected infrastructures are some examples of causal factors of vulnerability used in the PAR model. Although the PAR model provides a strong theoretical explanation for the link between physical hazards and people’s vulnerabilities, Adger (2006) argues that as an analytical tool the model is limited in its analysis of quantifiable or predictive relationships.

Alexander (1997) has argued that the degree of polarisation between the most vulnerable in the developing world and least vulnerable in the developed world may require the use of separate models of explanation. He writes that:

> *It is high time we rethought the models we use to characterise disaster in order to make them fit a new, complex reality in which fewer fixed assumptions can be permitted than in the past. Although this is perhaps true throughout the world, the degree of polarisation is such that it may be necessary to produce separate models for developing and developed countries, although not to the extent that differences are reinforced instead of reduced* (Alexander, 1997, p. 299).

Alexander's research does not undermine the value of the PAR model; instead he refers to the model as an alternative view of vulnerability that models the socio-economic and political underpinnings of vulnerability to disaster (Alexander, 1997, p. 292). While developing vulnerability assessments based on simple conceptual equations, Alexander (1991) classified several different types of vulnerability based on their societal context. Some of these classifications such as '*total vulnerability'* and '*economic vulnerability'* focus on situations of extreme poverty or economic marginalisation, and are more characteristic of what might be found within developing countries as opposed to wealthier countries. For wealthier countries, Alexander (1991 & 1997) includes *technological* or *technocratic vulnerability.* This is the type of vulnerability that can often lead to large monetary losses from natural disaster. Yet it may be that such losses are more often an inconvenience than a personal tragedy, and can be compensated for by insurance claims. He also suggests that this type of vulnerability reveals existing disparities between people at individual, local, and global scales. For example, the well protected urban populations against the more vulnerable rural populations, developed wealthy countries against the developing poorer countries, and the ruling elites against the impoverished proletariats (Alexander, 1997, p.292). Such contrasts are confirmed by Cutter et al. (2003) who show that rural and urban populations can increase their vulnerability, albeit in different ways. For example, rural residents were more vulnerable due to lower incomes and type of economic activity (i.e. farming and fishing); whereas, the high density of urban areas complicated evacuation thus maintaining exposure to hazard (i.e. Cutter, 2003, p.247).

Alexander (1991 & 1997) also describes *residual unameliorated vulnerability* as a type of social vulnerability. This type of vulnerability includes buildings and infrastructures that were built prior to modern safety standards. These types of buildings are more susceptible to natural hazards and are thus sources of risk when there is no will, political mechanism, or funding to upgrade them (Alexander, 1997, p.292). Although Alexander does not appear to include modern infrastructure within this classification of social vulnerability, the category itself does highlight a link between the built-environment as a source of risk and people's vulnerabilities. Cutter et al. (2003) explain that the type and density of infrastructure and lifelines are a major factor for influencing vulnerability. Cutter et al. (2003) write:

> *The quality of human settlements (housing type and construction, infrastructure, and lifelines) and the built environment are also important in understanding social vulnerability, especially as these characteristics influence potential economic losses, injuries, and fatalities from natural hazards (Cutter et al., 2003, p. 245,249).*

Lifelines are those built systems that are crucial to the well-being of a society. They include various critical infrastructure (CI) pathways linked to water, waste disposal, energy, transportation, and communication (Cruz, 2012, p.676). Cruz (2012) writes that society's lifeline systems are "vulnerable to natural hazard forces or other external hazards" (Cruz, 2012, p.676). Cutter et al. (2003) constructed the Social Vulnerability Index (SoVI), which is an index used to measure social vulnerability to environmental hazards. Testing this index in 3,141 U.S. counties, the authors are able to show, among other things, that an increased presence in the scope and use of infrastructure increases social vulnerability for counties (Cutter et al., 2003, p.247). Many natural hazards such as earthquakes, hurricanes, lightning strikes and freezing rain have the ability to damage or disrupt infrastructure. The 1998 Ice Storm in eastern portions of Canada and the United States is one example of a natural hazard having a severe impact on infrastructure systems. This thesis is concerned primarily with ice storms as a source of a natural hazard, and as such, discussion herein is narrowed toward this particular threat.

Little has been said by geographers regarding ice storms as natural hazards. Lecomte et al. (1998) state that from a meteorological point of view, the severity of an ice storm is dependent on ice accumulation, wind speeds, duration of freezing rain, and size of the affected area. These storms tend to be broadly categorized under hydro-meteorological or climatological hazards in the literature (i.e. Wisner et al., 2012) and are sometimes placed together with blizzards and major snowstorms (i.e. Cross, 2001). The 1998 Ice Storm disaster in eastern Canada and the northeast U.S. brought some attention to the phenomenon, albeit briefly. It could be speculated that one reason for the lack of discussion may be that freezing rain does not typically result in the same degree of damage and at such frequent intervals as other hazards like hurricanes, earthquakes, or tornados. It may also be that freezing rain itself is not as damaging as the subsequent technological and infrastructure failures that its presence can generate, and so more attention is given to other forms of hazard. In writing about the 1998 Ice Storm, Murphy (2001) states that, "The freezing rain was produced by nature, but disaster only occurred because of the construction of dependence on a vulnerable power grid. This resulted in the inadvertent manufacture of a technological catastrophe" (Murphy, 2001, p.336). He further adds that the destructiveness of the freezing rain was largely dependent on the presence or absence of vulnerable human constructions (Murphy, 2001). This does not necessarily go against the premise in which hazards intersect with vulnerability to create risk and disaster; however, it does highlight a problem of consistency in categorizing hazards, particularly when both natural and technological forces are at play. Wisner et al. (2012) emphasize that disaster characteristics may not always emerge clearly from the hazard typology and that simultaneous or sequential hazards could represent the disaster challenge (Wisner et al., 2012, p.173). With ice storms, the difficulty may be in determining whether the true hazard is more in the subsequent technological failures rather than the physical ice storm. Wisner et al. (2012) write:

> *The overall lesson is not necessarily to avoid a universal typology of hazards. Instead, it is to recognise that 'hazardousness' (Hewitt and Burton 1971) is largely, but not completely, a human construct. Hazards are influenced by humans, but also exist in their own right. Hazards must be understood within the context of the limitations and inconsistencies in all approaches to categorizing (Wisner et al., 2012 p. 174).*

2.2 The Transition from Single Hazards & the Capturing of Complexity

The Routledge Handbook of Hazards and Disaster Risk Reduction edited by Wisner et al. (2012) contains within its pages a series of papers on the physical characteristics, vulnerability characteristics, and disaster risk reduction options for specific hazard categories. Similar traits or characteristics from other hazard types are, with some limitation, comparable to severe ice storms. For example, ice storms tend to occur in cold conditions that are more difficult to cope with when there is no electricity to provide heat. In this sense, one could take characteristics from extreme cold hazards (as discussed by McCormick, 2012) and apply them to ice storms. Moreover, severe ice storms have the ability to damage and disable energy infrastructure resulting in prolonged blackouts that can negatively impact other important infrastructures. Jonkman et al. (2012) describe the consequences of coastal storms and floods as producing multiple types of damage including damage to homes, buildings, and infrastructures. In this sense, the impact of coastal storms and flooding on infrastructure systems are comparable to what may occur during an ice storm. Jonkman et al. (2012) also suggest that in addition to the initial consequences to infrastructure, coastal storms and flooding can also influence *chain-reactions*. The authors are brief in their discussion on 'chain reactions'; however, they touch upon a seemingly related and emerging concept in hazards literature termed *cascading failure*.

To date, very little has been discussed by geographers about the concept of *cascading failure*. The term has been used with greater frequency in engineering and technology based research (i.e. Rinaldi et al., 2001; Zarnani et al., 2012; Gheorghe & Mili, 2004; Little, 2002 & 2010) in which there is growing concern with regard to understanding and preventing cascading failures in technological infrastructure systems. The concern is based on the premise that such failures in infrastructure are disruptive, costly, and can impose significant security concerns (Rinaldi et al., 2001; Grubesic & Murray, 2006). Little (2010) provides a definition for a cascading failure that is used in technology studies and engineering disciplines:

> *A cascading failure in an engineered system occurs when a failure in one of the collection of interconnected parts that delivers a service triggers the failure of successive parts. When this is translated to the case of infrastructure, cascading failure can be conceptualized as a situation where an infrastructure disruption spreads beyond itself to cause appreciable impact on other infrastructures, which in turn cause more deleterious effects on still other systems (Little, 2010, p. 29).*

Cruz (2012) writes about the vulnerability of infrastructure and lifelines (i.e. infrastructure systems) exposed to natural hazards. According to Cruz (2012), exposure to natural hazards can damage lifeline systems which include: roads, bridges, power generation and distribution systems, communication systems, and water and waste systems. Of these infrastructure systems it is noted that electrical power and communication systems are both highly susceptible to natural hazard impacts and that emergency response capability is hindered when these systems are impacted (Cruz, 2012). By understanding the vulnerability of exposed systems, adequate protection measures can be designed and implemented to ensure the continual operation of CI during and after a disaster (Cruz, 2012). Cruz (2012) argues that in the context of protecting infrastructure systems, it is important to analyse them as part of a larger connected system, as opposed to an independent entity. It is suggested that this can be achieved through a more comprehensive approach that integrates, "structural and non-structural measures, strengthens the capacity of local communities and promotes the participation of all stakeholders in disaster planning" (Cruz, 2012, p. 686).

An important question is raised about whether specific natural hazards like ice storms, earthquakes, or floods each have their own risk implications for if and how a cascading failure occurs. Cruz (2012) writes that "the vulnerability of buildings and lifelines will vary for each type of hazard, as well as the risk reduction measures available for their protection" (Cruz, 2012, p.679). By replacing 'buildings' with 'infrastructures' in that statement, it is logical to suggest that hazard impact on infrastructure and lifelines is determined by the type of infrastructure system. For example, underground pipelines are far more susceptible to earthquakes than to high winds or freezing rain. Alternatively, electrical power systems are susceptible to both earthquakes and storms that can produce high winds and freezing rain (Cruz, 2012). Going beyond the scope of what is discussed in Cruz's (2012) article, are questions about how specific hazards intersect with cascading failure should one occur, and what implications this may have in a disaster scenario. Geographical analysis and techniques could help answer such questions.

Cruz (2012) explores the danger to infrastructure systems exposed to natural hazards as well as highlights the need for a comprehensive infrastructure protection strategy; however, her work does not address the greater implications of cascading failure in the context of people's risk and vulnerability to natural hazard, nor does it highlight what geographers can contribute to the analysis of cascading failure in infrastructure systems. Grubesic & Murray

(2006) use geographical analysis to explore the vulnerability of exposed infrastructure systems, arguing that cascading failure has a significant geographical context. Their research evaluates a range of potential vulnerabilities in geographically linked networks. Their work is highly technical focusing on the structural network components of infrastructure systems and does not explore the deeper social and environmental ramifications of cascading failure in disaster; however, their research does suggest that cascading failures may have great influence on the spatial pattern and extent of disaster. For example, Grubesic & Murray (2006) write, “the loss of vital nodes in a geographically linked network can both motivate and exacerbate the spatial dimensions of cascading failure” (Grubesic & Murray, 2006, p. 80). Vital nodes in this sense refer to the structures that link together an infrastructure or infrastructures, for example, telecommunication switching centres or electrical substations (Grubesic & Murray, 2006). The authors also show how economic and political factors, through lower cost incentives, economies of scale, and sometimes private ownership of infrastructure systems, influence the network formation of vital nodes and their links, creating an increased susceptibility to cascading failure. In this sense, the political and economic structure of a society can encourage the construction of highly interdependent and interconnected infrastructure. Little (2010) also describes the sometimes profit and efficiency driven interests of infrastructure stakeholders as a reflection of the longstanding institutional failures and weaknesses that serve to promote greater susceptibility to cascading failure. Indeed, research has shown, (i.e. Little, 2002 & 2010; Rinaldi et al., 2001; and Cruz, 2012) that highly interdependent and interconnected infrastructure systems promote the greater possibility of cascading failures occurring. Cruz

(2012) reinforces this with the suggestion that past disasters provide enough reason for a better understanding of the societal significance of infrastructure interdependencies.

The work done by Grubesic & Murray (2006) shows how geographical spatial analysis can contribute to understanding the spatial characteristics of cascading failure; however, such knowledge is likely to be used by local and national agencies as part of the technical countermeasures added to individual systems or components in an attempt to improve redundancy and reliability of these systems (Menoni, 2001). In line with geographers' movement away from a problematic technocratic approach to hazard mitigation, Menoni (2001) argues that too much focus on, "technological fixes, no matter how sophisticated, tend to fail if they are not combined with the organisational improvement of emergency and recovery operations" (Menoni, 2001, p. 103). Menoni (2001) examines *chains of damage and failure* in metropolitan areas. Menoni (2001) argues that natural hazards trigger chains of damage and failure throughout the social, technological, and environmental components that make up the complete and complex disaster scenario. She writes,

> *In most cases, in fact, damage is not the result of natural forces only, but rather of the interaction of the latter with vulnerable social and economic systems and with poorly constructed built environments … the physical event is just the triggering factor, which provokes physical damage (to vulnerable structures), but which also reveals organisational failures and the elements that make systems prone to systemic damage (Menoni, 2001, p. 108).*

Her work is structured around an emergency management or planning perspective; however, she employs concepts of risk and vulnerability in the same fashion as geographers. She does not use the term 'cascading failure' in her research but her descriptions regarding *chains of damage and failure* are transferable to the idea that hazards have a role in initiating cascading failures in critical infrastructure. For example, Menoni (2001) shows how infrastructure systems impeded by an earthquake led to affects in what the author refers to as 'subsystems' which include: economics, emergency services, and social systems (Menoni, 2001). This suggests that cascading failures are not limited solely to the technological components of infrastructure, but are also linked to a multitude of factors such as social vulnerabilities, environmental hazards, and the organisation of emergency preparedness and response.

As cities grow increasingly complex in their population, functioning, and infrastructure, it becomes difficult, due to the nature of a cascading failure, to predict how a disaster will unfold. This in particular has significant implications in emergency management, and the mitigation and adaptation of disaster. Little (2002 & 2010) discusses in great detail the behavior and far reaching consequences of complex interconnected infrastructure systems exposed to hazards. Although he acknowledges natural hazards as potential threats to infrastructure systems, his analysis is focused more on the technologically induced and human induced failures that result in cascade disruptions. Little (2002) argues that it is not only important to understand the technological systems and how they will perform mechanically when exposed to a hazard, but also to consider the human component of the technological system within the context of better management of interdependent infrastructures during an emergency. However, the 'human component' in this sense is limited to the operation and configuration of the infrastructure service. For example, better training and stricter regulation for those people involved with the performance of an infrastructure system. His analysis addresses the mitigation and adaptation of CI to the threat of cascading failure, with the understanding that human action impacts the operation of CI services. From a hazards geography perspective, focusing entirely on the improvement and continued operation of infrastructure systems is problematic in that it is characteristic of the technocratic approach to hazards mitigation. Regardless, Little (2010) acknowledges that despite great improvements in the design, construction, and performance of infrastructure systems threatened by hazards, failures are fully expected to continue occurring. Thus, it is important to look beyond the behaviors and consequences of just the technical components of cascading failure and to consider the environmental, social, and technological domains that cascading failure reaches.

2.3 Actor – Network Theory & Complexity in Hazards Research

This thesis is concerned with cascading failure in critical infrastructures brought on by a natural hazard. When a natural hazard triggers a cascading failure in infrastructure systems resulting in a disaster, that failure can be understood, depending on one's perspective, as having travelled throughout either social, environmental, or technological domains. Some researchers choose to explore the technical aspects of cascading failure by observing its behavior and consequences in the technical components of infrastructure systems (i.e. Little, 2002; Rinaldi, 2001). Others may choose to focus on emergency planning practices to explain how groups organise themselves when threatened by cascading failure (i.e. Menoni, 2001). And some research will consider the ways in which specific natural hazards can impact an infrastructure system to produce disaster (i.e. Cruz, 2012). The difficulty is in adequately creating a complete picture of events when such seemingly separate and large domains as the technological, social, and environmental are present in the context of cascading failure brought on by natural hazard. Actor-Network Theory (ANT), as developed by Latour (1987, 1999 &

2005) and Michel Callon (1986 & 1991), offers a means for including the technological, social, and environmental into one network of study without placing privilege over any single domain. Moreover, it explores how relations between objects, people, and concepts are formed, rather than why they are formed. This section will briefly describe ANT and how it will be used in this thesis to help explain and understand cascading failures in the context of hazards and disasters.

ANT does not subscribe to technological determinism, social determinism, or environmental determinism. Latour (2005) claims that to make concrete distinctions between what is social or what is technological in a network is difficult. For example, a computer has both technological aspects and social aspects, neither of which should be ignored. In order to remove the separation between the social, technological, and natural, ANT seeks to treat human and non-human agents, which are both referred to as 'actors', as equal. This is done through three principles adopted by ANT and discussed by Tatnall & Gilding (1999). These principles include: agnosticism, generalised symmetry, and free association. Tatnall & Gilding describe these three principles:

> *… Agnosticism means that analytical impartiality is demanded towards all the actors involved in the project under consideration, whether they be human or non-human. Generalised symmetry offers to explain the conflicting viewpoints of different actors in the same terms by use of an abstract and neutral vocabulary that works the same way for human and non-human actors … the principle of free association requires the elimination and abandonment of all a priori distinctions between the technological or natural, and the social (Tatnall & Gilding, 1999, p.958).*

According to ANT, an actor does not exist only as an object but as an association of heterogeneous elements that organize into a network (Tatnall & Gilding, 1999; Latour, 2005). Thus, a network is an assemblage of actors and their links or associations with other actors.

With such a network, it is possible to analyse the strength of associations, the stability or instability of the network whole as well as what happens when elements of the network change. In this sense, the scale of a network changes depending on perspective since actors are not only a part of a larger network but are themselves a network composed of smaller actors. For example, a city can be viewed as a working whole that exists as an actor within a larger network where it maintains links and associations with other city actors. Yet, any city can be broken down into smaller component actors such as the electrical infrastructure system that powers the city, the people that live and work in the city, or the meteorological conditions that play out over the city. And those actors that make up the city network can themselves be considered merely the sum of even smaller actors. Thus, ANT provides a scale of study depending on the perspective or context chosen by the researcher. This is related to the concept of *punctualization* and *depunctualization* (Latour, 1999); a process in which elements of a network remain hidden until the network breaks down. For example, infrastructure is largely unnoticed by the people who rely on its services. A lamp has electrical and mechanical components, all of which are generally hidden to the person who uses the lamp for light. When the infrastructure that helps power the lamp is damaged, and the supply of electricity stops, then punctualisation also stops (*depunctualization*) and the person using the lamp becomes aware of the collection of parts that produce the light. Latour (1999) uses the example of opening a black box to describe depunctualization. When the box is closed it is perceived simply as a box, but when it is opened, all of the elements inside of it become visible. The 1998 Ice Storm disaster can also be viewed in the same terms as a black box. Use of the name *Ice*

Storm summarizes into two words the meanings, experiences, events, actors, and outcomes of what occurred in January 1998.

It seems then that the scale of actors and networks can be incredibly complex when network actors are opened and their contents reconsidered. ANT acknowledges the complexity of networks and so it is suggested that being completely aware of all networks is unfeasible (Latour, 2005). Instead, networks provide a means for simplifying a complex world. In doing so, ANT enables an exploration of the ways in which the network of relations are composed, how they emerge and come into being, how they are constructed and maintained, how they compete with other networks, and how they are maintained over time (Tatnall & Gilding, 1999; and Latour, 2005). In this sense, with the idea of being able to observe a network without giving privilege to the technological, social, or environmental components, it becomes possible to discuss cascading failure. The remainder of this chapter will discuss how ANT is to be used in discussing cascading failure.

2.4 The Intersection of Cascading Failure and Actor-Network Theory Research

Using ANT's ideas of actors and the linkages between actors that create a network, this thesis presents a case study that allows a tracing of the actors. The cascading failure that occurred in the study area can be used, in the context of hazard and disaster, to identify a network of actors whom are connected in some way to the cascading failure. In this way the cascading failure acts as an aid for which to identify actors and connections, thus helping to choose a network to work from. It may then be possible to predict the stability of the network and how the network will behave if the actors within are modified or removed; or how it will respond if new actors are added. The challenge is in determining the role of cascading failure in the network. In one sense, it could be presented as an actor within the network. However, it may be better to present cascading failure as a modification in the links between actors. It is a pre-existing pathway for adding, removing, or modifying actors within the network. To be clear, it is the cascading failure that brings attention to those crucial links that bind actors together, and when broken, creates an unstable social network in the form of a disaster. As a result, it is possible to understand how cascading failure occurs in the context of hazard and disaster.

ANT is used by providing a unique view of a cascading failure as a change or modification within the associations that bind seemingly different but highly interconnected CI systems together. For example, under normal operating conditions, eastern Ontario's electricity network and its provincial highways (although linked in various ways) are perceived as having different uses that function separately from one another; however, when an electrical wire collapses over a major highway, the association between the two infrastructures is modified with consequences or challenges to other infrastructure and to the people that rely upon them.

ANT has not been previously applied in hazards geography and cascading failures research; however, there are several examples in which ANT has been used to explore environmental issues. For example, Allen & Lukinbeal (2010) apply ANT to the Rock Art Stability Index used by physical geographers. With ANT, they are able to show links between natural science and human learning in relation to weathering processes. Callon's (1986) use of ANT to investigate the causes for sea scallop decline in St. Brieuc Bay, France explored the links between economic, biological, and social factors involved in the decline of the sea scallops.

Examples of ANT's use in relation to environmental issues highlights ANT's ability to broaden the context of a single area of study to include a wider range of causal factors. This in turn suggest ANT’s contextual broadening should be useful in hazards geography research where broad concepts of risk and vulnerability are used to explain factors contributing to disasters.

In Regions of Risk: A Geographical Introduction to Disasters, Hewitt (1997) describes vulnerability as a pre-existing trait that is revealed when vulnerable people are exposed to a hazard. ANT can help determine whether the conditions needed for a cascading failure to occur are already in place prior to the occurrence of a hazard, or whether the failure only exists after the hazard’s arrival. It is the point of view of this thesis that the conditions conducive to a cascading failure are indeed present prior to the arrival of a natural hazard. The 1998 Ice Storm case study presented in Chapters 3, 4, and 5 will help illustrate this final point by carefully presenting to the reader an assemblage of actors (i.e. organisations and various CIs) that are structured in such a way that is conducive to a cascading failure occurring when initiated by a natural hazard. In the final section of this chapter, key notions of ANT in combination with concepts used in hazards geography research are incorporated into a cascading failure in critical infrastructure framework. Such a framework provides the foundation for establishing those pre-existing conditions.

2.5 Thesis Framework

Thus far, Chapter 2 has displayed the contents for a framework that supports the remainder of the thesis, and in particular helps in the formulation of Chapters 3 and 4. Chapter 2 has described the evolution of hazards research in geography and how risk, vulnerability, and context are now considered by geographers as crucial components for the understanding of hazard and disaster. Moreover, single hazard categories such as an ice storm can be understood as being far more complex. This complexity is brought about by the multiple contexts found in disaster and where the seemingly separate domains of the social, technological, and environmental converge and overlap. The occurrence of a cascading failure in CI can both highlight this complexity through a tracing of events and display the challenges, risks, and vulnerabilities faced by societies dependent upon modern infrastructures. Appropriately, given the undertaking of understanding complex hazards, ANT is used to identify and interpret the causal relationships associated with a natural hazard that initiates a cascading failure.

The following offers a framework for answering the questions posed by this thesis and for addressing its primary purpose: to demonstrate how an extreme weather phenomenon intersects with the built-environment to create a complex hazard event initiated by the occurrence of a cascading failure. In accordance with ANT principles, it is necessary that such a framework identify which primary actors' within an infrastructure failure help to isolate and determine the contextual aspects of the 1998 Ice Storm disaster. This requires interpretation of a number of different sources ranging from government reports created following the disaster to newspaper articles written during the days of the 1998 Ice Storm. ANT's application to this research is dependent upon the ability of an actor to reveal its own network to which it belongs to, operates in, and is influenced by and/or has influence on. In this way, information taken from each source (i.e. newspapers, books, government reports, and empirical weather data) is used to build the initial network of study and offer evidence that supports a tracing of the cascading failure that occurred during the 1998 Ice Storm. ANT-based research often incorporates the use of interviews to establish a stronger tracing of an actor's contributions to stressed environments as well as possible responses to adverse and/or positive outcomes. However, given 15 years has passed between the Ice Storm and this research, it is likely that individuals' perceptions of what occurred from January 5 to January 10 in 1998 have changed. Regardless, the choice to exclude interviews from this research is justifiable when one considers that not all actors in a network are human. Therefore, by tracing the 1998 Ice Storm through non-human critical infrastructure actors such as electricity, transportation and communication systems it is possible to utilize other forms of data.

Since networks as they are understood by ANT are theoretically infinite and therefore far exceed the intentions for this thesis, it is helpful to define a specific geographic perspective in order to limit the scope of actors and their connections to a more realistic and obtainable area of focus within the human-environment relationship. Moreover, it is preferable from a hazards geography perspective to isolate source information that defines the relationship between nature and society rather than the relationship between nature and calamity (disaster). This is where the Ice Storm disaster, CI, and the core principles of hazards geography – risk, vulnerability, and context – are collectively used to better understand a cascading failure in CI.

Figure 2.0 contains the elements of a cascading failure in CI framework. The blue arrows above each box in the figure represent a flow of information that continually overlaps with each subsequent chapter. In the first box are key concepts and tenets related to hazards geography and ANT. These concepts and tenets are presented in Chapter 2 and they are used to inform each chapter of the thesis.

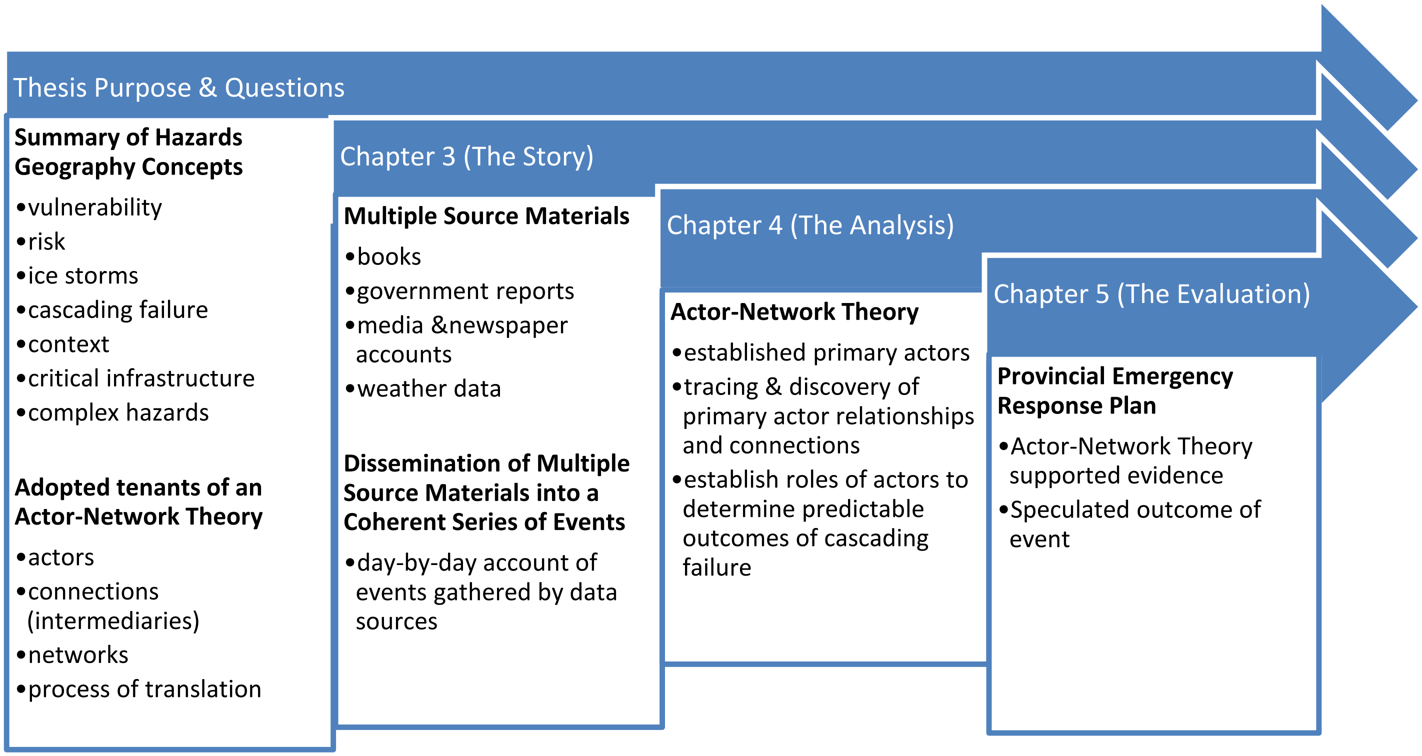


Figure 2.0 Summary of how this thesis presents the analysis of the cascading failure in critical infrastructure.

Chapters 3 and 4, which are shown in the second and third boxes in Figure 2.0, are carefully developed by combining a hazards geography framework with the core principles of ANT. Chapter 3 has two important roles in this thesis: first, to describe through the consideration and unpacking and then re-constituting many different information sources into a coherent series of events - essentially a story of the Ice Storm limited to within a predetermined scope of study where nature and society intersect through the built-environment. Second, once the information is coherently laid out, this 'story' of the Ice Storm is better suited for identifying which actors are of importance in the network. In other words, it becomes more apparent from a researcher's point of view as to which actors have power and influence over other actors within the network that is engaged in the disaster.

Although the idea of primary actors and their influence on a network is largely ANT based, they still tie in to the theoretical components of hazards geography research. For example, it can be discovered within a tracing of events that one actor's presence and influence in a network increases or reduces the network's overall vulnerability to a cascading failure triggered by a natural hazard. On its own, Chapter 3 does not establish a deep understanding of how disaster occurs or what characteristics of risk and vulnerability are present in the nature-society interaction. Thus, Chapter 4, which is shown in the third box in Figure 2.0, focuses the information described in Chapter 3 under the principles of an ANT where broadly defined CIs are analysed and their relationships to other infrastructures, people and organizations, and Earth's natural processes are carefully traced. These tracings are important because they establish a set of relationships within a network that extend to a concept of vulnerability. Broader elements of vulnerability, hazard, and disaster (risk) within the context of infrastructure disruption are best categorized using a model similar to the Pressure and Release (PAR) model developed by Blaikie et al. (2004). The PAR model is useful within this framework (Figure 2.0) because it outlines a hierarchy of causal factors that determine the preconditions for disaster.

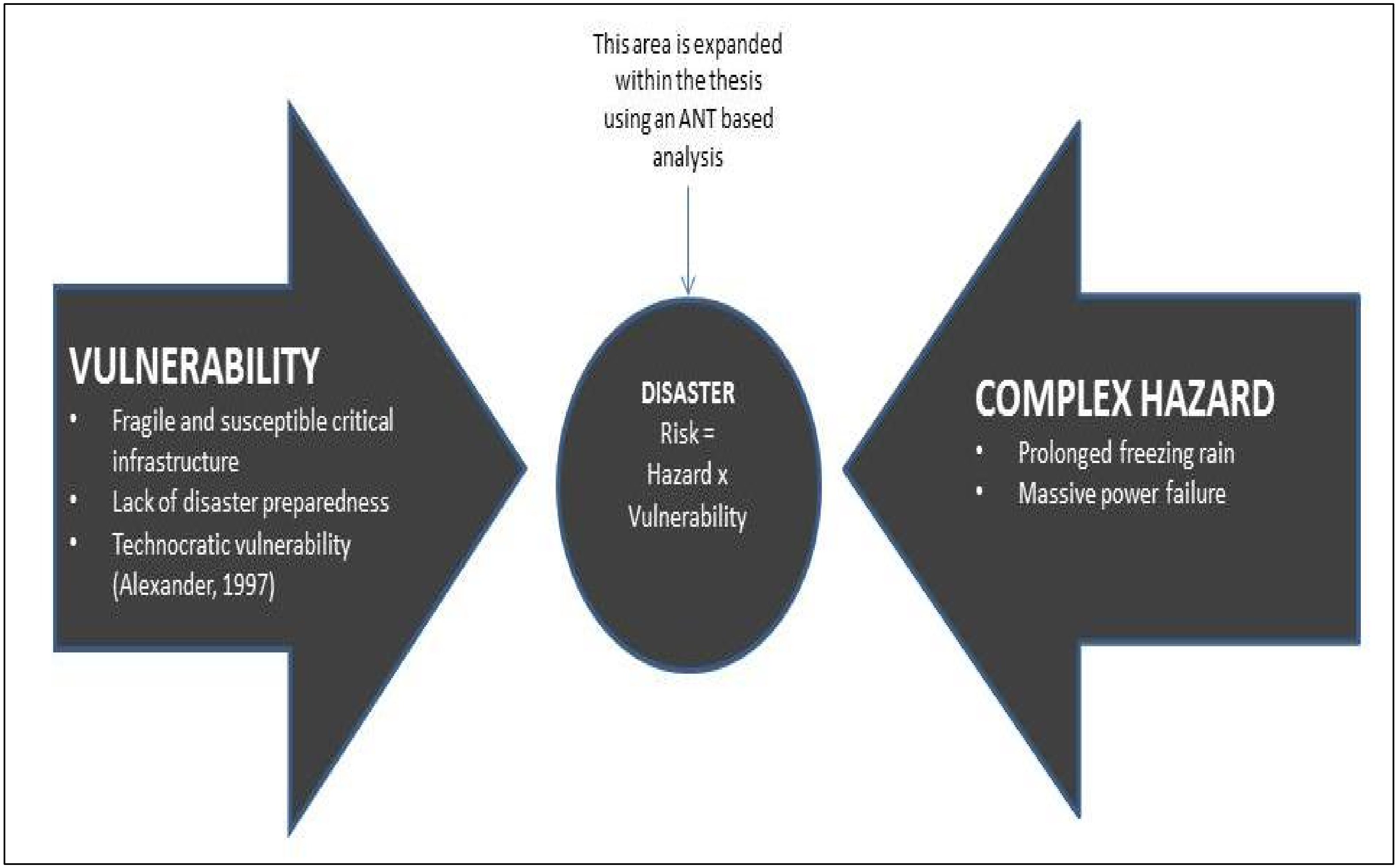


Figure 2.1 A modified version of Blaikie et al.'s 2004 PAR model, adapted in this thesis to include wealthier regions within the context of infrastructure disruption (Derived from Blaikie et al., 2004).

The PAR model developed by Blaikie et al. (2004) is also a useful tool for categorizing elements specific to a cascading failure in critical infrastructure framework. This model focuses on infrastructure and the influence these systems have on the degree of vulnerability for a society threatened by a prolonged ice storm. On the right-hand portion of the figure is the hazard; this is the initiating agent of a disaster whose presence puts pressure on a vulnerable society. The natural hazard being explored in this thesis is an ice storm and since the 1998 Ice Storm is the centre of focus of this study, a massive power outage is also included within the hazard category of the PAR model depicted in Figure 2.1. ANT does not focus on the differences between nature and technology but rather draws attention to the relationships. As such, the two primary hazards experienced during the Ice Storm (freezing rain and a prolonged power outage) are categorized under the term 'complex hazard' rather than their more limiting individual technological or natural hazard categories.

Both Hewitt (1997) and Blaikie et al. (2004) identify characteristics of vulnerability as the pre-conditions for disaster that are present prior to the occurrence of a hazard. These broadly defined characteristics limited to within the concerns of this thesis are shown on the left side of the figure under the 'vulnerability' heading. This is where infrastructure disruption is categorized as influencing a society's degree of vulnerability. Under the vulnerability heading are those processes that are included in a framework focused on infrastructure disruption. First, *fragile and susceptible critical infrastructure* puts pressure on a society confronted by a hazard; however, the fragility between different infrastructures is highly variable. Different hazard categories have different impacts on individual infrastructures. In this way, the framework must recognize that the degree of vulnerability varies in accordance to the type of hazard that presents itself. It should be noted that ANT makes no a priori assumptions about what infrastructures are susceptible, to what hazard categories, and to what degree. As such, the PAR model depicted in Figure 2.1 does not list specific CIs. These infrastructures are only identified through a process of translation as dictated by ANT. In accordance with ANT, the actors must reveal the network connections that determine an infrastructure's susceptibility to a specific hazard type. In other words, a tracing of an actor-network that includes prolonged freezing rain and a widespread power outage will determine which infrastructures can be listed as fragile and susceptible under the 'vulnerability' heading in Figure 2.1.

Blaikie et al. (2004) include a 'lack of disaster preparedness' within their own PAR model as having influence on a society's degree of vulnerability. Simply put, successful disaster preparedness translates into a form of resiliency which lowers the degree of vulnerability. This element of vulnerability is included in the framework because examples from the 1998 Ice Storm ultimately reveal a lack of preparedness that worsened the disaster in eastern Ontario. This in particular, relates to Chapter 5 of this thesis in which Ontario's 2008 Provincial Emergency Response Plan (PERP) is reviewed for its ability to reduce the impact of another ice storm disaster. Also included under the vulnerability heading in Figure 2.1 is 'technocratic vulnerability'. Technocratic vulnerability relates to the dependency wealthier nations have on technological infrastructure systems (Alexander, 1991). Including a technocratic vulnerability into this framework is a departure from Blaikie et al.'s (2004) original PAR model. Technocratic vulnerability, is geared more towards the type of vulnerability experienced in economically wealthier cities and regions; whereas, the model developed by Blaikie et al. (2004) is better suited to regions of greater economic, political, and environmental turmoil and/or poverty.

What is important to this framework is that technocratic vulnerability alters the consequences of disaster for wealthier regions where the trend involves large monetary losses in conjunction with fewer fatalities.

The PAR model depicted in Figure 2.1 describes the causal structure of disaster as it is perceived through developments in hazards geography research. However, on its own, it is not a sufficient analytical tool as is suggested by Adger (2006). The analysis is strengthened by incorporating ANT into the model. For example, in the centre of Figure 2.1 between hazards and vulnerability is the disaster - ANT'S process of translation maps the disaster and in doing so allows the actors to reveal intermediary connections and relationships that identify the specific elements categorized in the PAR model. In this way it is possible to identify specific infrastructure failures and the associated pre-determined or reactionary managerial responses of the province and other emergency responders. The result is a more systematic portrayal of what elements in the built-environment are susceptible to ice storms and what pre-existing vulnerabilities are present and therefore conducive to a cascading failure.

Chapter 3: The 1998 Ice Storm Series of Events

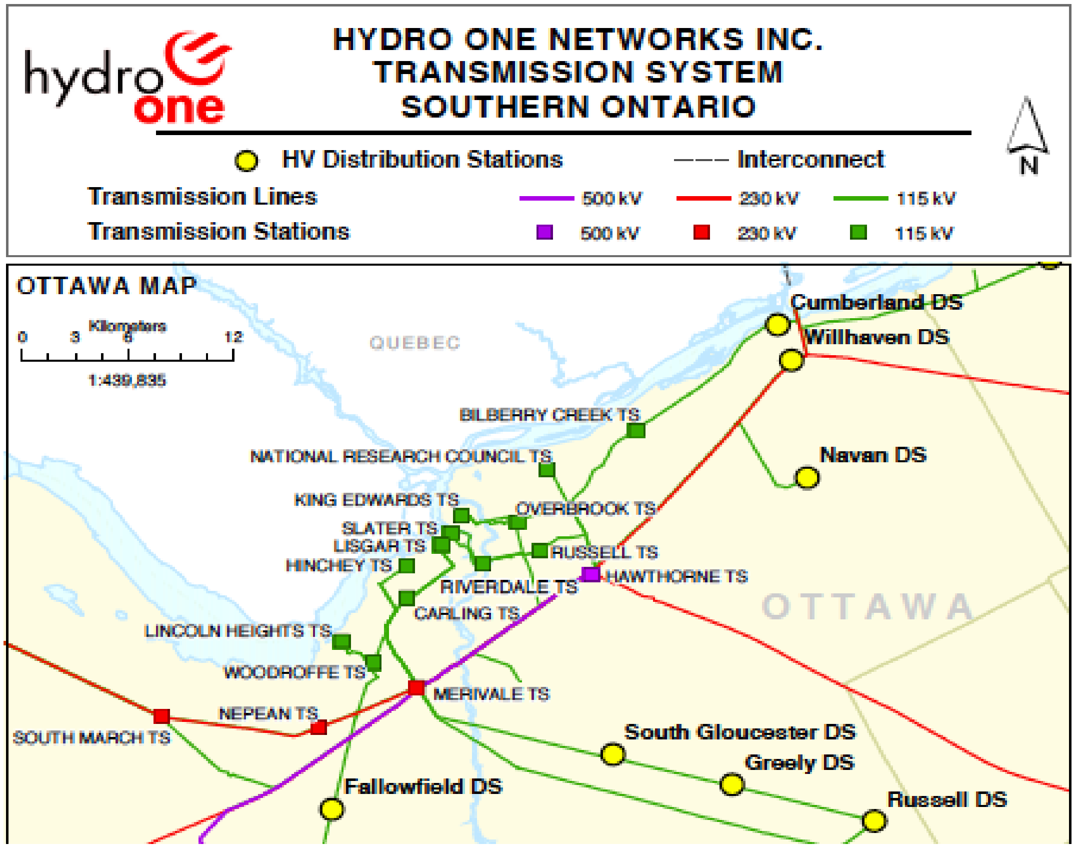
This chapter sets out a narration of events that occurred during the January 1998 Ice Storm from January 5 to January 15. Although the Storm greatly affected multiple municipalities and regions across eastern Ontario, Quebec, eastern Canada, and the eastern United States, the primary focus herein is to show how the Storm impacted the City of Ottawa in the Ottawa-Carleton region and how the province of Ontario acted in an emergency response role to assist the region. While focus is on the City of Ottawa, this chapter acknowledges the affected rural and suburban communities in the Ottawa-Carleton region - Kanata, Nepean, Gloucester, Orleans, Ottawa Valley, South Frontenac, Rideau Township, Stormont, Dundas, and Glengary - since it permits for recognition in later chapters of the rural-urban division that occurred during the response to the Storm. Municipal and federal roles are also described as far as they relate to the Ottawa-Carleton region, the City of Ottawa, and the response efforts of the province through Emergency Management Ontario (EMO) and the provincial ministries. The scenario of failure and response outlined in this chapter is also primarily focused around the Storm's disruption of those critical infrastructure (CI) and lifelines that provide a crucial service, which when absent is detrimental to a community.

The information portrayed in this chapter will help to identify in later chapters those points where the risk of cascading failure was increased or minimized. This information has been gathered using a wide range of sources and a detailed account of these sources are found in Appendix A. Examples of these sources include various local newspaper articles that provide a record of events that occurred during the Storm. Raymond Murphy's (2009) book, *Leadership in Disaster: Learning for a Future with Global Climate Change* and Lecomte et al.'s (1998) *Ice*

Storm '98 are also used as sources of information pertaining to the day-to-day coverage of the event. Also, a government report containing interviews with emergency management personnel and which is authored by Purcell & Fyfe (1998) is cited multiple times throughout this chapter. This particular report is located online in Public Safety Canada's archives and is used in this chapter insofar as it identifies specific roles and responses of emergency personnel during the Storm. Finally, meteorological data was recorded by Environment Canada and archived online under the Government of Canada's *National Climate Data and Information Archive*. This is an historical record of hourly temperature, precipitation, and wind speed measurements taken at Ottawa's MacDonald-Cartier International Airport (refer to Appendix A for reference). Moreover, weather forecasts presented to the public during the Ice Storm are gathered using a combination of the sources described above. For ease of presentation in the remainder of this chapter's text, footnotes are used and any direct quote is noted in-text.

There are instances throughout this chapter where technical information is used to describe the state of electricity distribution in Ottawa. To ensure a clear understanding of how events progressed, a brief discussion on electricity distribution is needed. To begin, Figure 3.0 contains a map of Ottawa's electrical grid system with notes regarding key aspects of the map.

Figure 3.0 Ottawa's Electrical Grid System



Notes:

1. This map was imported from Hydro One's website at: http://www.hydroone.com/RegulatoryAffairs/Documents/EB-2006-0501/Exhibit%20A/Tab_6_Sched_1-Transmission_System_Map.pdf

2. The 500kV (purple) line represents the main feed into the region from the power generation station. The 230kV (red) line represents feeders to a local power authority such as the City of Ottawa. The 115kV (green) lines represent lower capacity distributions with a city.

3. In January 1998, the 500kV line was damaged by ice and unavailable to bring electrical power into the region. In addition, the 230kV lines from the south and into Hawthorne TS and Willhaven DS were also damaged and power supply was interrupted. Only the 230kV line from the west into Merivale TS was operational during the 1998 ice storm (Petricevic, 1998b; Murphy, 2009).

It may be helpful to think of electricity distribution in Ontario as moving from large-capacity lines, to medium-capacity lines, and then to lower-capacity lines. For example, electricity is transferred from a power generation station (i.e. a nuclear generating station, natural gas facility, or hydro dam) to the eastern Ontario region by large-capacity 500kV transmission lines. These are wires that run along large hydro corridors and are identifiable by the tall metal towers (energy pylons) that carry these wires across a landscape (energy pylons are depicted in Figure 3.1 below). A 500kV transmission line is represented by the purple line in Figure 3.0. At the time of the Ice Storm, these lines were managed by Ontario Hydro.

The 500kV lines are then connected to substations that transfer the electricity to medium-capacity 230kV lines. These transmission lines, which are shown in Figure 3.0 as red lines, distribute electricity across the Ottawa-Carleton region. It is from these lines that municipal hydro firms such as Ottawa Hydro or Nepean Hydro would get their electricity to distribute to their own customers. Transformer stations would then transfer the electricity from the medium capacity 230kV lines to lower capacity 115kV lines. These lower-capacity transmission lines are represented in green in Figure 3.0. It is with these lines that Ottawa Hydro provides power to Ottawa's residents and businesses. However, the important message to take from this is that a disruption in the larger 500kV lines and/or a disruption in the 230kV lines would put tremendous pressure on Ottawa's electricity transmission capability.

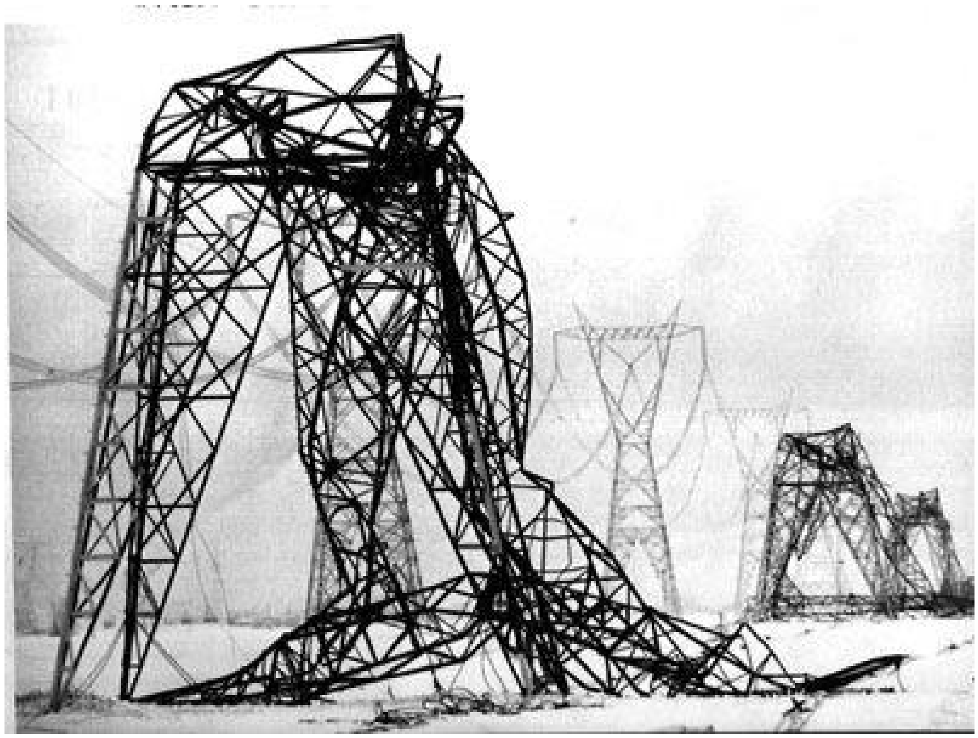


Figure 3.1: Image of electrical pylons crippled by the freezing rains of the 1998 Ice Storm (Source: Schmidt, 2006).

Moreover, the electricity grid in Ontario is made up of utility poles, transmission wires, pylons, transformers, and substations, and other mechanical components. The entire system is shaped much like a web with connecting points. This means that in the case of a disruption in one component, electricity can be rerouted by the hydro companies to another area in the grid. Ultimately, the large geographical extent of the ice storm caused multiple points of the grid to become damaged (i.e. power lines, pylons, utility poles, and transformers), hindering the ability to reroute electricity through to other parts of the system. This is shown in the series of events that follows.

The series of events are informed by Table 3.0, which shows a summary of the data presented within this chapter. It is important to recognize that portions of this data are estimates and that some data is missing for certain categories on particular days. The table is separated into two categories; the first is *weather data*, which includes daily temperatures, wind speeds, and freezing rain totals complied by Environment Canada. The second category of data is displayed under *disruptions and responses*. This data looks at information as it relates to affected critical infrastructure systems and the governmental groups largely responsible for those infrastructure systems. This data is compiled from sources listed in Appendix A.

Table 3.0: Ice Storm progression in the Ottawa area from January 5, 1998 – January 11, 1998

	January						
	5	6	7	8	9	10	11
WEATHER DATA[1]							
Total precipitation (mm)	27.2	10.6	5.9	24.6	9.1	Trace amount	0
Temp – Max (°C)	-1.5	-0.1	-0.8	0.1	0.8	1.4	-5.4
Temp – Min (°C)	-9.9	-4.5	-5.9	-2.3	-4.3	-6.8	-13.9
Max wind Speed (km/h)	<31	No data	<31	35	No data	59	44
DISRUPTIONS & RESPONSES[2]							
Number of homes without power	>30,000 in eastern Ont. No data specific to only Ottawa	Estimated 30,000 in Ottawa >100,000 in National Capital Region (includes Ottawa and rural areas surrounding it)	Estimated 25,000 to 50,000 in Ottawa	50,000 to 60,000 in Ottawa Rural Regions around Ottawa: 7,500 in Gloucester and 10,000 in Nepean	122,300 in eastern Ont. No data specific to only Ottawa.	Ottawa mostly restored	Rural homes still w/out power
Estimated number of flight cancellations (Ottawa)	32	No Data	All flights cancelled	No Data	All flights cancelled/ Airport Closed	No Data	No Data
Federal employees ordered not to work	No Data	No Data	No Data	>6000	No Data	No Data	No Data
Accessibility of major highways	Open	Open	HWY 417 Complete closure	Partial HWY 417 & 416	HWY 417 Partial Closures	Open	Open
Number of armed forces deployed in Ottawa Region	0	0	0	0	1400	500	500
Number of hydro repair crews sent to Ottawa	0	No data	9 crews from Toronto	0	800	No data	No data

Information Sources:

(1) Weather data is from the Government of Canada's historical records taken at Ottawa MacDonald-Cartier Int'l Airport and can be found at http://climate.weather.gc.ca

(2) Data under 'disruptions and responses' are compiled from the list of sources in Appendix A.

Monday January 5, 1998

Freezing rain warning issued by Environment Canada with 16mm of precipitation expected.[3] *This day showed a mean temperature of -5.7°C, a total precipitation of 27.2mm, and wind speeds greater than 31km/h.*[4]

Beginning just after midnight, a storm moving in from the west arrived over the Ottawa-Carleton region eventually releasing a total of 24mm of freezing rain by the end of the day.[5] Surfaces in the area including trees, wires, transmission towers, telephone lines, roads, and sidewalks were coated in a layer of ice by the early morning hours. The accumulated ice load on trees caused branches to break off, some of which took down electrical lines suspended underneath or beside them. Other electrical lines broke under the weight of ice that had been building up on their surfaces. At 5:30 a.m. the first reports of power outages in the Ottawa-Carleton region came in from the Ottawa suburb of Gloucester.[6] In response, Gloucester Hydro had sent out repair crews to respond to the rash of power outages affecting 2000 of its customers. Although no power outage data pertaining only to Ottawa could be found, it is known that by the end of the first day of the Storm, greater than 30,000 homes across the entire eastern Ontario region were without power.[7]

The freezing rain had also covered all of the roads in the Ottawa-Carleton region as well as the two major highways that stretch across the region – Highway 416 (running north to south) and Highway 417 (running east to west). Both highways and most roads remained open

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[3] Murphy, R. (2009). *Leadership in Disaster: Learning for a Future with Global Climate Change*. Kingston: McGill-Queen's University Press.
[4] Each day's numerical weather data is compiled from Environment Canada historical records taken at Ottawa MacDonald-Cartier Int'l Airport by Environment Canada (see Environment Canada in Appendix A).
[5] Murphy, 2009.
[6] Atherton, T. (2008). The Great Ice Storm of '98. *The Ottawa Citizen*. Retrieved April 13, 2014 from http://www2.canada.com/ottawacitizen/features/icestorm/icestorm/index.html
[7] Murphy, 2009.

throughout the day but there was a noticeable increase in traffic congestion and in vehicular accidents.[8] Ottawa's MacDonald-Cartier International Airport cancelled 32 flights and flights that weren't cancelled were delayed while crews cleared the runways and de-iced the planes.[9] Trains were still running throughout the region and telephone service was largely unaffected at this time. For some people in the greater Ottawa area, the Storm up to this point is likely being perceived as a bad bout of freezing rain accompanied by the inconvenience of slower commutes and more difficult walking conditions. A search through local area newspapers written during this time reveals very little about the weather beyond its impact on such things as the slushy and poor skating conditions of the Rideau Canal.

Tuesday January 6, 1998

Environment Canada forecasts the Storm to continue throughout the day.[10] The day showed a mean temperature of -2.3°C and a total 10.6mm of freezing rain.[11] Wind speeds were negligible.

Despite Environment Canada's initial predictions about the Storm ending January 5, the freezing rains had continued over the Ottawa-Carleton region throughout most of January 6.[12] An additional 10.6mm fell over the region adding to the 24mm that had already fallen the day before. Murphy (2009) identifies the problem of a *positive feedback loop of freezing drizzle* that had begun to occur throughout the affected region. The ice that accumulated on surfaces the day before had effectively created a larger surface area for more ice to accumulate. This in

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[8] Bell, P. (1998, January 6). Ice storm batters region: Two die during vicious weather, which left icy blankets on road. *The Ottawa Citizen*.
[9] Boswell, R., Rogers, D., Ellis, G., Hughes, G., & Bell, P. (1998, January 7). In winter's icy grip: `Worst ice storm since 1986' leaves 100,000 people in the dark. *The Ottawa Citizen*. p. A1.
[10] Murphy, 2009.
[11] Environment Canada.
[12] Murphy, 2009.

turn created an exponential increase in the weight of ice on trees, electrical towers, and power lines. The result was an increasing number of power lines falling either because trees fell on them or because they could not support the added weight of the ice. The additional weight given to both the power lines and the fallen tree debris also meant that hydro poles and towers were also becoming increasingly susceptible to damage when an adjacent tree or connected line fell. So while hydro repair crews were sent to restore power to homes and businesses in one area, an increasing number of new areas were experiencing power outages as the day progressed.

By 8:00 a.m. 100,000 homes in the National Capital Region (NCR) had lost power.[13] It should be noted that this number includes not only the City of Ottawa but also municipalities surrounding the city as well as Gatineau which is located directly north of Ottawa in the province of Quebec. In the City of Ottawa, the number of customers without power hovered around the 30,000 mark as hydro crews were able to restore power for some while outages continued to occur elsewhere throughout the city.[14] This large jump in power loss from the day before is accredited mainly to the damage of two 115kV transmission lines that were providing portions of Ottawa with electricity.[15] Fortunately, these 115kV lines were not the only sources of electricity for the city. Ottawa's main source of power came from a 500kV feeder that was still operational.[16] The 115kV lines and a set of 230kV power lines both ran along a corridor from Cornwall up to Ottawa and along the Ottawa River to the city – directly under the Storm's

[13] Murphy, 2009 & Boswell et al., 1998.
[14] Murphy, 2009.
[15] Ibid.
[16] Information pertaining to Ottawa's 115-kV and 230-kV lines is derived from an interview in: Boswell, R. (1998, January 18). Hydro system was 'hanging by a thread': hydro officials admit they had no plan for disaster on scale of ice storm. *The Ottawa Citizen*. p. A1.

path. These 115 and 230kV lines were considered lower-voltage secondary transmission lines that would normally take on the extra energy load should the 500kV feeder become damaged. Unfortunately, with the loss of the 115kV lines, part of the backup system had been incapacitated. If the 230kV line were to be damaged leaving both sets of secondary transmission lines inoperable, the 500kV feeder would be the only thing preventing Ottawa from experiencing a complete blackout within its entire area.

Meanwhile, the freezing rain was continually adding ice to highways and roads across the region. Regional roads Manager Richard Scott reveals in the *Ottawa Citizen* that a crew of 111 employees were working double shifts just to keep up with salting (Boswell, 1998). Despite the best efforts of road crews, conditions were not good and driving was quickly becoming even more hazardous. This slowed down first responders like the Ottawa-Carleton ambulance service whose response times were being delayed trying to reach the growing numbers of injured pedestrians and drivers who had injured themselves on the slippery ice-coated surfaces.[17]

At this point in the series of events, individual municipalities like the City of Ottawa were responding independently to the non-electrical related problems like traffic congestion and individual’s injuring themselves. The city's fire department was kept busy with a series of house fires as people began using fireplaces that weren’t properly cleaned or had been unused for too long. A provincial response had not yet begun; however, regional staff were beginning to take notice of the Storm and offer assistance. For example, Ottawa-Carleton’s regional government began offering free hotel rooms to the more vulnerable low-income and elderly members of

[17] Boswell, 1998.

the region's population.[18] Moreover, any problems in electricity transmission, or lack thereof, were being dealt with separately by utility companies like Hydro Ontario or Ottawa Hydro. The differences between Hydro Ontario and the municipal hydro companies like Ottawa Hydro and Gloucester Hydro is that these smaller municipal companies extract their power from the larger Hydro Ontario power grid. The large electrical pylons that run through corridors from Cornwall to Ottawa carry a larger voltage capacity that each municipality feeds from.

Wednesday January 7, 1998

As a new ice storm approaches, forecasts predicted freezing rain to continue throughout the day and into the next.[19] Freezing rain accumulation was expected to total 28mm over the next several days.[20] The day showed a mean temperature of -3.4°C and a total precipitation of 5.9mm for the day; wind speeds would reach less than 31km/h.[21]

As the initial ice storm passed over the region, a brief absence of freezing rain occurred during the early morning hours of January 7.[22] During the lull in freezing rain, Environment Canada observed on their radar screens a massive storm front coming in from the Gulf of Mexico and at 4:28 a.m. promptly issued a warning that another storm was approaching with a new wave of freezing rain.[23] The day's cooler temperatures meant that this new wave of freezing rain was predicted to cover nearly everything in its path. The second ice storm arrived at approximately 10:00 a.m. and continued throughout the day with a brief pause between

[18] Ibid.
[19] Atherton, 2008.
[20] Murphy, 2009.
[21] Environment Canada Meteorological Data
[22] Environment Canada.
[23] Atherton, 2008.

roughly 12:00 p.m. and 3:00 p.m.[24] At 3:30 p.m. Environment Canada revised its original estimate of 28mm of freezing rain by storm's end to 40mm.[25]

With the unrelenting ice accumulation, electrical infrastructure was not faring well and hydro-transformers could be heard exploding throughout the region. Repair crews were working 16 hour shifts trying to restore power to homes and businesses but they simply could not keep up with the increasing number of fallen power lines.[26] In the City of Ottawa, the number of customers without electricity appears to have been anywhere from 20,000[27] to 50,000[28]. Although no specific number is confirmed, reports from various sources (i.e. Murphy, 2009 & Atherton, 2008) place the number at a point within the range of 25,000 to 50,000 customers. It may be that both the continued restorations and disruptions of Ottawa's electricity grid make it difficult to determine precisely how many customers were without power. Regardless, at this point in the Storm, officials from Ottawa Hydro informed the Ottawa-Carleton region's Emergency Measures Unit (EMU) that it was unsure of how quickly it could fully restore power to the city. Hydro officials suggested to the EMU that they begin to open shelters to house the growing number of people without electricity, and, as an added consequence of having no electricity, without heat (Murphy, 2009).

Over the previous 24 to 48 hours, some individual households and businesses, including gas stations, took the initiative of acquiring generators to keep the power on.[29] This was a crucial step for many gas stations in the region that were unable to pump fuel for the first few

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[24] Environment Canada.
[25] Murphy, 2009.
[26] Ibid.
[27] Ibid.
[28] Atherton, 2008.
[29] Purcell M. & Fyfe, S. (1998). *Queen's University Ice Storm '98 study: emergency preparedness and response issues*. Emergency Preparedness Canada, Ottawa.

days of the Storm. Indeed, with a lack of electricity and poor road conditions, the supply of fuel had become scarce, creating a fragile fuel infrastructure. The Ministry of Transportation (MTO), which had taken on the role of keeping the highways and roads open for the ever increasing emergency response, does not store its own fuel supply so they were extremely dependant on the same fragile and scarce fuel source as everyone else in the region.[30] Until gas stations could power up and resupply themselves, the ministry's fuel needs were maintained by patrols that passed near a working fuel source and by also scavenging fuel from unused equipment.[31]

Although road crews worked diligently to keep the region's two main highways clear, surface transportation had nevertheless deteriorated to such a point that the highways were completely covered in ice and extremely dangerous to traverse. The Ontario Provincial Police (OPP) ordered the complete closure of Highway 417 – an important route for commuters moving east and west across the City of Ottawa; especially during the middle of a work week.[32] According to Murphy (2009), at 11:00 p.m. municipal road crews from each end of the highway began barricading the on-ramps. At the same time as the road crews were working on closing the highway, MTO had its trucks salting it. It took the road crews until 4:00 a.m. to complete the closure of the highway; however, at the same time as the last barricades were put up, the ministry had finished coating the highway with salt and the crews were ordered to remove the barricades and reopen the highway in time for rush hour traffic.[33]

With the impacts of the Storm escalating, Ottawa Mayor, Jim Watson, under the authority of the Municipal Act declared the first ever state of emergency for the City. This

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[30] Ibid.
[31] Ibid.
[32] Murphy, 2009; Purcell & Fyfe, 1998; & Spears & Hill, 1998. [Spears, T. & Hill, M. (1998, January 8). Police close the Queensway. *The Ottawa Citizen*.]
[33] Murphy, 2009.

essentially gave City officials the ability to do, within the law, whatever was needed in order to respond to the Storm; it also activated the City's emergency plan. Ottawa was the first municipality in the region to declare an emergency, but most others in the region had begun doing so as well. Following the declaration, the city contacted regional officials to encourage them to also declare a state of emergency.[34] The viewpoint of the City at the time was that it would be sensible for the region to make such a declaration since the police worked under the responsibility of the region and because the Storm was affecting a geographic area larger than just Ottawa. In response, directors of the Regional Municipality of Ottawa-Carleton (RMOC) held a special meeting to debate the possibility of declaring a regional emergency. According to Murphy (2009), the region's Director of Emergency Planning was reluctant to declare a regional state of emergency since it would be harmful to the economy. Although no records could be found that suggest this view encouraged the delay in an official declaration, the meeting ended with an announcement to the media by Regional Chair Bob Chiarelli that any decision to declare an emergency would be deferred to the following day (January 8).[35]

While individual municipalities were beginning to declare states of emergency and the region was deciding whether to do the same, the province's emergency measures department, also referred to as Emergency Management Ontario (EMO), had already activated its own operations centre in Toronto and entered into an advanced monitoring stage.[36] This required that EMO form a duty team in which the duty operations manager would be informed by an individual municipality like Ottawa on the development of the emergency. Not only did the

[34] Boswell, R., Hughes, G., Rupert, J., Starnes, R., & Sutherland, S. (1998, January 8). On the edge of emergency. *The Ottawa Citizen*.
[35] Ibid.
[36] Ibbitson, J. (1998, January 9). What a whopper!!! storm of century: Ice, freezing rain . . . millions without heat: Harris accepts Chretien offer to send troops to help out in crisis. The Spectator, pp. C.1.FRO-C1 / FRONT.

operations manager have the job of providing guidance on the best time to declare an emergency, the manager also acted as a municipality's point of contact with the province's emergency organisation.[37] However, damage to electrical infrastructure as well as the collapse of telephone lines was affecting communication between Toronto, where EMO was located, and Ottawa, where the freezing rain was. To compensate for the unreliable and spotty phone service (long distance service had been cut for portions of the region's population), EMO would use ham radios when it could.[38] When ham radio wasn't an option, the OPP were called upon to deliver messages between EMO and the affected municipalities.[39] Eventually, in the upcoming days, the military would also take on the role of messenger.

Thursday January 8, 1998

On this day, Environment Canada forecasted a continuation of the ice storm with a prediction of 40km/h winds and 20mm to 30mm more of freezing rain before Friday.[40] Meteorological measurements for the day show a mean temperature of -1.1°C with 24.6mm of total precipitation and winds speeds of up to 35km/h.[41]

January 8, 1998 was a busy day for emergency responders, hydro-repair crews, and municipal and regional staff involved in coordinating a response to the unrelenting freezing rain. As Environment Canada had predicted a day earlier, the ice storm had remained over the Ottawa-Carleton Region. This second storm's power had originated when the hot, moist air of a southern storm that had moved from Texas to Kentucky, had collided with a cold air front that had moved in from the north (Murphy, 2009). The line between the cold and warm air masses

[37] Purcell & Fyfe, 1998.
[38] Ibid.
[39] Ibid.
[40] Atherton, 2008.
[41] Environment Canada Meteorological Data.

was located directly over the Ottawa-Montreal region, and as long as it stayed there the freezing rains were expected to continue.

Despite the attempts of hydro repair crews to keep up with the ever growing power outage, Ottawa Hydro officials realized at 4:00 a.m. that 50,000 homes in the city were without power.[42] At 4:30 a.m., shortly after Ottawa Hydro's realization about the state of electricity distribution in the city, officials from the Ottawa-Carleton region's EMU met at the regional headquarters to further discuss an emergency declaration.[43] By 5:00 a.m., while the meeting was underway, the number of customers in Ottawa without power increased by 10,000.[44] Place du Portage, Ottawa's largest federal office building, was one of these customers and as a result 6,000 government employees were sent home from work.[45] Rural regions outside of Ottawa were also experiencing large electrical blackouts. For Gloucester Hydro, this day marked the peak of their power outage numbers during the Storm with 7,500 of its customers without power.[46] At 10:30 a.m. Nepean Hydro had 10,000 of its customers without power.[47] By mid-day, two thirds of the electrical transmission capacity for the entire eastern Ontario region had been destroyed by wind and ice.[48]

As promised a day earlier, regional officials would decide on whether to declare a regional state of emergency, and at 10:00 a.m., Regional Chair Bob Chiarelli made that

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[42] Murphy, 2009.
[43] Ibid.
[44] Atherton, 2008.
[45] Duffy, A. (1998, January 9). [A state of emergency has been declared...]. *Postmedia News*. Canada, Don Mills, Ont.: Southam Publications Inc.
[46] Atherton, 2008.
[47] Ibid.
[48] Murphy, 2009.

declaration for the Ottawa-Carleton region.[49] This declaration of a state of emergency included Ottawa as well as ten other municipalities surrounding the city including: Kanata, Nepean, Gloucester, Orleans, Ottawa Valley, South Frontenac, Rideau Township, Stormont, Dundas, and Glengary. The declaration was meant to convey to the public the growing severity of the situation while also getting all non-essential services to shut down. It was also a means for reducing vehicular and pedestrian traffic – both of which had become dangerous leading to several deaths and multiple injuries.[50] This was probably welcome news for Ottawa's overburdened hospital since later in the evening at 9:20 p.m. they made an announcement that they no longer had available beds and were cancelling any scheduled elective surgeries.[51]

The declaration of a state of emergency in the Ottawa-Carleton region now allowed the region to request the help of the province. One of the Chair's first requests was that the military be brought in to aid hydro repair crews and to help clear highways and roads of tree debris and fallen electrical infrastructure.[52] Following organisational protocol, the City of Ottawa also made a direct request to EMO for military assistance.[53] In response, Federal Defence Minister Art Eggleton announced at the request of provincial Premier Mike Harris that soldiers would be dispatched to aid areas severely impacted by the Storm.[54] Meanwhile, Ottawa-Carleton Regional Police Chief Brian Ford put every available officer, including

[49] Duffy, 1998 & Murphy, 2009.
[50] Kirkey, S. (1998, January 9). Region on 'red alert' as firefighters, police are stretched to limit. *The Ottawa Citizen*.
[51] Murphy, 2009.
[52] Ibid.
[53] Dunn, M. (1998). Ice storm tightens grip on eastern Ontario. Canada, Toronto: *The Canadian Press*.
[54] Murphy, 2009 & Dunn, 1998.

undercover units, on duty or standby.[55] Much of the work done by these officers involved placing barricades around fallen electrical wires and trees to protect the public and give space to hydro-repair crews to work.

Several hours after the declaration of a state of emergency, the disruptions to electrical infrastructure grew even more severe when the risk of a complete electrical blackout for Ottawa had become a very real threat. Electrical infrastructure, in particular, the transmission pylons such as the ones used by the 115kV, 230kV, and 500kV lines, are sometimes protected by the use of 'skywires'.[56] These wires, which run along the tops of electrical pylons, are insulated to protect the infrastructure from lightning strikes. Because these wires are insulated, they don't produce any heat – heat that on other non-insulated lines would normally melt the frozen precipitation that fell on them. According to Murphy (2009), at 3:25 p.m. a skywire used to protect the twin 500kV power lines had begun to sag onto one of the lines. As a result, the line had become damaged and the electricity transfer that was being shared between the twin lines had to be transferred over to the one remaining line that worked. This was now the only line preventing Ottawa from a complete blackout.[57] The normal back-up lines – the 115kV line and the 230kV transmission line – had already become damaged during the last several days of the Storm. Eleanor Clitheroe, Executive Vice-President and Managing Director of Ontario Hydro had found out that the transmission system was in jeopardy and that a complete blackout in Ottawa was a very real threat.[58] She adds that at the time of the failure, any proper assessment regarding the state of the 500kV infrastructure was hindered by the

[55] Campbell, D. (1998, January 9). Ice storm leaves police lost for radio codes: situation anything but normal for police service. *The Ottawa Citizen*, pp. A.6.
[56] Murphy, 2009.
[57] Boswell, 1998.
[58] Ibid.

intensity of the Storm (Boswell, 1998). Until the freezing rains and high winds settled down, little could be done by the overworked hydro repair crews to address the problem. As reported by Boswell (1998) in *The Ottawa Citizen*, Ms. Clitheroe later admits that Ontario Hydro did not anticipate a storm of this magnitude and therefore did not have an adequate emergency plan in place.

Transportation infrastructure was also rapidly deteriorating by this point in the Storm. All trains arriving into the City or departing the City were cancelled and all roads and highways were in very poor condition.[59] Also, it continued to be difficult to procure fuel since many gas stations did not have electricity to run the pumps. Furthermore, stations with power were running out of fuel since it was in high demand to keep the growing numbers of generators running.[60] Over the previous days the demand for generators had grown tremendously. They were being used at such high frequency that reports were coming in to both the ministries and to EMO that generators hooked up to communications towers and fuel stations were faltering due to overuse.[61] The Ottawa-Carleton Region set up a special group to locate generators by any means; calls were made to unaffected cities in western and central Ontario, the federal government, and the military.[62] EMO also set up a group of coordinators to search for government departments and private corporations with available generators to lend out.[63] The coordinators would then place the owners of the generators in direct contact with a municipality in need – essentially creating a match service. During the evening hours, a hotline

[59] Dunn, 1998.
[60] Purcell & Fyfe, 1998.
[61] Purcell & Fyfe, 1998; & Murphy, 2009.
[62] Purcell & Fyfe, 1998.
[63] Purcell & Fyfe; & Murphy, 2009.

was created by the provincial government that could be used by people with generators who wanted to offer help.[64]

Although telephone and cell phone infrastructure was not nearly as crippled as the electrical infrastructure; service had become unreliable, at best. A cell phone tower was damaged at some point during the day and cellular service in Ottawa was completely unavailable for five straight hours.[65] Moreover, telephone lines and poles had been falling during the Storm which affected cell phone usage so that even with operational towers, cellular lines were being jammed with overuse. There was concern amongst both emergency response officials at EMO and the MTO that communication would be brought down, making for a more difficult coordinated response to the Storm.[66] For instance, EMO had begun having difficulty finding out what was really happening in the Ottawa region. This was not only due to the inconsistent phone service but also because recent amalgamations in Toronto had changed the structure and hierarchy of the response organization so that EMO had difficulty procuring the appropriate names and contact numbers of people who knew what was happening. From that day forward, EMO was quite dependant on the OPP and the military to deliver messages. This break in communication between EMO in Toronto and the storm-affected municipalities of the Ottawa-Carleton region is perhaps best realized when Murphy (2009) claims that it was at this time during the Storm, amongst multiple declarations of a state of emergency, and the decision to create a military response role that EMO didn't yet believe that a provincial emergency had been occurring.

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[64] Dunn, 1998.
[65] Murphy, 2009.
[66] Mackie, R. (1998, January 10). Losing battle, Ontario Hydro says troops arrive to reinforce relief efforts as eastern Ontario struggles through blackouts. *The Globe and Mail*, p. A.7.

Friday January 9, 1998

The day's mean temperature was -1.8°C with 15.8mm of total precipitation.[67] *A wind speed measurement for the day is not available. The freezing rain has now damaged many automatic weather stations and disrupted communication between some meteorological centres.*[68]

This day marks the point during the Storm where the previous day's calls for resources began to arrive. According to Murphy (2009), at 8:30 a.m. 2000 soldiers from Canadian Forces Base Petawawa began arriving in waves into Ottawa. The military had defined its role during the Ice Storm as one of supporting local authorities (rather than replacing them), and as such, upon arriving, they were sent out from Ottawa to the most devastated areas in and around the region.[69] In addition to the military arriving to help, also 100 OPP and 800 Ontario Hydro linemen were transferred to the region to provide assistance.[70] Solicitor General Bob Runciman also arrived in Ottawa to coordinate assistance from the provincial level.[71] The provincial response had been occurring through the various Ontario ministries; for example, the Ministry of Natural Resources (MNR), the Ministry of Agriculture (MOA), the Ministry of Health (MOH). and the MTO. Throughout the day, the MTO managed to get much needed chainsaws, heaters, and portable radios to response crews.[72] They also worked with the military to set up a basecamp to accommodate hydro workers. Having been without electricity for several days, the livelihoods of rural dairy farmers in the region had become increasingly vulnerable as large numbers of cattle could no longer be mechanically milked, leading to infection and death in the

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[67] Despite freezing rain damage to meteorological instruments in Ottawa, Environment Canada archives still show temperature and precipitation totals for the day.
[68] Murphy, 2009.
[69] Ibid.
[70] Morris, J. (1998). Ice storm begins to chill spirits [in Ontario]. Canada, Toronto: *The Canadian Press*.
[71] Foot, R., & Ibbitson, J. (1998, January 9). [Provincial aid floods into eastern Ontario, gripped …] Southam Newspapers, Don Mills, Ontario: *CanWest News*.
[72] Purcell & Fyfe, 1998.

animals. The MOA was making an effort to find generators for the 2000 dairy farmers affected by the Storm (Murphy, 2009). This effort was likely drawing on the understanding that even when power would be restored, it would happen in urban areas first; rural farming areas would not likely get power back for quite some time.

Despite the best efforts of Ontario Hydro repair crews, power outages were still increasing as the freezing rains continued. According to Murphy (2009), lines were still falling faster than they could be repaired and 60 Ontario Hydro towers had been damaged by this point in the Storm. He adds that without an appropriate emergency plan that would help govern an appropriate crew rotation for this type of event, it was becoming evident that line crews were becoming severely overworked (Murphy, 2009). At this point during the Storm, numerous articles discussing the extreme work conditions experienced by hydro repairmen were beginning to appear in local newspapers like *The Ottawa Citizen* (i.e. Spears, 1998; Petricevic, 1998a). Although losses in power continued to outweigh the gains made by the repair crews, a brief lull in the freezing rain during the early morning hours allowed Ontario Hydro enough time to repair a transmission line running through Arnprior into southern Nepean.[73] This repair helped restore power to 10,000 Nepean Hydro customers.[74]

By this date, 400 generators had been delivered across eastern Ontario and more were expected to arrive.[75] For example, fifty gas generators were being stored at Toronto's Pearson International Airport until they could be shipped to affected areas across eastern Ontario.[76] EMO had been receiving calls from unaffected municipalities who were ready to offer

[73] Smith, S. & Uncles A. (1998, January 10). A day in the life of an ice-bound emergency. *The Ottawa Citizen*.
[74] Ibid.
[75] Murphy, 2009; Foot & Ibbitson, 1998.
[76] Foot & Ibbitson, 1998.

assistance and generators.[77] To avoid overwhelming the response staff and to help keep roads clear, Premier Mike Harris used the media to tell people to stay out of the region and to not send aid until it was requested.[78] Moreover, the OPP had once again closed sections of Highway 417 because of the increasingly dangerous driving conditions, and Ottawa's airport and train station closed their doors until conditions improved.[79] Whether or not it was from the Storm or Harris' announcement, there had been, according to Murphy (2009), a significant decrease in road traffic throughout the Ottawa-Carleton region to one-third of the use from the previous day.

Telephone service in the region remained inconsistent and at 11:30 a.m. thousands of AT&T customers were without long distance service.[80] Despite this disruption however, the service was proving to be much more reliable than the electricity grid even though accumulating ice was bringing down both telephone wires and electrical wires. The telephone service, still dependant on electricity, was being sustained by batteries in the remotes that serve each area with phone service.[81] Although the batteries would only last for five hours at a time, the phone companies had been able to get generators to most of the remotes since the Storm began affecting the electricity grid.[82] The telephone system is also a decentralised system, meaning in the event that the phone company could not get a generator to a remote, it would only affect service for a small area.[83]

[77] Purcell & Fyfe, 1998.
[78] Foot & Ibbitson, 1998.
[79] Bertin, O. (1998, January 10). Ice grounds most planes, trains and passengers. *The Globe and Mail*, p. B.3.
[80] Murphy, 2009.
[81] Ibid.
[82] Ibid.
[83] Ibid.

The increased use of generators by homes, businesses, dairy farmers, and CIs such as water pumping stations, fuel stations, and telephone service was using up fuel quickly and more gas stations were running out, making it more difficult to acquire. Also, with the highways partially closed and dangerous to traverse, bringing in fuel to refill the gas stations in the region was difficult. Regardless, EMO was prioritizing getting generators to the Ottawa-Carleton region. One way of doing this was through the use of 'twinning', where an affected municipality is matched up with an unaffected municipality that could offer help and generators.[84] EMO twinned Ottawa with Durham Region, located on the east end of Toronto.

According to Murphy (2009), when the Regional Chair had declared a state of emergency on Thursday, it had been expected to be lifted by Saturday. However, as an indication of how badly things had been progressing to this point, Bob Chiarelli announced at 3:00 p.m. that the state of emergency would be extended indefinitely. Shortly after, at 5:40 p.m., the freezing rain over the Ottawa-Carleton Region stopped abruptly and Environment Canada ended its warnings (Murphy, 2009).

Saturday January 10, 1998

Environment Canada has ended its freezing rain warning; however, a cold Arctic air mass is approaching the region with colder temperatures forecasted.[85] The day has a mean temperature of -2.7^{o}C, trace amounts of precipitation, and wind speeds of up to 59km/h.[86]

The freezing rain had ended but colder temperatures were expected over the next few days. The City of Ottawa had its electricity restored on this day; however, the grid was still severely damaged for rural areas outside of Ottawa, leaving many in those communities with

[84] Purcell & Fyfe, 1998.
[85] Murphy, 2009.
[86] Environment Canada Meteorological Data.

neither electricity nor heat. According to Murphy (2009), these residents were told that they would have to wait at least ten more days until power could be restored. Except for Highway 417, which runs through the City of Ottawa, Highway 401 and Highway 416 was still largely deserted except for long lines of military convoys.[87] The rural-urban divide was starting to show itself and more rural communities like Ottawa Valley were completely cut off with no passable roads, no telephone or cellular service, no electricity, and no access to water wells.[88] To keep emergency communication in those municipalities intact, the province sent out working satellite telephones.[89] The MNR continued to loan out equipment such as trucks and backhoes while General Rick Hillier directed 500 troops to assist the residents of Ottawa Valley.[90]

Sunday January 11, 1998

The day is cloudy with clear periods.[91] Temperatures have dropped to -9.7°C and wind speeds fall slightly to 44km/h.[92]

This day marked the point when hydro repair crews began making gains in restoring electricity to the region.[93] Repair crews had left Ottawa and were moving towards rural areas where thousands were still without power.[94] The 115kV transmission system was still damaged and unable to supply power to those areas south of Ottawa including: Gloucester, Greely,

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[87] Murphy, 2009.
[88] Duffy, 1998, January 10.
[89] Purcell & Fyfe, 1998.
[90] Duffy, 1998, January 10.
[91] Atherton, 2008.
[92] Environment Canada Meteorological Data
[93] Ayed, N. (1998, January 11). Rural eastern Ontario new focus of ice storm battle. Canada, Toronto: *The Canadian Press*.
[94] Ibid.

Russell, Manotick, and Nepean.[95] The worst hit area for pole damage was the rural community of Vankleek Hill; 90 percent of this community of 34,000 was still without power.[96] On this day, there were 1000 hydro workers in the Ottawa-Carleton Region working on restoring power.[97] Transportation had greatly improved by this point and roads and highways were being reported as nearing normality.[98] Fire crews were delayed for most of the day while responding to the many fire alarms being triggered throughout the city as power was being restored.[99]

According to Murphy (2009), EMO finally realized on this day the total impact of the Ice Storm. In previous days, EMO had not known that the reported number of customers without electricity was only those of Ontario Hydro. In their updates to EMO, the hydro company had not been including those customers belonging to the other 45 utilities that bought electricity from Ontario Hydro.[100] This made conditions seem much less severe than they had been and when the numbers were sorted out it was realized that the overall number of customers in eastern Ontario without power had actually been 700,000.[101]

January 12 to January 26, 1998

At 6:00 a.m. on January 12, Ontario Hydro reported that 85,000 homes in eastern Ontario were still without power, including 11,000 in Rideau Township and almost every home in Osgoode Township.[102] Ottawa Hydro reported that 15,000 of its customers were still without

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[95] Boswell, R. & McIntosh A. (1998, January 11). Black out far from over in rural areas. *The Ottawa Citizen*.
[96] Ibid.
[97] Ibid.
[98] Rupert, J. (1998, January 11). Driving conditions easier, for now. *The Ottawa Citizen*, p. A.5.
[99] Ibid.
[100] Murphy, 2009.
[101] Ibid.
[102] Atherton, 2008.

power.[103] EMO decided that this day was the right time to encourage a return to normal supply processes and so the ministries were contacted with a request to begin resupplying eastern Ontario.[104]

On January 13 the Federal Government in Ottawa reopened its offices and at 3:30 p.m. the regional government of Ottawa-Carleton announced the end of the state of emergency for urban areas; however, the emergency declaration was being maintained for rural municipalities outside of the City of Ottawa.[105] Through local media outlets the Chair of Ontario Hydro and the provincial energy minister made a formal apology for the utility's poor communications during the Storm.[106] On January 15 all levels of government began focusing on monetary compensation for those affected by the Storm; particularly for rural dairy farmers.[107] Finally, on January 26 the last community in eastern Ontario without power – Ste. Anne de Prescott – was connected back into the power grid.[108]

Summary Remarks

What this series of events highlight is a back and forth struggle between emergency managers, who were trying to maintain operations in CI, and the freezing rain, which continued to disrupt this infrastructure. Clearly, critical infrastructure stakeholders such as MTO and Ottawa Hydro could not make gains in restoration while the freezing rain continued. Yet, even after the freezing rain had ended on January 9, electrical disruptions were still present, particularly in rural areas surrounding Ottawa. Most importantly, this shows that the 1998 Ice

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[103] Ibid.
[104] Purcell & Fyfe, 1998.
[105] Atherton, 1998.
[106] Murphy, 2009.
[107] Brown, J. (1998). Ottawa looks for ways to aid storm victims [ice storm in eastern Ontario and Quebec]. Canada, Toronto: *The Canadian Press*.
[108] Atherton, 2008.

Storm disaster had begun as a natural hazard but that the disaster had ended as a technological hazard. This sets the context for the next chapter of this thesis where Actor-Network Theory is used to help explain the transformation from a natural disaster to a technological disaster, and the role that cascading failure had in this.

Chapter 4: Interpreting the Ice Storm and Tracing the Cascading Failure

The prolonged freezing rains of the 1998 Ice Storm adversely impacted infrastructure systems across the Ottawa-Carleton region leading to one of the largest and most expensive disasters in Canadian history (Lecomte et al., 1998; Murphy, 2009; & RMS, 2008). This chapter is an interpretation of those events through the lens of an Actor-Network Theory (ANT). It is a tracing of the failures that occurred in Ottawa's critical infrastructure (CI) as a result of the freezing rain produced by the Storm; the purpose of which is to identify how these failures were able to cascade from one actor to another. Important to this chapter are concepts derived from ANT including the idea of *translation* and the concept of *intermediaries*. Callon (1986), who is one of the primary individuals credited with the development of ANT, writes that,

> *Translation is a definition of roles, a distribution of roles and the delineation of a scenario. It speaks for others but in its own language. It is an initial definition. But ... no translation can be taken for granted for it does not occur without resistance* (Callon, 1986, p.26).

Translation in ANT is about the formation of networks – it is ANT in practice. It involves identifying actors, their roles, and the type of relationships they have with other actors, and how this all works towards a stable (or unstable) network. This chapter is a translation of the Ice Storm because it identifies the primary actors of the study – electricity, communications, transportation infrastructure, and freezing rain – and their roles and impact not only on other smaller actors, but also on the network of study. In doing so, this chapter places limits on the network of study by establishing visible boundaries, particularly needed because in ANT, a single network could be infinite. Thus, it is important to note that this is a modified version of

ANT that utilizes a chosen set of core principles. As some critics and users of ANT attest to, adopting this theory in its true form is arguably either too difficult or not entirely possible to achieve in research.

Intermediaries are the second key notion of ANT used in this chapter to help describe the connections between actors. Simply put, intermediaries are what draw actors into the relationships that exist between them. Callon (1991) writes that, "an intermediary is anything passing between actors which defines the relationship between them" (Callon, 1991, p.134). As the connection that exists between actors, Callon (1991) states that intermediaries can include but are not limited to: action, technical artifacts, an inscription (i.e. writings), money, and human beings (including the skills and knowledge that they incorporate). Through the principles of generalised symmetry and equal agency amongst actors in a network, intermediaries can also be given the status of actors and vice-a-versa. Overall, as a contributing concept to this chapter, intermediaries provide for a more precise identification and description of how a cascading failure flows through a network by allowing the network to take form or shape. As Callon (1991) states, these intermediaries, "describe their networks in the literary sense of the term. And they compose them by giving them form" (Callon, 1991, p.135).

This chapter is structured around a series of diagrams that describe the level of disruption freezing rain had caused to several of Ottawa's CIs. The diagrams focus on four primary actors including freezing rain, electricity infrastructure, transportation infrastructure, and communications infrastructure. As primary actors, these are the network builders that are followed. It is through their perspective from which it is possible to interpret the network construction. This is essentially the opening of Latour's (2005) metaphorical black box. In ANT-based research any actor can become primary for any number of reasons; however, this thesis focuses on these four as they are judged to be the most visible actors involved in Ottawa's Ice Storm failure.

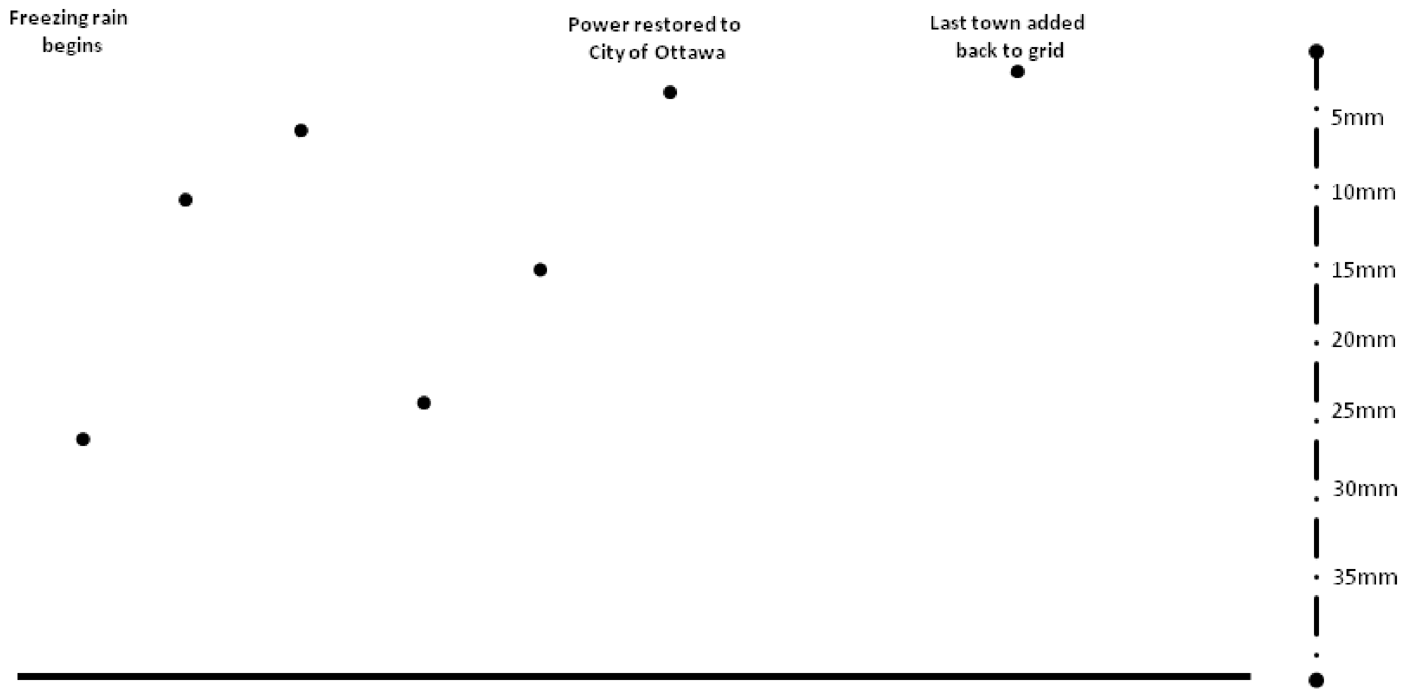
At this point, it is important to clarify how each diagram works for this chapter. Placed at the beginning of each section is a diagram. There are four diagrams in total, each of which depicts a specific network-actor including: the freezing rain, electricity infrastructure, transportation infrastructure, and communication infrastructure. To be clear, these diagrams are primarily concerned with infrastructure located in and immediately around Ottawa. The area outlined in red in Figure 1.0 in Chapter 1 is a rough representation of the scope for these diagrams. However, due to the sheer extent of the Storm, and the interconnected nature of infrastructure, the boundaries presented here must sometimes be expanded in the analysis in accordance with the data gathered. For example, the analysis on the disruption to electricity infrastructure will sometimes include data representative of the province and/or the Ottawa-Carleton region, both of which maintain a much larger scope than the City of Ottawa.

4.1 The Freezing Rain

Hewitt (1997) states that the hazardousness of an ice storm is largely derived from the total amount of freezing rain produced. Ice that accumulates on surfaces can overburden exposed infrastructure leading to damage and disruption of services provided. With the constant and prolonged bouts of freezing rain during the 1998 Ice Storm, electrical infrastructure in the Ottawa region was heavily damaged; highways had become dangerous and impassable; and maintaining communication within the region and beyond was unreliable at the best of times. As a source for the impending cascading failure, it is necessary to include the

Ice Storm as an actor within the disaster network. Thus, as a beginning point for an analysis of the cascading failure, Figure 4.0 presents the total daily precipitation as freezing rain between January 5 and January 26. An analysis of this diagram helps to unravel the association that exists between the freezing rain and the built-environment. This is also an opportunity to set out those things that are significant in relation to the freezing rain specifically. It should be noted that the recorded totals as taken from Environment Canada's archives may in some instances include trace amounts of non-freezing rain precipitation such as snow and liquid rain. However, as these are only trace amounts they are insignificant in measurement and have no impact on identifying and analysing those trends depicted in the diagram.

Figure 4.0 Ice Storm daily precipitation totals in Ottawa from January 5 to January 12 1998



Date	Jan-5	Jan-6	Jan-7	Jan-8	Jan-9	Jan-10	Jan-11	Jan-12 ... Jan-26
Total Precipitation for Ottawa (mm)	27.2	10.6	5.9	24.6	15.8	Trace Amnt.	Trace Amnt.	Trace Amnt.

Of the more noticeable trends in Figure 4.0 are the two days during the Storm (January 5 and January 8) where freezing rain daily totals peak roughly around the 25mm mark. These two peaks coincide with the two separate waves of freezing rain that made up the totality of the ice storm, and as is discussed in subsequent sections, are influential in both initiating and maintaining the cascading failure. The second wave of precipitation produced a slightly lower total amount of freezing rain but the consequences were quite severe because of the damage already done during the first wave on January 5. As was discussed in Chapter 3, by the end of the first wave of freezing rain on January 7, the emergency response had become active at both a municipal and provincial level and hydro crews across eastern Ontario were busy restoring power to large portions of the region. The second wave on January 8 added an even greater burden to the response initiative, hindering the time to recovery while creating greater opportunity in both time and space for the cascading failure to spread.

Another point of interest taken from Figure 4.0 is the link between when the final wave of freezing rain ceased and the time the City of Ottawa recovered from the power outage. Friday January 9 was the last day for any significant amount of freezing rain and only trace amounts of precipitation were recorded in the following days. Although the freezing rains ended on January 9, hydro crews were only able to restore most of Ottawa's power on the following day. Chapter 3 described how the hydro repair crews were unable to keep pace with the damage being caused by the Storm and Figure 4.0 reiterates this by showing that it took a day of little to no freezing rain to restore power back to the city. However, it is insufficient at this point in the analysis to suggest that the freezing rain is the sole reason for a lag in recovery. Other factors such as the influence of additional infrastructure and infrastructure subsystem failures, or the cascading failure as a whole, must also be considered. Subsequent chapter sections will build upon this through separate analysis of individual network actors.

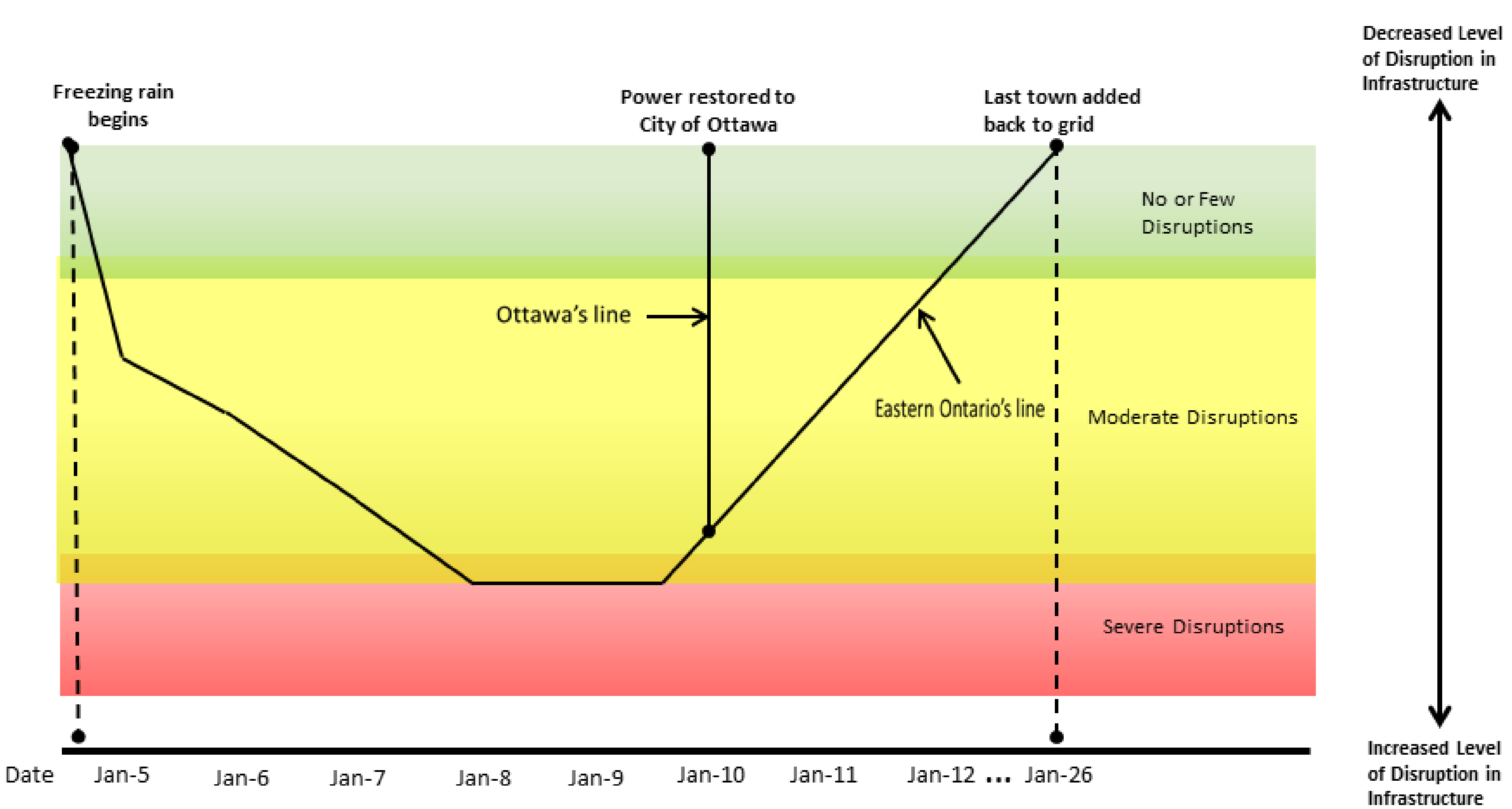
Summary Remarks

Consideration must be given to those associations that exist between freezing rain, people, and the built-environment; associations that are revealed only by their importance in relation to the cascading failure of the 1998 Ice Storm. By removing electrical, transportation, and communication infrastructure from the ice storm scenario, the freezing rain itself does not maintain the same degree of hazardousness for people as it does with these systems in place. Other hazard types such as volcanoes, lightning strikes, tornadoes, and forest fires, through their own physical force, can directly harm an individual or many individuals. Freezing rain, however, poses little to no significant danger to individuals directly. Temperatures, although cold during an ice storm, tend to hover just below the freezing mark making exposure less risky compared to hazards that exhibit extremely cold temperatures such as blizzards. Murphy (2009) highlights this fact with a discussion about Mennonite communities that do not use electricity and who also experienced the 1998 Ice Storm. These communities, which do not rely on electricity and other infrastructure in the same way as large urban centres such as Ottawa do, were far less affected by the freezing rain. This is largely because these communities are not organized around the same types of infrastructure that urban dwellers are accustomed to. Indeed, it appears that separating people from a dependency on modern infrastructure weakens the hazardousness of an ice storm; however, given the nature of the relationship between people and infrastructure, and the deeply engrained organization of modern urban societies, this separation is neither practical nor likely to occur.

4.2 Electricity Infrastructure

Today's modern cities maintain a constant supply of electricity in order to meet the demands of households, businesses, and other infrastructure systems. Failure to meet this demand can have consequences in both predictable and unpredictable terms. During the 1998 Ice Storm, electricity supply had been adversely affected in eastern Ontario including the City of Ottawa. Figure 4.1 uses a line (termed the *disruption line*) to show the degree of disruption to Ottawa's electricity infrastructure during the 1998 Ice Storm. The green zone across the top of the figure represents periods of no or few disruptions in electricity output whereas the red zone located across the bottom represents severe disruption in the network. The yellow zone in the middle, which the majority of the electricity disruption line moves, shows moderate disruptions. Overall, the line's movement up or down represents a decreased or increased level of disruption in the infrastructure system. Subsequent diagrams in the following sections of this chapter also incorporate this exact format with variations in the disruption line between individual infrastructures.

Figure 4.1 Electricity Infrastructure Disruptions during the 1998 Ice Storm



Notes:

1) The line depicted in this diagram is an amalgam of actual data (i.e. number of outages) and subjective assessments of accumulating disruptions and restorations to infrastructure. The line illustrates general trend changes as do the lines represented in Figures 4.2 through 4.6.

The disruption line used in Figure 4.1 represents the state of electricity transmission throughout the City of Ottawa. However, there are several days during the Storm in which available data regarding the exact number of Ottawa customers who lost power had significant gaps. Much of the reporting for which customers went without power had been done by Ontario Hydro; however, Ottawa Hydro would have reported a different number for its own customers in Ottawa. It is essentially a problem of multiple organizations releasing different estimates with no clarification or sharing of information (Murphy, 2009). Moreover, with hydro workers working to lessen the number of people without electricity; and, with freezing rain creating new numbers of people without electricity, it is difficult to get a precise daily estimation of customers without power. To compensate for these gaps, Ottawa's power outage numbers are considered in combination with numbers gathered at different regional scales such as eastern Ontario and the National Capital Region (i.e. Ottawa and its outlying communities). To be clear, educated assumptions about the state of Ottawa's electricity distribution needed to be made; this is in part why the disruption line is subjective.

Although the movement of the disruption line in Figure 4.1 is based on a combination of mixed data related to Ottawa and outlying areas, this negates neither the analysis conducted herein nor how the movement of the disruption line is determined. With ANT, components tied to electricity infrastructure and that comprise its network become visible from the failures that occur during the Storm. These parts can include damaged power lines, the activities of hydro workers, or the number of people in Ottawa without power. It is from these parts that a subjective interpretation of the disruption in Ottawa's electrical infrastructure is made. The data itself is used in this respect to help identify in an infinitely complex actor-network those crucial points during the disaster where an infrastructure failure is most visible.

The progression of the disruption line in Figure 4.1 is largely derived from both the total population affected by the power outage and the extent of damage to components that form the energy distribution network. In other words, this line speculates to the degree to which electricity infrastructure in Ottawa has been disrupted by the Storm. The number of people without power provides a representation of how damaged the system has become. The significance of certain mechanical and non-mechanical components within the infrastructure such as the actions of hydro workers or damage to large capacity transmission lines helps in this speculation. Overall, this is an example of how ANT is used to narrow in on a particular component that reveals itself during a failure.

To begin with, there are three significant movements within the disruption line for Figure 4.1. First, between January 5 and January 8 the line moves downward showing an increased disruption for electrical infrastructure in Ottawa and the region. Second, January 8 and January 9 are the two days during the Storm where the disruption was at its most severe, and third, the disruption steadily decreases from January 10 and onward. A more in-depth narrative that focuses on these three movement trends will help clarify the state of electricity transmission and distribution for Ottawa throughout the duration of the Ice Storm.

When the freezing rain begins on January 5 the disruption line moves abruptly in Figure 4.1 from the green zone of no or few disruptions to the yellow zone of moderate disruptions. This abrupt change signifies the inability of the electricity grid to resist significant disruptions in services. During the first day of the Storm, smaller more localized components of the electrical network (i.e. transformers and utility poles) had become damaged first; whereas the larger components that carry a bigger capacity of electricity to a greater number of people (i.e. energy pylons and large kilovolt transmission lines) had for the most part made it through the first day of the Storm intact, albeit weakened by a larger burden of ice accumulation. With over 30,000 customers in eastern Ontario being affected there is evidence that the grid had, by day one of the Storm, been damaged beyond an ability to adequately reroute power to affected areas. Such damage would ultimately persist throughout the duration of the Storm, but for the first day, the result in Figure 4.1 is an abrupt movement from few disruptions towards moderate disruptions in energy infrastructure.

By January 6 larger components of the electricity grid such as the two 115kV transmission lines feeding power into Ottawa had become damaged. The overall robustness of the energy grid is taken into question when the loss of these two transmission lines means there are fewer avenues for power to be rerouted. Moreover, this in combination with the growing number of utility poles and low capacity transmission lines being damaged explains the sudden increase of power outages in the National Capital Region (NCR). More than 100,000 customers in the NCR were without power at the beginning of the day and an additional 30,000 were added by day's end. Taking into consideration the fact that hydro crews were working full-time to restore power, this is likely a significant increase from the day before. It should be noted, however, that between January 5 and January 6, the differences concerning the scale of the power outage data presented in Table 3.0 in Chapter 3 means that certain assumptions must be made regarding an increase in the disruption line. For example, the line increases by taking into consideration Ottawa's total population. During the Ice Storm, Ottawa-Carleton region had a total population of 730,000[109] people. 30,000 customers in the entire eastern Ontario region lost power on the first day (January 5) of the Storm; a significant increase in power disruption is visible when the scale of the data shrinks and the values in the data increase. For example, the data scale shrinks from a higher population to a lower population (i.e. from eastern Ontario to Ottawa Region) and the data value increases (from 30,000 to over 100,000). At a smaller, less populated regional scale, the number of customers without power climbs from January 5 to January 6. Thus, the larger assumption to be made is that with these 100,000 customers in Ottawa-Carleton Region, 30,000 of which dwell in Ottawa, a significant increase in power disruption had occurred.

Disruptions increase yet again on January 7 with continued breakages in the components that make up energy producing infrastructure and with the additional numbers of hydro customers losing power. Ottawa Hydro's continuing efforts to restore power combined with the continued breakages make it difficult to decipher an exact number of customers who lose power on this day. For example, newspapers often reported that some number of customers would have their power restored while an equal or greater number would lose power on the same day. Based on data described in Chapter 3, between 20,000 to 50,000 customers in the City of Ottawa were, at any given time during the day, living without electricity. Following January 7, this number appears to remain consistent throughout the remainder of the Storm with fluctuations on both higher and lower ends. It may be a modest number when taking into consideration the hundreds of thousands of people in the city who still had electricity. Yet, the constant fluctuation in which thousands would regain power and

[109] Population totals are taken from a 1996 Canadian Census and include those communities that have since amalgamated with the City of Ottawa (City of Ottawa, 2013).

thousands more would lose power shows that repair to the system had not yet exceeded new points of damage. The fact that ice induced breakages were keeping hydro workers on 16-hour shifts[110] and that these workers were still unable to outpace new damage being caused to the grid shows an increase in the degree of disruption to this infrastructure. Figure 4.1 represents this with a movement towards the red area where a severe disruption occurs while still remaining within the moderate yellow zone.

Figure 4.1 shows that by January 8 the disruption to Ottawa's energy infrastructure had entered into a much higher severity level. This increase in disruption is representative of the loss of one of two major transmission lines that made up nearly the entire electricity supply for the City of Ottawa. This meant that Ottawa had been one significant breakage away from a complete electrical blackout. Adding to the intensity of the situation, the last remaining transmission line was at risk of being damaged in the same way as the first, leaving Ottawa residents in a highly vulnerable position for the next three days until it was resolved. Despite the apparent severity of the situation the disruption line in Figure 4.1 does not fully enter into a zone of severe disruption but rather hovers just above it and stays this way until January 10 when the larger threat is resolved. It could be argued that the loss of such an important transmission line may, in its own right, qualify as a severe disruption to Ottawa's electrical infrastructure. However, points regarding the unaffected portions of electricity supply to Ottawa and the overall robustness of the electricity grid should also be taken into consideration. For example, although the damaged line reduced the robustness of the network and increased the risk of Ottawa losing all power the fact remains that the back-up line was still

[110] This is according to Murphy, 2009.

functioning and never actually failed. In this respect, an ability to reroute power from damaged lines protected the city from a more severe power disruption, with the result being that the majority of Ottawa's residents still had access to electricity. An important distinction is made here with regards to the way people were losing power in Ottawa. It was not the major transmission pathways that were creating the most trouble for Ottawa, though for the rest of eastern Ontario this may not have been the case. Instead, it had primarily been the smaller components of the city's electricity grid; broken utility poles, exploded transformers, and smaller localized power lines brought down by trees had been the major point of failure in the system.

A unique characteristic in the electricity infrastructure's disruption line is its continual and steady movement downward (from few to moderate to almost severe disruption) from January 5 to January 8. There are no plateaus marked by sharp drops, just a continual worsening in the state of electricity transmission and distribution. This represents two forces working in opposition of each other to which one force maintained a steady but unbroken edge. Each day of the Ice Storm brought more damage to power lines, utility poles, and other components that aid in the transmission and distribution of Ottawa's electricity. One of the more visible forces counteracting this damage was hydro repair crews. As the damage increased daily, the number of people and hours needed to make repairs also increased to the point that on January 9 roughly 800 Ontario Hydro employees are transferred to eastern Ontario. It is unknown how many of these 800, if any at all, were needed directly in Ottawa by this point in the Storm. The point to make from this is that there were no days during the Storm that restoration maintained pace with disruption; hence, no visible plateaus in the progression of the disruption line from January 5 to January 8. There is however a plateau from January 8 to January 9, but this is not because disruption was being matched by restoration efforts. This plateau exists because there is no concrete data regarding the state of electricity distribution in Ottawa for January 9. What is known is that the military had been called in to Ottawa and one of their tasks was to help clear debris so that Hydro crews could continue with repairs. Thus, without the sufficient data to support a change in the disruption to Ottawa's electricity infrastructure, the line in Figure 4.1 remains constant from January 8 to January 9.

Just one day after the freezing rain ended in Ottawa, the city had nearly all of its power restored and Figure 4.1 shows this with an upward line movement away from the red disruption zone. Although Ottawa's power had been nearly restored, rural areas outside of the City, some of which were being serviced by Ottawa Hydro, were still experiencing moderate to severe disruptions. This is represented in Figure 4.1 where the disruption line splits, separating Ottawa from Eastern Ontario. Although it is not known precisely when Ottawa Hydro's last customer had power restored, it is known that on January 26 Ontario Hydro had restored all power and that the last community affected in eastern Ontario was added back into the grid.

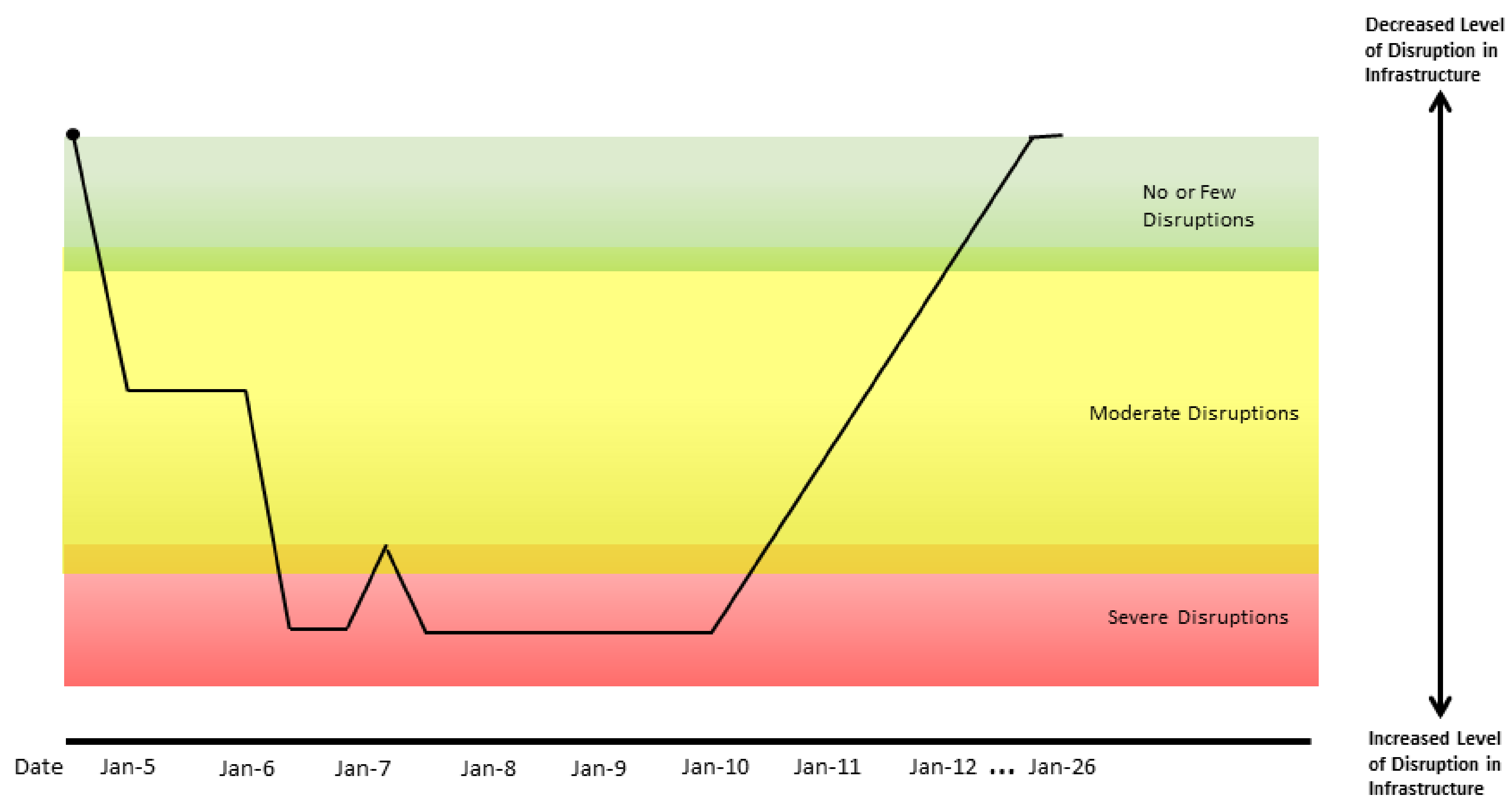
Summary Remarks

The electricity disruption that occurred as a result of the Ice Storm has already been engrained in Ottawa society as a defining characteristic of the disaster. Moreover, the validity and role of electricity infrastructure as a primary actor to this thesis has been clearly set-out in this section. This section has described how the disruptions occurred within this particular infrastructure and through its own lens, as is preferred when using ANT. The consequences and risks associated with the type of electrical disruption experienced during the Ice Storm and described in this section are far reaching. The power failure impacted work related operations in both the public and private sectors. Between January 8 and 9 over 6,000 Federal employees in Ottawa were sent home because of power outages. Also, damaged mechanical components in the infrastructure created debris such as live wires that would pose significant threat to individuals whom they came into contact with. And of course, people were affected in their own homes when no electricity often meant there would be no heat. One of the largest threats to the public during the Ice Storm, outside of driving on slippery debris covered roads, was carbon monoxide poising; an outcome derived from people seeking alternative forms of heat such as from blocked fireplaces and incorrectly placed generators.

4.3 Transportation Infrastructure

The transportation infrastructure diagram in Figure 4.2 contains a line showing the degree of disruption to Ottawa's transportation infrastructure during the Ice Storm. As its own network, transportation infrastructure in Ottawa is vast with ties to many different actors such as provincial highways, city roadways, traffic lights and road signage, air travel, and rail travel. Using ANT to isolate those major components that are a part of the Ice Storm failure helps to organize this grouping of actors and make sense of how this infrastructure was impacted during the Storm. For example, the condition of Ottawa's major highway (Highway 417) during the Storm is one of the primary influences for the movement of the disruption line in Figure 4.2.

Figure 4.2 Transportation Infrastructure Disruptions during the 1998 Ice Storm



It is the largest highway through Ottawa and therefore garners much attention from media and emergency responders during an abnormal weather event, making for a much fuller data source than smaller city streets. Taking into consideration both the importance of the highway and the expectation that the highway remain open, any such closure warrants a more severe disruption to Ottawa's transportation infrastructure. However, despite the significance of the highway, consideration must also be given to Ottawa's McDonald-Cartier Airport and Ottawa's Via Rail station. Not only are these important transit hubs for the city during normal conditions but they were also impacted by the Ice Storm with forced closures and delays. From an emergency management perspective this limits the number of entry points for external resources to arrive in the city. With regards to the transportation network it is another point of failure that increases the disruption within the network.

There are three major movements to observe in Figure 4.2: first is the steep and rapid drop in the figure's disruption line where there are moderate disruptions occurring on January 5 and more severe disruptions occurring towards January 7. Second, from January 7 to January 10 there is a maintained period of severe disruption to Ottawa's transportation infrastructure, though the disruption decreases for a brief period on January 7 before returning to a more severe state (this is marked by the spike in the disruption line in Figure 4.2). Third, during the remainder of the Ice Storm disaster the disruption line again moves abruptly but towards a period of moderate and then few disruptions. A more in-depth analysis on these three trends helps to clarify the state of Ottawa's transportation infrastructure during the Ice Storm.

On January 5 when the freezing rain first began to fall, disruption to Ottawa's transportation infrastructure was moderate with some impact to surface and air transportation. Figure 4.2 shows this with a downward movement in the disruption line. Normal de-icing operations kept all roads open, though there was a clear increase in traffic congestion as well as an increase in vehicular accidents throughout the city. An in-depth study might help to reveal a more detailed cause for the impact on traffic congestion and traffic accidents but with the information currently available a logical speculation still points to several broad factors: slippery roads were leading to higher than normal vehicular accidents and slower travel times; traffic lights affected by the power outage delayed traffic flow; and downed trees, utility poles, and power lines blocked roads and made travel more dangerous. With regards to other forms of travel, there were multiple delays and cancellations at Ottawa's McDonald-Cartier airport but Via Rail trains were still running into and out of the Ottawa station. Similar conditions persist throughout the next day on January 6 but this quickly worsened on January 7 when Highway 417 needed to be closed overnight so crews could salt the road.

Beginning at 11:00 pm on January 6 and continuing throughout the early morning of January 7, the Ontario Provincial Police (OPP) and the Ministry of Transportation (MTO) collectively closed both directions of Highway 417. This decision was made by the OPP in response to the dangerous driving conditions of the ice covered 417. Ministerial road crews were involved with barricading and restoring the highway to near-normal conditions. Figure 4.2 shows these combined activities and the subsequent closure with a downward movement in the disruption line into an area of severe disruption. Quite simply, a full closure of the highway increases disruption. The line movement is exacerbated by the fact that Via Rail had also begun to experience train delays; however, these delays appear to have been caused more so by debris strewn across tracks and downed electrical switching equipment as opposed to the ice directly. Also, because of power outages, roughly 70 intersections across Ottawa did not have operating traffic lights on January 7[111], with impacts to traffic flow throughout the city. Regardless, at this point during the Storm all land-based travel had been adversely affected resulting in slow commutes and dangerous conditions and the beginning of otherwise severe disruptions for the city's transportation network.

There is a noticeable spike included in Figure 4.2 for January 7 and it is used to show the opening and re-closing of Highway 417. With the full re-opening of Highway 417, the disruption line in Figure 4.2 briefly moves out of the red area and into the yellow to form the tip of the spike. Although conditions were still poor across Ottawa and there were still intense disruptions in Ottawa's transportation network, the reopening of the city's major highway helped to relieve these disruptions and the line reflects this. However, when the highway was ordered closed for a second time because live electrical lines had fallen onto it, the disruption again increases in severity and the line in Figure 4.2 again moves downward. One significant point regarding this particular disruption is that ice was no longer the primary reason for closing the road; instead, it was closed because of live electrical wires and other dangerous debris. Although municipal and provincial road crews had been prepared to deal with large volumes of accumulated ice (as was made evident by the fact that the highway had been salted and reopened before the beginning of rush hour traffic), there was still the problem of dealing with dangerous live electrical wires. Knowledgeable hydro-repair staff needed to be present or at least consulted before such debris could be removed. This presented challenges for both an overstretched hydro system struggling to keep up with repairs and for road crews working to

[111] Boswell, R. & Kirkey, S. (1998, January 9). Communities band together: Region declares state of emergency. *The Ottawa Citizen*.

keep the highway and city streets clear. Furthermore this highlights two significant points about the disaster: first, this is a point during the cascading failure in which consequences for one infrastructure sector can be traced towards having an impact on other infrastructure network actors. Second, this is a point during which the initial hazard disruption (freezing rain) becomes more akin to a technological disruption for transportation infrastructure.

The conditions created by the Ice Storm were presenting new risks to land-based travel across the city and such risks coincide with the severe disruption being caused to Ottawa's transportation infrastructure. By January 8, all trains into and out of Ottawa were cancelled because of fallen debris on the tracks, and portions of both Highway 417 and Ottawa's city streets had been closed for similar reasons. In bringing attention to these risks, Ottawa officials declared a state of emergency with the intention of keeping people off of roads and highways. Taking into consideration that such a declaration had never been made in Ottawa's history, this in itself highlights the severity of the disruption and justifies the position of the line in Figure 4.2 for January 8. Since similar conditions persisted throughout January 9, in which portions of Highway 417 remained closed and there was an ongoing state of emergency, the line in Figure 4.2 remains constant. The only additional disruption for this day was that Ottawa's airport officially closed, cancelling all flights into and out of the city.

The disruption line in Figure 4.2 makes an abrupt upward movement beginning roughly around January 10 signifying several points of recovery in this network. Although no information is available for the condition of Ottawa's Highway 417 on January 10, Murphy (2009) makes reference to Highway 401 being deserted except for long lines of military convoys. This highway does not run through Ottawa but if it is an indication of land-based travel in eastern Ontario, it suggests that road conditions were still generally poor throughout the region and that most people were avoiding major highways. However, there are also indications that things had begun to improve for Ottawa's transportation network. An article that appeared in the Ottawa Citizen (Rupert, 1998) makes mention of improved road conditions in Ottawa on January 10 with trains and buses being close to returning to normal by January 11. By also taking into consideration that the freezing rain had ended on January 9 and that this would limit the number of power lines and trees being brought down across roadways and train tracks, it's a likely indication that transportation conditions had begun to improve by January 10. As a result the disruption line in Figure 4.2 begins a movement away from the red area representing severe disruptions. Media and government reports contain little to no information about the state of Ottawa's transportation infrastructure in the days following January 11. It is assumed that following the end of the freezing rain, conditions steadily improved as debris was being cleared from roads and train tracks faster than it was added. Also, flights had resumed at the airport, and power had been restored to the city meaning traffic lights would likely be working again to help with congestion. For these reasons, the line in Figure 4.2 moves steadily upwards to signify a decrease in the level of disruption to Ottawa's transportation infrastructure.

Summary Remarks

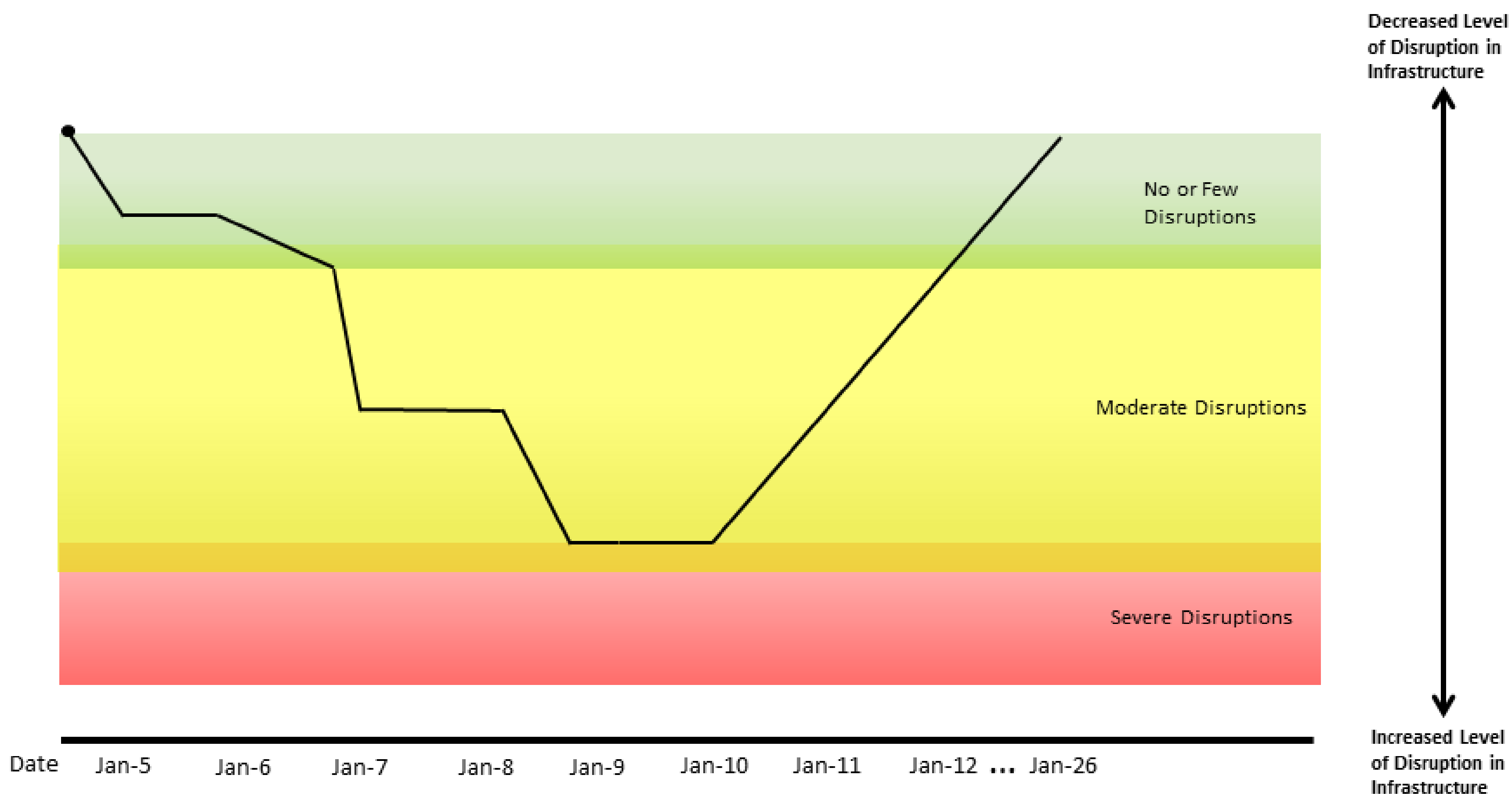
Transportation infrastructure is a crucial component for any city or community, especially during an emergency situation. During the 1998 Ice Storm, the highways that ran through the Ottawa region were used to transport resources such as generators, military personnel, and knowledgeable hydro workers from un-affected municipalities into storm weary communities. Hewitt (1997) refers to certain hazards as ‘barrier-hazards’ that can hinder or prevent mobility. Physical phenomenon such as fog or heavy snow falls can create physical barriers that prevent people from travelling on roads and highways. In this sense, freezing rain can also be considered as a barrier-hazard since icy road conditions are a great risk to drivers, some of whom will not chance the risky experience and instead decide to avoid it entirely. However, ice was not the only barrier on Ottawa’s roads during the Storm. Non-natural elements such as live electrical lines were also a significant disruptive force to Ottawa’s roads, highways, and rail ways. The combined mix of natural and technological road hazards emphasises the complexity of this storm. It also highlights how a natural phenomenon intersects with portions of the built-environment and shows evidence of the occurrence of a cascading failure.

As an important infrastructure resource in an emergency response event, a failure in the transportation network has several consequences and risks associated with it. Unlike electricity infrastructure in which risks associated with a disruption occur at some distance from the actual disruption; the risks associated with transportation disruptions occur directly at the source where ice or power lines create dangerous barriers in mobility. The significance of these risks to the health and safety of Ottawa’s population is emphasized by the decision to declare a state of emergency in Ottawa. Such a decision had never been made prior to the Storm and it had been done with one of several intentions being to encourage drivers to stay off of roads. This intention was made clear by Ottawa-Carleton Regional Chair Bob Chiarelli.

4.4 Communications Infrastructure

Previous sections in this thesis have dealt with electricity and transportation infrastructure from a perspective in which specific points of infrastructure damage are subjectively measured. For example, the closure of Highway 417 increased the disruption severity for transportation infrastructure and the number of Ottawa Hydro customers without power was representative of the severity of the disruption in electrical infrastructure. However, one of the challenges of discussing the state of communications infrastructure during the Storm is the lack of information existing specifically for Ottawa. It is known that there were communications troubles on several fronts: telephone poles and lines had been damaged in the same fashion as utility poles and electrical lines. Also, there was inconsistent telecommunications service between Toronto and those communities in eastern Ontario. Unfortunately, information could not be found pertaining to an accurate number of Ottawa customers without telephone or cellular service. To compensate for these challenges, Figure 4.3 shows the degree of disruption to communications infrastructure for not only Ottawa but also for the general eastern Ontario region. The following narrative clarifies how this disruption occurred.

Figure 4.3 Communications Infrastructure Disruption during the 1998 Ice Storm



No specific information could be found pertaining to the state of communications infrastructure for January 5 and January 6. This thesis makes the logical assumption that there were some disruptions because phone lines would have fallen in the same manner as hydro lines. This assumption is backed by mention within media and government reports that communications trouble had been occurring between Emergency Management Ontario (EMO) in Toronto and other municipalities affected by the Storm. However, given that there was no greater discussion about phones not working it is likely there were few disruptions or that these disruptions were dwarfed by larger disruptions in other infrastructures such as electricity and transportation. Moreover, it is known that phone companies were using batteries and generators early on in the Storm[112]. This has implications for any disruptions that may or may not have occurred because of the power outage. As a result, the line in Figure 4.3 moves to an area of few or no disruptions for these two dates, under the assumption that freezing rain had damaged some of the components needed by communications services.

For January 7 and January 8, there is still little info regarding the state of communications in Ottawa. Again, it is known that communication had been a problem over longer distances, but to what degree is uncertain. Since the impacts to other infrastructure sectors were beginning to escalate by this time and since the freezing rain continued to fall for several days, it can be speculated that disruption to communications had also increased. Taking this uncertainty into consideration, the line in Figure 4.3 increases from an area of few disruptions to an area of moderate disruptions. To be clear, this movement is largely made to coincide with the growing severity in other infrastructure sectors; particularly the electricity

[112] Murphy, 2009.

sector which maintains the same type of exposed components (i.e. poles and wires) that were being increasingly damaged and destroyed by the freezing rain.

On January 9 of the Storm, thousands of AT&T customers in Canada lost long distance service for several hours. The exact reason for this is not known but Murphy (2009) makes mention that despite this disruption, telephone service had not been as affected by the Storm as electricity had been. Part of this had to do with the decentralization of the telephone and cellular network. Communications infrastructure is unique because it operates and is maintained under private entities. This is unlike other CI in Ottawa, which is tied into some form of government control. The benefit of privatization is that different groups maintain their own systems; therefore, if a breakage or disruption occurs in one company's line, other companies may not be affected and service is maintained for their customers. Regardless, the disruption line in Figure 4.3 increases slightly via a downward movement in accordance with the disruption in long distance service. Furthermore, On January 10, it is known that many telephone lines were still down in both Ottawa and in eastern Ontario but the disruption line in Figure 4.3 remains constant between January 9 and 10. This is largely based on EMO sending out satellite phones on January 10 to Ottawa and other municipalities for use in emergency communications.[113] It is likely that disruptions were still occurring between Toronto and Ottawa and that these phones could keep emergency communications open. Without the adequate data, the remainder of the disruption line climbs steadily from January 10 to onward under the assumption that communications infrastructure would begin to recover following an end to the freezing rain and the subsequent restoration of electricity to Ottawa.

[113] According to Murphy, 2009.

Summary Remarks

Although there is little information pertaining to the actual state of communications infrastructure in Ottawa, based on its significance during an emergency response, it is still important to include this system as a primary actor in the Ice Storm network. The Ice Storm occurred over a large area and affected a diverse arrangement of groups and structures. Moreover, a significant movement of supplies including generators and people among other things, made their way into the affected storm region. For these reasons, such an event requires a coordinated response effort over a relatively large area, which can only be made possible through an effective means of communication. Moreover, for any number of reasons, the media reported very little on phone service during the Storm; however, there are several instances outside of the media, such as in government reports (Purcell & Fyfe, 1998; & Lacomte et al., 1998) where communications are brought up as being vital during an emergency response, but also a major challenge during the 1998 Ice Storm. Even though this challenge had been met with the incorporation of a number of back-up systems (i.e. batteries, generators, HAM radio, and police/military channels) it is still necessary to explore if there were intermediaries present in the network that would allow the failure to spread into and out of this infrastructure. In the following section, each infrastructure is brought together into one unified network. It is from this that it will be determined whether such intermediaries were present in not only communications infrastructure but also in electricity and transportation infrastructure.

4.5 Creating the Network of Cascading Failure through an ANT Perspective

Consistent to notions about ANT, Ottawa's CIs do not operate in isolation before or during a disaster and so it is necessary to bring together each infrastructure into one heterogeneous network and expand the analysis by tracing the connections between them. Thus far, the events leading up to the disaster in Ottawa and the disruptions that played out in each critical infrastructure have been considered largely in isolation from one another via a series of diagrams. The purpose of these diagrams is two-fold: first, they provide a means for identifying which components of the disaster had an impact on Ottawa's CI and are therefore relevant to this study by their relationship to one or more of Ottawa's CIs. Second, the diagrams are a way to more clearly organise all of the actors and intermediaries tied to the failure in Ottawa's CI. This section of the thesis will now bring each of these actors together, creating the full network of study. In this way, the boundaries of the network of translation become more clearly defined by the actors and intermediaries that transfer failure. To be clear, this section helps identify when and where the cascading failure began. Ultimately, the aim is to gain detailed insights into how disaster comes into being when freezing rain provokes a cascading failure in CI. The associations that bind actors together and influence the type of agency they have during disaster cannot exist in isolation. Under the premise of ANT, to study these actors in isolation would dissolve the cascading failure and destabilize the network which the 1998 Ice Storm belongs.[114]

[114] This relates to Law's (1997) discussion of the *naked ape*: a phone, a big office and a man placed together form the image of a powerful office manager; but studied in isolation the manager becomes just a naked ape. (See: Law, J. 1997. *The manager and his powers*. Centre for Science Studies: Lancaster, UK).

Moving forward with the analysis of the cascading failure, three disruption diagrams are presented in the remainder of this chapter. These three diagrams, which are presented in Figures 4.5 to 4.6, each contain an overlay of the primary actors discussed earlier in the chapter. The orange line shows the transportation infrastructure disruption; the black line shows electricity disruption; and the green line shows communication disruption. These lines are presented again, exactly as they were in previous sections. Also included is a blue line that shows the total freezing rain precipitation for each day of the Storm. Precipitation amounts increase when the line moves downward and decrease when the line moves towards the upper portion of Figure 4.4 to Figure 4.6. For example, January 5 has the highest amount of freezing rain precipitation and January 8 has the second highest amount in each of the figures. What differentiates each of the three diagrams in Figure 4.4 to 4.6 is a shaded-box used to pin-point a specific event during the Ice Storm. Although there are many points throughout the disruptions diagrams that can be shaded, a limited number of points have been chosen to keep this chapter at a reasonable and manageable length. This is the challenge of a true ANT; the tracings are by principle endless and so limitations must be set when using the theory. Despite such limitation, the primary goal of this section is to show in practical terms how ANT is used to identify and describe the cascading failure that occurred during the Ice Storm. This section argues that conditions conducive to a cascading failure were present prior to the actual Ice Storm event, using ANT to reinforce this argument.

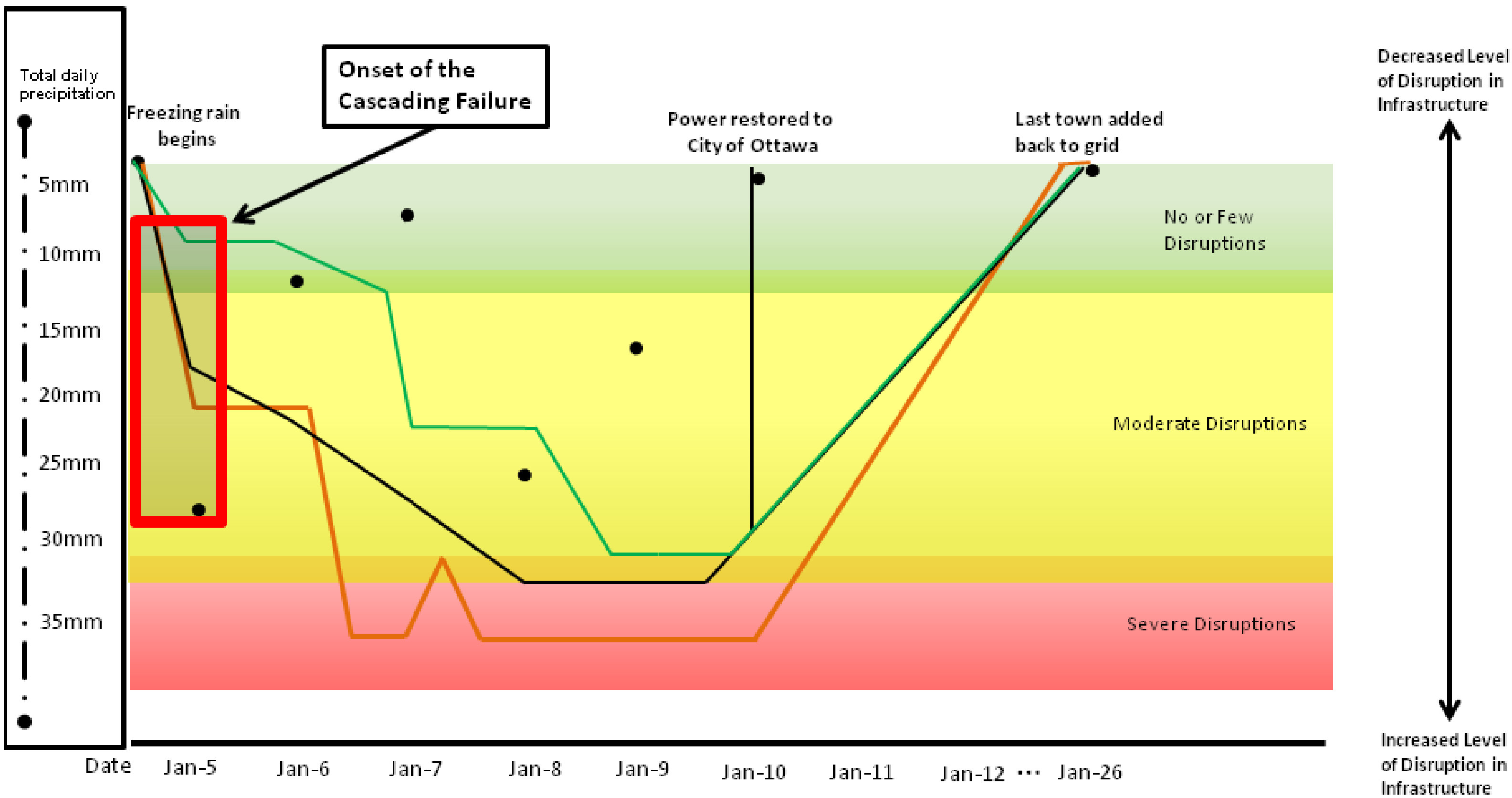
The remainder of this section delves more deeply into the various stages of the 1998 Ice Storm disaster. To ensure accessibility for the reader, section sub-headings are included with each diagram and associated discussion. First is the “Onset of the Cascading Failure” where

Figure 4.4 is used to help pin-point the conditions in Ottawa that were conducive to the beginnings of a cascading failure. Second is the "The Emergence of the Cascading Failure" in which Figure 4.5 helps identify a single point during the disaster where the cascading failure begins. Third, is the "Continuation of the Cascading Failure" in which Figure 4.6 helps in identifying the spread of the cascading failure to other network actors.

The Onset of the Cascading Failure

During the early portions of the Ice Storm, disruptions in CI are traced mainly to the direct effects of the freezing rain. This is outlined by the shaded-box that is located on January 5 in Figure 4.4 when the amount of freezing rain released had been at its highest as marked by the blue line. Two CIs immediately and noticeably affected during the first day of the Storm were electricity and transportation infrastructure. For these two infrastructures individually, the initiating agent that caused the disruption was the freezing rain. Heavy ice load brought down electrical wires knocking out power in some areas; and, roads were coated in slick ice causing congestion and an increase in accidents. These were moderate disruptions that occurred throughout the first day and as such there is little information to support that a cascading failure had yet transpired for the City of Ottawa. Surely, some traffic lights would have been affected by the power outage, and perhaps the delays and cancellations that occurred at Ottawa's airport may be tied into the disruptions in electricity but without proper data this is speculative.

Figure 4.4 The Onset of the Cascading Failure



Black circle: Total daily precipitation
Orange line: Transportation infrastructure
Green line: Communications infrastructure
Black line: Electricity infrastructure

As such, the freezing rain's disruptive impact had yet to show any material signs of cascading from infrastructure to infrastructure since the disruptions in electricity infrastructure and transportation infrastructure were happening largely independent of one another. Thus, with a high degree of certainty it is known that the freezing rain had been a common source of disruption between these infrastructures early in the Storm but the disruptions were not yet cascading from one to the other – only accumulating.

Early in the Storm, CIs with a heavy dependency on electricity such as communications infrastructure had been able to adapt to the disruption in electrical infrastructure. Although transportation infrastructure also utilizes electricity in the form of traffic lights and road signage, it is to a much lesser extent than communications infrastructure. Research on infrastructure interdependencies show that disruptions in electricity output can easily cascade to disruptions in other CIs (i.e. Rinaldi et al., 2001; Murphy, 2009; and Little, 2010). This is simply a case of certain technological systems needing a maintained source of power to operate. As such, any system with a dependency on electricity from traffic lights to telephones can be affected. Communications require a continuous supply of electricity in order to provide their own services, more so than transportation infrastructure does. Simply put, roads and highways are still useable without power; communications are typically not. However, during the Ice Storm any outage in Ontario Hydro and Ottawa Hydro's power grids had no immediate disruptive impact on communications infrastructure. The exception was that telephone lines were still being damaged in a similar fashion as power lines. In this respect, initial disruptions in telephone service appear to have been due to broken phone lines rather than electrical failure. Regardless, both communications infrastructure and water and sanitation infrastructure in

Ottawa had survived the initial power outage through a series of previously installed back-up energy systems consisting of batteries and generators. Using ANT, and continuing to focus on the shaded-box in Figure 4.4, it is possible to follow the connections that helped these networks resist a disruption.

For communications infrastructure, back-up systems were in place that would help adapt to a disruption in regional power supply. For example, telephone companies used batteries that would last for up to five hours during a power outage. If and when those batteries failed (a likely scenario given the overall length of the power outage for many neighbourhoods in Ottawa) back-up generators were in place that could maintain a constant power supply. It should be noted however, that there is no data to suggest that phone companies used their generators during the early point in the Storm. What is known is that the problems experienced with electricity transmission and distribution in Ottawa was not having a discernable impact on communications infrastructure in the city. Rather, the disruption was being shaped and distributed by the ice accumulation of the freezing rain - a susceptibility to damage in material components created by an exposure to severe ice storms. This is highlighted further by looking at one CI that did not experience any disruption in services during the Ice Storm – namely, water and sanitation. This particular CI is not included in the disruption diagram because there was no reported disruption in its service, but it is discussed herein to bring attention to the above mentioned points. Moreover, in order to maintain a linear progression in the discussion, this thesis will be referring to water and sanitation as it exists in the shaded-box in Figure 4.4. It is important to consider that this infrastructure is only discussed as it relates to Ottawa, and although disruptions in water and sanitation did occur outside of the city, such considerations fall outside the boundaries of this thesis.

Although not eligible for inclusion in the disruption diagram, water and sanitation infrastructure nevertheless highlights two important points: first, its continued operation during the Storm reinforces the notion that exposure to freezing rain had been the initial agent for the disruption in other CIs. Second, this infrastructure provides an example of how actors are enrolled into a network and how they can make that network durable. In regards to the first point, water and sanitation infrastructure operates underground and in sealed buildings that are not impacted by accumulating ice. Any failure in water and sanitation that could have occurred during the Ice Storm would likely have to originate through a failure in electricity or some other unforeseeable force. But with generators and the knowledge and resources to keep them running, this particular infrastructure was protected from any such failure. Recall that Callon (1986) believes that intermediaries can be technological artifacts, action, and even human beings; a key notion for giving agency to both human and non-humans alike. This means that both knowledge and material resources could be considered as intermediaries since they define the connection that exists between actors. Thus, what sets this infrastructure apart from other CIs impacted by the initial accumulation of freezing rain was that both its physical structure and its stability against power failures each act as intermediaries that block freezing rain from entering into their networks.

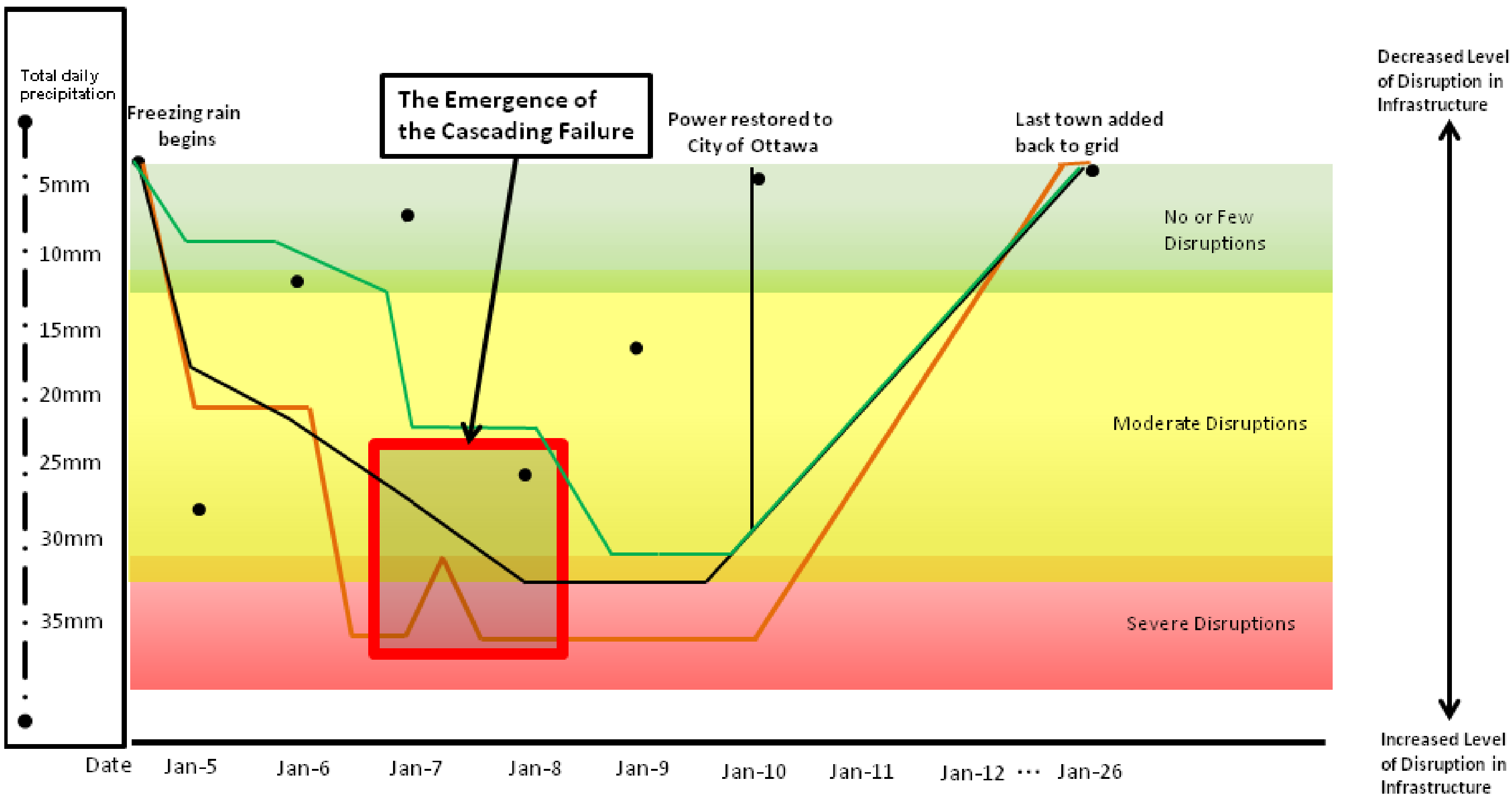
Moreover, a third actor, the Ministry of Environment (MOE), with unexpected ties to Ottawa's water and sanitation infrastructure is revealed as having played a role in establishing those intermediaries that protect from interruptions in electricity. Prior to the Storm, an initiative undertaken by the MOE encouraged water and sanitation departments to incorporate back-up generators into their systems.[115] The program had been adopted by water and sanitation departments across Ottawa and generators were added to the infrastructure network. A key notion in ANT is the concept of translation, a term used by Callon (1986) to refer to the processes involved in the forming of a network. A part of this network formation involves finding shared or aligned interests between actors and assembling those interests into action.[116] The MOE had been concerned that a power failure would pose a significant threat to the environment if water and sanitation infrastructure were to be affected. The MOE had defined a problem and extended that problem to the interests of the water and sanitation infrastructure in Ottawa. The convergence of these two groups created a network capable of withstanding a severe ice storm. This is important because neither group could have predicted that an ice storm would be a threat but the program had clearly been a success considering the state of water and sanitation in Ottawa during the Storm. This is an example of how ANT can show in practical terms that the behavior, beliefs, and internal operations of one actor (i.e. MOE) can manifest themselves into a more durable network where failure does not easily occur during an abnormal ice storm and connections are not corrupted between actors. Furthermore, this is chosen for its simplicity in understanding and outlining how concepts of ANT are to be used herein. Thus, a similar type of analysis is undertaken throughout the remainder of the chapter but with focus returning to just the primary actors.

[115] Purcell & Fyfe, 1998.
[116]Callon's (1986) examination of marine biologists trying to restock the St. Brieauc Bay with scallops contains more in-depth explanation of translation and the steps of creating a network.

The Emergence of the Cascading Failure

A primary goal of this thesis is to discern how a natural phenomenon such as an ice storm intersects with the built-environment in such a way that results in disaster. Those portions of the built-environment that are in question are the CIs that a city cannot function without. Though there are many CIs to consider, this thesis has narrowed the focus down to three primary actors: electricity, transportation, and communications infrastructures. To begin with, the shaded-box outlined in Figure 4.5 shows a trend worth inquiring about in which infrastructure disruption peaks but freezing rain totals are lower than on the first day of the Storm. If freezing rain had been the primary agent causing the first disruptions in infrastructure, what was occurring that would cause all three infrastructures to become drastically more disrupted despite a decrease in the amount of precipitation? Was the freezing rain itself responsible for this increase or were other factors at play such as the occurrence of a cascading failure? Addressing such questions helps to describe in terms of ANT, the intersection between the natural and the built-worlds. Also, such questions help identify those pathways conducive to a cascading failure that were present prior to the Storm.

Figure 4.5 The Emergence of the Cascading Failure



Black circle: Total daily precipitation
Orange line: Transportation infrastructure
Green line: Communications infrastructure
Black line: Electricity infrastructure

To understand how disruptions were greater on the third day of the Storm when freezing rain totals were at their lowest, it is helpful to look at the nature of freezing rain. Between January 5 and January 8 there had been no opportunity for ice to melt from surfaces but there was still additional ice being added. This in itself is a unique characteristic of this particular ice storm in which there were no lulls in the Storm. Without the right environmental conditions to allow for melting, smaller amounts of freezing rain could still produce significant damage in infrastructure. To make matters worse for infrastructure, more ice on things such as power lines and utility poles created more surface area for even more to accumulate.[117] So, even if freezing precipitation totals were lower, the amount of ice already present on surfaces during the first two days was magnified by an even greater area of coverage leading to a greater opportunity to overburden exposed and susceptible structures. Quite simply, isolated disruptions in CIs could continue regardless of the amount of total precipitation. However, this explanation is in the absence of other actors external to the freezing rain such as hydro crews, road crews, generators, the OPP, EMO, or the military. To discover the true meaning behind the increase in disruption it is also necessary to conduct a tracing of these actors and their intermediaries. In doing so, it becomes possible to more thoroughly describe the growing disruptions that are seen in the shaded-box of Figure 4.5. To do this, it is important to first distinguish the difference, if any, between actors and intermediaries.

In an ANT perspective, humans and non-humans are viewed as either actors or the intermediaries that tie other actors together. Each CI is tied to groups made up of people, their shared knowledge of a particular infrastructure, and access to resources utilized by the CI; for

[117] The exponential increase of ice accumulation on surfaces is explained in Murphy, 2009.

example, hydro repair crews or municipal and ministerial road crews. In theoretical terms, these groups are situated between both the freezing rain and its adverse impact on an individual CI. Their actions, knowledge, and resources which are themselves intermediaries, were directed towards removing the impact of freezing rain from infrastructure. Such intermediaries worked in contrast to the damage caused by the freezing rain; they were intermediaries in opposition. Ultimately, one force will overpower the other and in the case of the Ice Storm, the freezing rain on all fronts outpaced those forces working against it. In this regard, freezing rain is also viewed as an intermediary created by the interaction between an ice storm and the built-environment. This conforms to Callon's (1991) premise in which any actor at any given time and in any given context can also be an intermediary. It should be noted that one of the criticisms of ANT's use of intermediaries is that they are infinitely layered between actors. For example, between each intermediary and actor is another intermediary, and between that intermediary there exists even more intermediaries and so on. This thesis acknowledges such criticisms but limits the potential number of intermediaries to those that are described herein. Regardless, the roles of both freezing rain and ice storms and, to a lesser extent the forces that work in opposition of them, are now being situated more clearly into the network of connected CIs. A next step is to identify the power and influence these actors and intermediaries have on other actors and the network as a whole.

ANT is particularly useful for analysing how power is both directed and used in the formation or destabilisation of a network. The freezing rain was working to destabilize infrastructure, resulting in consequences for the network of normalcy in Ottawa.[118] The infrastructures affected attempt, from within their own networks, to resolve the freezing rain's impact and return to a state of normalcy. How infrastructures do this brings attention to those actors tied to infrastructures that work in opposition to freezing rain. Since there are many actors/intermediaries that could be considered, specific examples are taken from the shaded-box in Figure 4.5 to help narrow it down.

Again, it is important to reiterate that ANT's equalization of human and non-human actors permits for the type of terminology being used herein. To state that the freezing rain is working to destabilize the system is not the same as stating that the freezing rain has *decided* to damage the system. Instead, it is doing so purely because its presence in a network forces the network to reconfigure itself. In ANT terms, the freezing rain has agency and when it is introduced into a network of a particular configuration it can create either a favorable or an unfavorable outcome for other actors in the network. In the case of CIs, the presence of freezing rain clearly creates an unfavorable outcome for people that rely on these crucial services. For example, the mechanical components of electricity infrastructure are made up of utility poles and power lines that have a pre-existing sequence of responses to freezing rain. Their position within the network determines how they are affected by freezing rain and in turn, what affect this has on other actors tied to the infrastructure. In practical terms, susceptible infrastructures may respond to the presence of freezing rain with a mechanical or technological breakdown that has a disastrous impact on a population. In other words, freezing rain's introduction into a pre-established network made up of infrastructure and people causes

[118] The *network of normalcy* refers to how these infrastructures are collectively used under normal conditions and as a part of the built-environment.

a reconfiguration and therefore destabilisation in the previous network of normalcy. This has theoretical implications that provide evidence for the pre-existing conditions conducive to failure.

What can be concluded up to this point is two-fold: first, that each of the CI primary actors opposes freezing rain because the associations that make-up these infrastructures work to remove its footprint from the network. Second, that an inability to eliminate the freezing rain's impact on the infrastructures suggests that the Storm is exerting a power that supersedes the adaptive powers of those infrastructures it is affecting and the intermediaries associated with them. This in part accounts for an increase in the disruptions to electricity, transportation, and communications infrastructure in Figure 4.5. There are however, differences to consider that set transportation infrastructure apart from the other two CIs. In particular, municipal and ministerial road crews were more successfully able to counteract the direct and disruptive force of the freezing rain. This begs the question of how transportation infrastructure is in a more disruptive state than both electrical and communication infrastructure, as shown in the shaded-box in Figure 4.5. One of the events that occurred at this time was the closure, reopening, and then re-closing of Highway 417 (as represented by the spike on January 7). Though the highway had closed, which is represented by the portion of the line leading up to the spike in Figure 4.5, this particular disruption both began and ended by the responsive actions of road crews and the OPP.

A combination of many traceable variables exists that describe how road crews were able to combat the freezing rain. A few of the more visible tracings taken from the 1998 Ice Storm include: increasing the number and duration of both work shifts and personnel; having pre-established methods for removing ice (i.e. salting); access to both resources and the knowledge to use them (including workers, salt, trucks, gasoline, barriers, etc.); and access to weather forecasting to prepare resources and personnel. Used in combination with one another, these things led to a situation in which efforts to restore Highway 417 exceeded or at least kept pace with the disruptive efforts of the freezing rain. However, when the line progresses past the peak of the spike in Figure 4.5 it is showing that the highway had returned to a level of severe disruption due to its second closure ordered by the OPP. This time however, it was not due to the freezing rain, though this was certainly keeping road crews busy. Instead, this new disruption came from damage being caused in the electricity grid when power lines had fallen on the highway. The first visible evidence for the occurrence of a cascade failure in which a disruption in one infrastructure causes a disruption in another.

Thus it appears that the first concrete sign of a cascading failure in Ottawa's CI had occurred within the third day of the Storm; the consequences of which are partly directed towards the safety of people using the road and who would be at risk of encountering dangerous obstacles. It should be noted that this type of disruption was not isolated to just the highway; accounts provided in newspapers (i.e. Boswell & Kirkey, 1998) indicate similar problems were occurring on city streets. However, any example taken from this scenario is done in the context of Highway 417 as it is the most visible in terms of data. It should also be noted that it is possible that the true beginning of a cascading failure during the Ice Storm may have happened prior to this point; for example, power outages affecting street lights with consequences for traffic flow. However, without proper evidence to support an exact number or time for this failure it must be omitted. This is because ANT does not support the inclusion or tracing of an actor or intermediary that may or may not exist; it is more concerned with those tracings that make themselves most visible. Regardless, one important takeaway is that Ottawa's structural configuration included situating a major roadway next to electrical power lines and that this configuration led to the emergence of a cascading failure.

Identifying a point for where cascading failure occurs in Ottawa's CI, leads to two key ideas. First, a tracing of the cascading failure has expanded the network to include a visible connection between both electricity and transportation infrastructure; and second, new actors become visible, as do their roles as intermediaries. In regards to the latter, the OPP is identified as an actor with influence on the disruption of transportation in the city. For example, the OPP ordered portions of the highway closed on two separate occasions, albeit for differing reasons, but with both accounts amounting to an increase in disruption in Figure 4.5. The OPP can thus be traced to transportation infrastructure, but not as an actor that decrease disruption during the Ice Storm; rather, their position was one that used temporary disruption (i.e. closure of Ottawa's highway) to promote recovery. Furthermore, in order to remove the threat of downed electrical lines on Highway 417 and elsewhere throughout Ottawa, hydro repair crews were needed. This is because removing live wires requires a degree of expertise municipal and ministerial road crews may not have.

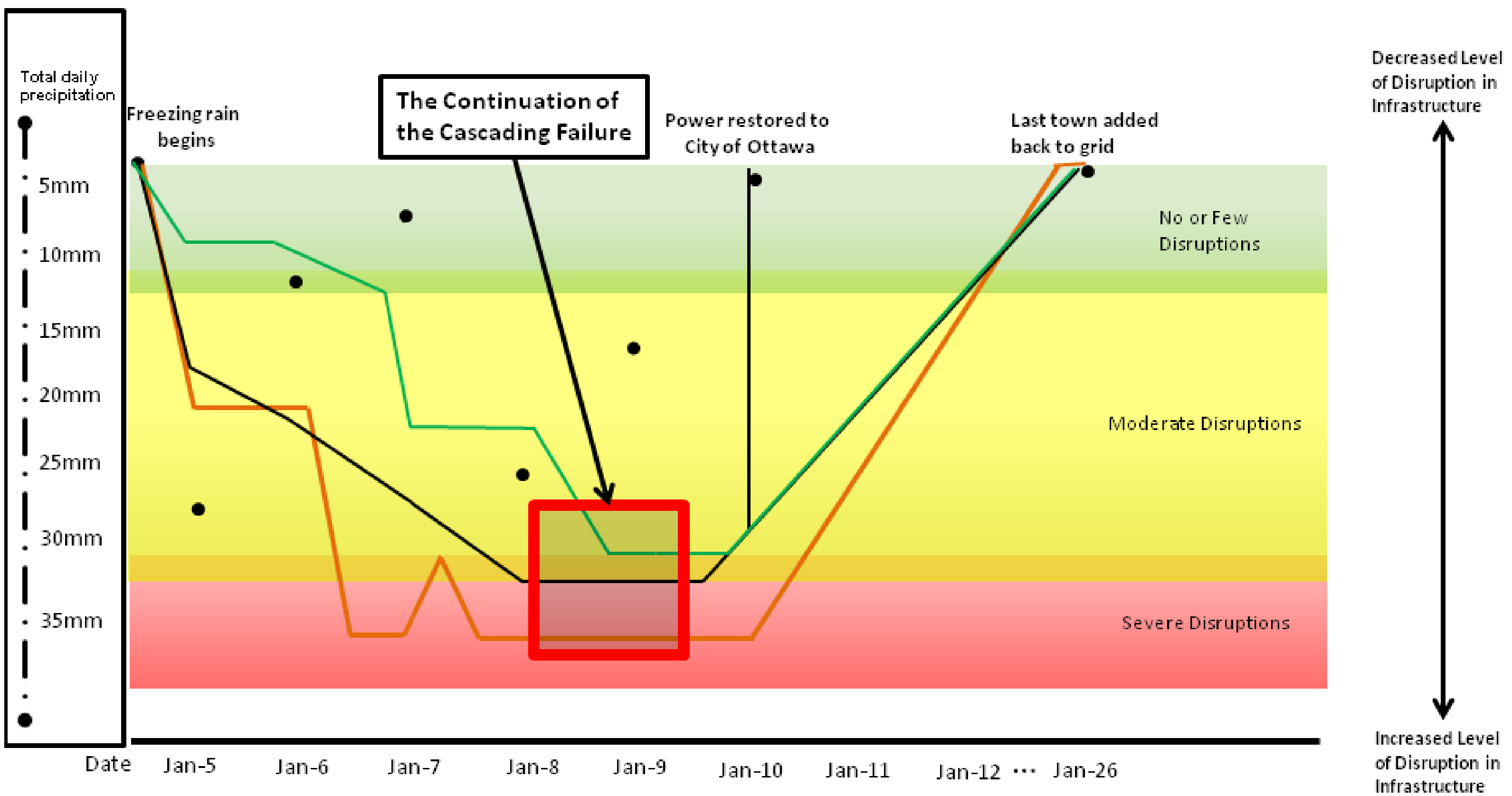
Unlike road crews and hydro crews that can be placed as intermediaries between the freezing rain and the infrastructure they are each most tied to, the OPP maintain a very different role when viewed through an ANT lens. This group acted as an intermediary between the public and the damaged and disrupted infrastructure. It was the OPP that determined whether the highway closed and it was the OPP that enforced that decision. The freezing rain initiated disruptions that became dangerous to human beings and the OPP acted as a barrier that separated this danger from people. Whereas one or multiple groups (i.e. hydro and road crews) involved itself or themselves in restoration with the goal of returning to a state of normalcy; the OPP was tasked with limiting damage while restoration occurs. This type of classification or distinction between groups is useful in transferring theory to practice. For example, identifying broader group roles during a failure can assist in both the planning and activation phases of emergency management in Ontario.

Furthermore, ANT notions about actors and intermediaries provide theoretical and practical insight into how cascading failure occurs when natural phenomenon intersects with the built-environment. For example, hydro crews had a greater number of connections in the network of electricity distribution than they do with Ottawa's highways and roadways. But when they were deployed to help restore disruptions to Highway 417, they became an intermediary that tied both of these infrastructures together. For example, until power lines were removed from the highway by knowledgeable crews with access to the right resources, it remained closed and therefore disruption in Ottawa's transportation infrastructure remained in a higher state. The intermediary connections were still greater in number between hydro crews and electricity infrastructure than they were between hydro crews and transportation infrastructure. However, as an intermediary, a new association appears that theoretically connects the two networks together. The result is a visible network, which, identified through incorporating principles of ANT also highlights the movement of a cascading failure when a natural phenomenon intersects with the built-environment.

The Continuation of the Cascading Failure

Now that a piece of the cascading failure has been established in which damaged electricity infrastructure was disrupting mobility in Ottawa, it is possible to continue the tracing of the cascading failure. What is known thus far is that transportation was greatly affected by both the freezing rain and by damaged electrical components. Does this disruption in transportation have any impact on the disruption of other CIs? To answer this, it is necessary to look at another point during the Storm outlined by the shaded-box in Figure 4.6.

Figure 4.6 The Continuation of the Cascading Failure



Black circle: Total daily precipitation
Orange line: Transportation infrastructure
Green line: Communications infrastructure
Black line: Electricity infrastructure

There are several points in the data gathered for this thesis from which the tracing of the cascading failure can continue. First, several sources (i.e. Murphy, 2009, Morris, 1998) make mention of how poor road conditions in eastern Ontario made it difficult to procure fuel and also that it was in high demand for generators. Generators were a growing commodity in Ottawa during the Storm to the point that many of the crimes reported at the time involved generator theft (Purcell & Fyfe, 1998). Moreover, generators were being imported into eastern Ontario in large numbers by multiple private and governmental organisations. As such, the threat of a fuel shortage had implications for the generators being brought into the region and for the generators already in use. From an ANT perspective, generators can be viewed as an intermediary between electricity distribution and an end user of that service; but they can also be viewed as a network themselves. In the context of the Ice Storm, the parts of the generator that were most necessary were that its mechanical parts were in working order, that it had fuel to run, and that end users had access to it. These three things should enable generators to maintain a role as an intermediary that helps block the occurrence of a cascading failure in other CI. However, a further tracing exposes that those necessary parts of a working generator were not always present and this allowed for electricity induced cascading failure to occur.

Although CIs in Ottawa had access to generators during the Storm, both the threat of a fuel shortage and the breakdown of mechanical components in overworked generators opened up potential avenues of failure. EMO was coordinating the shipment of this resource into Ottawa with the help of multiple private and government agencies. In any case, access to generators for CIs such as hospitals, water and sanitation, and communications (recall that phone companies had generators already in place) had not been an issue. However, Murphy

(2009) mentions that on January 8 there were reports of generators collapsing from overuse. Quite simply, this can be tied to the prolonged characteristic of the freezing rain and its ability to supersede reconstructive efforts being undertaken in the power grid. Thus, another intersection between a physical hazard and the built-environment becomes known: the characteristic prolonged duration of the freezing rain allowed electricity disruptions to bypass intermediary back-up systems. In theoretical terms, this is the removal of an actor (the generator) from the network of interconnected CI that maintains a state of normalcy in a city environment. ANT theorists (i.e. Callon, 1986 & Latour, 2005) argue that a greater number of connections help to strengthen a network and make it more durable; the opposite is also true in that removing actors and their connections from a network can create instability. The above mentioned example highlights this; however, it should be noted that the data used herein does not show whether overworked generators broke down specifically for individuals, businesses, or CIs.

Whereas overworked generators can be traced to the prolonged characteristic of the Ice Storm; an absence of fuel that could be used in generators, can be traced towards disruptions in electricity. In other words, a technological hazard in the form of a power outage is blended with the impacts created by a natural hazard (a prolonged ice storm). This means that if fuel supplies were not maintained, the network of CIs that was formerly protected by the power outage would make itself susceptible. Moreover, concerns about the shortage of fuel suggest that the emergency response was somewhat short-sighted on the particular resources needed in eastern Ontario. By January 8, EMO itself acknowledged that the resources needed in eastern Ontario had been underestimated by the organisation, to which their response was the formation of a resource team (Purcell & Fyfe, 1998). Coincidentally, the provincial emergency plan used at the time of the Storm also went into action on the same day (Purcell & Fyfe, 1998). This begs the question of whether EMO was 'late to the game' considering the level of disruption in critical infrastructures had already reached their peak as outlined by the shaded-box in Figure 4.6. In theoretical terms, this also identifies EMO as an actor whose intermediary (in)action with regards to the resource needs of the emergency response either supported or opposed the chance for the electrical failure to cascade to other generator dependant CIs. For example, sending generators to a region without the fuel to support them would allow for an electrical failure to spread.

A second series of events show the occurrence of electricity-driven disruptions in telephone and cellular communication. The first event occurred when a cell phone tower in Ottawa lost power disrupting cellular service in the city for five hours on January 8. This in itself is a cascading failure within the isolated confines of communications infrastructure. For example, prior to the tower losing power, cellular communications were already being jammed by over use when telephone lines went down due to freezing rain. The second event occurred at 11:30 a.m. on January 9 when thousands of AT&T customers in Canada lost long distance service (Murphy, 2009). These examples, in particular, the first involving the cell tower, show that the disruption in electricity infrastructure was, several days into the Storm, able to cascade into communications infrastructure. Informed speculation points to several possibilities that would allow this failure to occur: one, that the tower did not have a generator and that the growing power outage reached this tower several days into the Storm; a second option is that the tower did have a generator but it either ran out of fuel or broke down from overuse.

Regardless, this failure shows that electricity disruptions were cascading to both transportation and communications infrastructure.

To emphasize the extent and seriousness of the communications disruption (outside the example of a single cell phone tower being disrupted for just five hours), one need only to look at the concerns by members of the emergency response as they were expressed to the media. James Young, Ontario's Assistant Deputy Minister in the Solicitor General's Ministry of Public Safety, revealed to the *Globe and Mail* that on January 8 there was concern in the emergency management community that emergency communications would be brought down (Mackie, 1998). Similar to how generators supplement the normal transfer of electricity in the network, HAM radio and OPP and military channels were used in place of normal lines of communication. A point to make with regards to the military's role during the disaster is that they appeared to be tied into the disruption response network of each of the primary CI actors. They were used to communicate messages between Toronto and Ottawa; they helped clear debris off of roads; they aided hydro repair workers in the restoration of the electricity grid and helped distribute generators to rural farmers (though this last point is outside of the scope of this thesis). A future study about the role of military groups during disaster may find interest in examining this link further.

Summary Remarks

In theoretical terms, this chapter brings attention to a link between ANT and the idea of 'context' as it is used in hazards geography research. Recall that Mitchell et al. (1989) writes, "It is very difficult to derive broadly applicable conclusions from studies of specific natural disasters, because contexts are likely to vary" (Mitchell et al., 1989, p. 406). ANT is particularly adept at isolating the characteristics associated with an individual disaster and connecting them to broader outcomes. For instance, under the principles of ANT, conducting a tracing of individual aspects of the Ice Storm revealed that a cascading failure is a force made up of predetermined outcomes dictated by the associations that link actors together. Moreover, through the notion of generalised symmetry[119], no association can be overlooked since any actor in the disaster network, whether human or non-human, is given agency. Thus, ANT makes no distinction between broadly defined contextual characteristics (i.e. the social, environmental, political, etc.) and so connections can in fact be made between different contextual aspects. In this respect, ANT addresses a challenge for hazards research being able to broaden the disaster context and also make the crucial connections between different contextual aspects.

[119] Latour (2005) explains generalised symmetry as a means for creating impartiality between all actors in a network.

Chapter 5: Reframing the 1998 Ice Storm in the Context of the Current Provincial Emergency Response Plan

Despite a host of impressive and highly advanced technologies being used across the globe to monitor weather patterns, no one knows exactly where, when, or how the next powerful storm will hit. Regions typically rely on early warning systems to help identify incoming threats; while these systems are useful for warning a society of impending danger, they are not without their limitations. In terms of severe weather such as an ice storm, the technologies used in weather forecasts are useful for identifying incoming storms, but can be limited in their accuracy and time frame of predictions, leaving little time for an unprepared region to respond to a severe weather threat. Thus, it is prudent to have a plan in place that can be used to help prepare for and respond to any potential and unique threats.

The challenge with a cascading failure such as the one that occurred in 1998 is that it creates multiple emergencies that occur simultaneously; for example, a prolonged bout of freezing rain, an energy crisis, severe barriers in mobility, and a heavily damaged communications network among others. Each on their own would warrant a provincial response but in combination, resources become stretched and a special coordinated effort is required. As mentioned in earlier chapters, this thesis is concerned primarily with the type of disaster that is assembled within a network of complexity, integrally linked to a hazardous cascading failure across critical infrastructure (CI) systems. As is often the case with fragile infrastructure networks, creating more reliable and durable technologies that can withstand nature's hazards is often a primary focus in disaster mitigation. However, a purely technological approach does not, on its own, sufficiently address the challenges these hazards create for regions. This has been a longstanding view in hazards geography research and is also a view adopted in this thesis. Moreover, Actor-Network Theory (ANT) operates in relation to such a view by giving agency to all human and non-human actors in a network; this blends into a single network the seemingly separate roles of technology, nature, and the social. In understanding how natural hazards intersect with the built-environment, it is not enough to focus only on the durability of technological components in (CI). In doing so would run the risk that the physical hazard would outmatch the technology and a cascading failure would still occur. Thus, in practical application, emergency planning practices would be wise to consider the validity behind such a viewpoint and incorporate it into their emergency management practices.

As a practical contribution to emergency management in Canada, this thesis seeks to apply what has been learned from an ANT-based analysis of the Ice Storm's cascading failure and apply it to current emergency practises. Emergency management in Ontario maintains a hierarchical structure; at the top of this hierarchy is the 2008 Provincial Emergency Response Plan (PERP). This plan serves as an umbrella plan informing all those below it including: regional, municipal, ministerial, and community plans. Considering its position in Ontario's emergency management hierarchy, this plan has been chosen for review in this chapter. This review looks at how events in the cascading failure might have occurred differently had the PERP (2008) been in place during the Ice Storm. The chapter begins with a brief introduction of the PERP (2008) that describes how it is both structured and used. Following this is a comparison of how events experienced during 1998 might occur differently today with the existence of the PERP (2008). Within this discussion are recommendations that are derived from the study conducted in this thesis and that are applicable to emergency management practices in Ontario.

5.1 The Provincial Emergency Response Plan (2008): A Brief Introduction

In Canada, the *Emergency Management and Civil Protection Act* ensures that each province maintains an emergency plan that can be used for the coordination of a provincial response to any emergency. In Ontario, that plan is called the PERP, with the latest revisions made in 2008. The PERP (2008) is an umbrella response plan that describes the concepts, actions, and organizational and governmental hierarchy that is needed to safeguard the health, safety, and property of residents in Ontario. As an umbrella plan, the PERP (2008) is meant as a guiding tool for building more place-specific and event-specific plans such as those used in the City of Ottawa, in larger regions such as the Ottawa-Carleton Region, and in individual ministries such as the Ministry of Transportation. The PERP (2008), which was written and is maintained by Emergency Management Ontario (EMO) under the Ministry of Community Safety and Correctional Services, is self-described as a resource that "sets out the basic mechanisms, organisational structures, responsibilities, and procedures to guide Ministers and their staff when involved in a coordinated provincial response to emergencies in Ontario" (PERP, 2008, p. 3). Figure 5.0, which is taken directly from the PERP (2008) document, shows the hierarchical plan structure for an emergency response in Ontario. At the top of the diagram is the *Emergency Management and Civil Protection Act* from which all emergency plans flow.

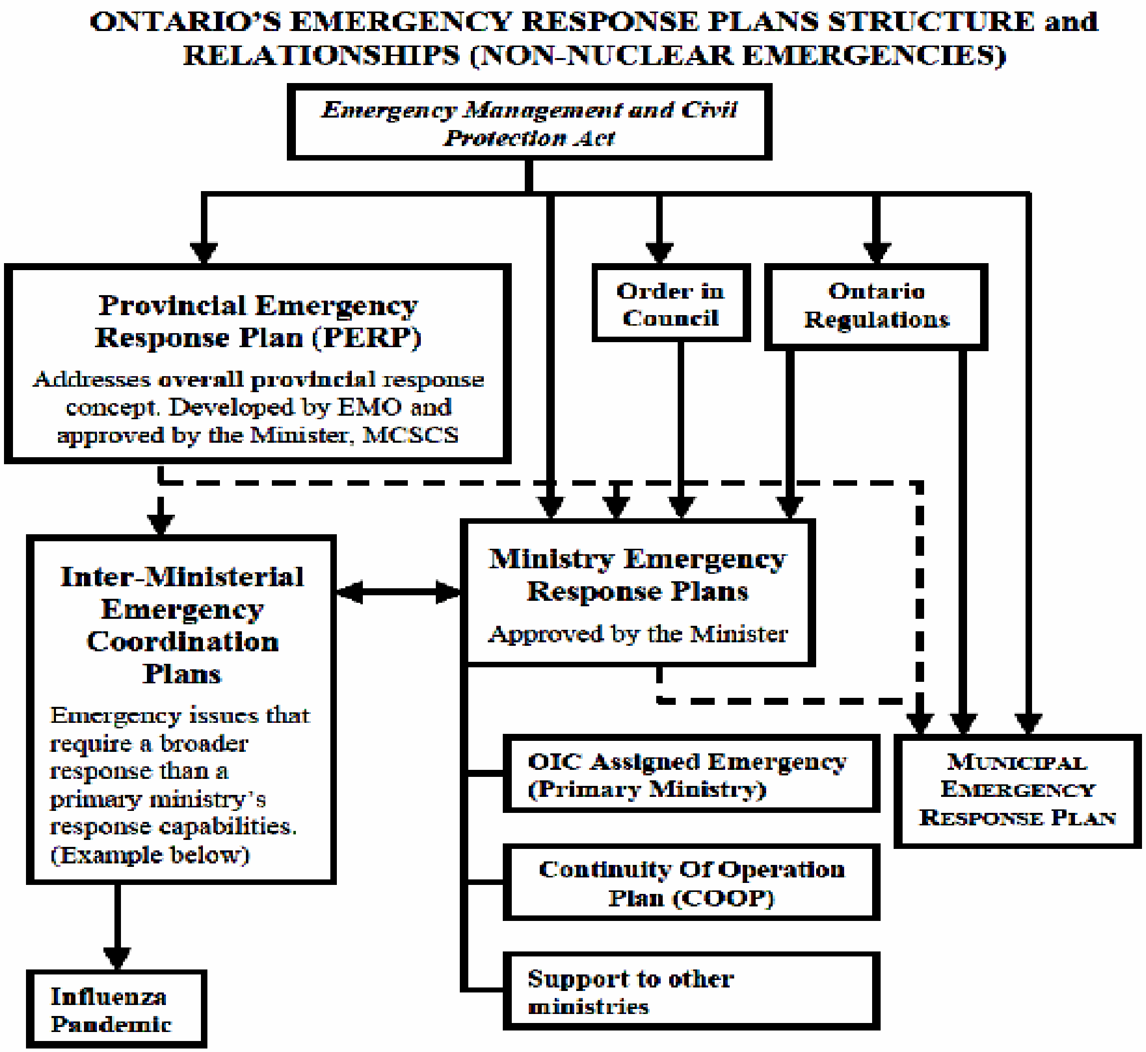


Figure 5.0 Hierarchical plan structure of Ontario's (2008) emergency response plans (Source: EMO, 2008, p.12)

As Figure 5.0 shows, the PERP (2008) is linked to both municipalities on the lower right and provincial ministries on both the left and middle of the diagram. This link is used to highlight the PERP's (2008) position within Ontario's emergency planning structure from which lower levels of government will create their own emergency plans. As a tool for building an emergency plan and responding to disaster the PERP (2008) contains chapters on emergency planning considerations and concepts (i.e. hazard analysis, operational priorities, jurisdiction etc.), emergency notification and declaration procedures, emergency response structure (i.e. levels of operational response during an emergency), and emergency response roles and duties. There are also chapters that describe how to work with the media, how to communicate and handle important information prior to and during an emergency, and how federal support is organised and utilized for an emergency response (i.e. requesting the help of the Canadian Forces). It is important to note that the PERP (2008) is not simply an information tool used by municipalities and ministries to build their own, more event-specific emergency plans. The PERP (2008) also dictates the procedures and protocols for a provincial response to an emergency, including widespread and complex emergencies like the 1998 Ice Storm.

Aside from highlighting the planning structure of emergency response in Ontario, Figure 5.0 also brings attention to the concept of a widespread disaster. The PERP (2008) identifies a widespread disaster as, "one that impacts a large geographic area and affects a large number of jurisdictions simultaneously … [and is] further complicated if it is of extended duration" (PERP, 2008, p.44). The 1998 Ice Storm is an example of this definition, and one may speculate that this definition had been added to the PERP (2008) with the Ice Storm disaster in mind. In fact, included in the PERP (2008) as an example of a widespread emergency is an 'extreme ice storm'; possibly chosen as an example due to the 1998 Ice Storm's significant and memorable impact on eastern Ontario.

In the PERP (2008), each ministry is tasked with the responsibility of specific hazard threats; for example, the MTO is responsible in planning for any emergency related to the province's highways, roadways, and other transportation routes. Table 5.1 below summarizes each ministry's responsibility during an emergency as outlined in the PERP (2008). Not all ministries are included in the table, only those ministries that were most active during the 1998 Ice Storm and would likely be active in another prolonged ice storm event. This is important for the discussion herein because the ministries were active during the 1998 Ice Storm scenario and because a provincial emergency response utilizes ministry support with clearly defined roles.

Ministry	Responsibility to plan for
Ministry of Community Safety & Correctional Services (MCSCS)[1]	Any emergency that requires the coordination of provincial emergency management, nuclear & radiological, severe weather, war, building structural collapse, explosion and structural fire, space object crash, terrorism, and civil disorder.
Ministry of Community and Social Services (MCSS)[2]	Any emergency that requires emergency shelter, clothing and food, victim registration and inquiry services, or personal services.
Ministry of Energy[3]	Any emergency affecting energy supply including electricity, natural gas, gasoline, etc.
Ministry of the Environment (MOE)[4]	Any emergency dealing with spills and pollutants including transportation spills. Also anything affecting drinking water.
Ministry of Health & Long-term Care (MOHLTC)[5]	Any emergency dealing with health including disease and epidemics. Also responsible for health services during non-health related emergencies.
Ministry of Transportation (MTO)[6]	Any emergency related to transportation.
Ministry of Natural Resources (MNR)[7]	Any emergency related to forest fires, floods, drought, dam failures, erosion, and soil and bedrock instability.

Table 5.1 Summary table listing emergency responsibilities for each ministry.

Sources:
(1) EMO, 2008, p. 67
(2) EMO, 2008, p. 68
(3) EMO, 2008, p. 71
(4) EMO, 2008, p. 72
(5) EMO, 2008, p. 73
(6) EMO, 2008, p. 82
(7) EMO, 2008, p. 79

As a means for preparing for a widespread emergency, the PERP (2008) encourages the development of inter-ministerial emergency coordination plans which are also shown in Ontario's emergency planning structure in Figure 5.1. These plans would be needed in the event that multiple ministries become involved in a coordinated emergency response. The existence of coordinated plans in Ontario's emergency planning structure shows that EMO (the 2008 PERP's authors) anticipated the need for a high degree of coordination when responding to a widespread emergency. The challenge is whether the PERP (2008) would be able to accommodate this need if an event similar to the 1998 Ice Storm causes widespread power failures that cascade to communications systems and other CI. Moreover, the presence of these plans suggests that cascading failure, as a source of widespread emergencies, should be taken into consideration when planning for such an emergency.

From the case study presented in Chapters 4 and 5 of this thesis, it is understood that a cascading failure across CI would be closely linked to the occurrence of a widespread emergency. Although each ministry is tasked with a specific responsibility suited for small-scale, single-point emergencies, the cascading failure characteristic of widespread disasters would have adverse impacts on multiple human and non-human systems requiring a coordinated response between the province (through EMO) and several different provincial ministries; hence the incorporation of inter-ministry coordination plans. It is important at this point to clarify that it is not within the scope of this thesis to address the adequacy of municipal response plans or inter-ministry coordination plans. It is enough to recognize that the PERP (2008) has designated that each ministry be able to coordinate an effective response when multiple ministries are involved. Moreover, it is the view of this thesis that individual ministries that acted during the 1998 Ice Storm performed well in responding to the disaster by using both improvised decision making and their own pre-planned protocol. This chapter is only concerned with how the current directives within the PERP (2008) itself would be used in an ice storm event similar to the one that occurred in 1998.

5.2 Comparison of Events from 1998 and the Current PERP (2008)

With the information presented in Chapters 3 and 4, it is possible to summarize the 1998 Ice Storm into several broad themes for discussion throughout the rest of this chapter. First, there is the concept that the 1998 Ice Storm was in fact a widespread emergency as evident by the unprecedented number of municipalities and regions across eastern Ontario that simultaneously declared an emergency. Second, due to the nature of a widespread emergency event, coordination across multiple groups was crucial for responding to this type of disaster. The current PERP (2008) tasks EMO with the job of coordinating the movement of resources to those communities adversely impacted during an emergency event, such as a prolonged ice storm. This includes those resources needed in order to adapt to multiple failures that are likely to occur throughout a highly interconnected and interdependent CI network that is susceptible to prolonged bouts of freezing rain. Locating and moving these resources in a timely and efficient manner can be more difficult when the CIs those resources are meant to maintain and repair are also the CIs that are needed for locating and delivering crucial resources. One key point to make is that during the 1998 Ice Storm, EMO was able to operate with all infrastructures functioning (i.e. electricity and telecommunications) because their headquarters were located outside of the Storm region; however, due to a series of miscommunications with Ontario Hydro and the difficulty of coordinating with emergency staff located within the Storm affected region, EMO was not fully informed on the severity of the situation in eastern Ontario.

The following is a comparison of how events that occurred during the 1998 Ice Storm might happen today with the current PERP (2008) in place. The ideas presented herein come from informed speculation, including the assumption that an ice storm of similar destructive force as the 1998 Ice Storm may one day reappear in the region. Such ice storms have already appeared in Canada and the United States since 1998; for example, on Friday December 6, 2013 a severe ice storm knocked out power to homes and businesses in Texas. Also, in December 2013 the Greater Toronto Area experienced a severe ice storm that impacted electricity distribution in the region. The potential of another severe ice storm occurring is likely. Moreover, all of the direct affects that potential future freezing rain could have on electricity, communications, and transportation infrastructure are assumed to be similar to the 1998 Ice Storm. For example, it is expected that there would also be a widespread power outage caused by damaged power transmission structures, telephone and cellular communications would still be disrupted by damage to phone lines and over-burdened cellular channels, and transportation would be hindered by debris from trees, power lines and icy surface conditions.

Disaster by its very nature is largely unpredictable, particularly when multiple threats such as widespread freezing rain and a prolonged power outage intersect with people and technology. Thus, the presumed effects a modern-day storm would have on CI are largely dependent on the susceptibility of today's infrastructure components versus components used in 1998. For example, would the weight bearing load of power lines, phone lines, utility poles, and energy pylons used today surpass the load bearing amount of the freezing rain? In other words, have CIs been upgraded since the Ice Storm? Have improvements in communications technology since 1998 opened up more pathways for people to communicate; thus limiting the severity of a communications disruption? Technological improvements can be helpful in some cases and they should not be ignored when considered in combination with other factors. Hazards geography research has already alluded to the problems associated with an entirely technocratic solution to hazards. As such, this thesis assumes that there is still the possibility that a prolonged ice storm would have enough force to disrupt even an upgraded CI network; this sets the parameters for the comparison conducted in the remainder of this chapter.

Table 5.2 summarizes ANT's application as both a forensic tool for deciphering a past event (i.e. such as what occurred during the 1998 Ice Storm) and as a tool for peering into the future to determine what, under the guidance of the PERP (2008), might occur during an Ice Storm today.

Table 5.2 Application of Actor-Network Theory as a Forensic Tool and a Futuristic Tool

Selected Key Events in the 1998 Ice Storm	**Application of Actor-Network Theory as a:**	
	Forensic Tool (i.e. what occurred in 1998)	**Futuristic Tool (i.e. what might have occurred under guidance of the PERP (2008)**
Prelude to a Cascading Failure: 1) The ill-prepared coordinated response and miscommunication with Ontario Hydro: -Ministries and municipalities criticise Emergency Management Ontario's late resource response to the Ice Storm -No coordinated provincial plan exists	**Prelude to Cascading Failure:** 1) The severity of the Ice Storm in eastern Ontario is not clearly expressed to EMO by Ontario Hydro. Despite an increase in critical infrastructure disruption, it takes several days into the Storm before EMO coordinates the deployment of generators into Ottawa and the affected eastern Ontario region.	**Prelude to Cascading Failure:** 1) The PERP (2008) mandates that coordination between ministries (i.e. MTO) and key infrastructure stakeholders (i.e. Ottawa Hydro) be taken into consideration in individual emergency plans. The experience of the 1998 Ice Storm is now included in the network, making it more likely that (1) EMO's response will come sooner, and (2) other infrastructure-linked organisations (OPP, MTO, etc.) have the knowledge to prepare for a massive power outage (although, this does not suggest they will in fact be prepared). **A strict adherence by municipalities and key infrastructure stakeholders to the recommendations outlined in the PERP (2008) makes it likely that resources (human and non-human) will be more readily available earlier during a storm.**
2) The generator lifeline: -Large numbers of generators brought into the eastern Ontario region are put into use.	2) The duration of the ice storm causes mechanical failures in some generators. Also, the fragility of the fuel supply increases with each day of freezing rain making it more likely that generators' will also fail (i.e. the disruption of a cellular tower in Ottawa).	2) As mandated in the PERP (2008), the back-up systems necessary to maintain the service of CIs during a black out are heavily centred around the use of generators **Thus, it is likely that the extent of a cascading failure within the network will be dependent upon the ability of critical infrastructures to maintain working generators.** **Also, as an intermediary, fuel will likely remain a point of fragility within the network, particularly with each additional day of continuous freezing rain.**

Selected Key Events in the 1998 Ice Storm	**Application of Actor-Network Theory as a:**	
	Forensic Tool **(i.e. what occurred in 1998)**	**Futuristic Tool** **(i.e. what might have occurred under guidance of the PERP (2008)**
Emergence of the Cascading Failure: 1) The closure of HWY 417: Prolonged pressure of freezing rain on exposed infrastructure causes disruptions to mechanical (i.e. power lines) and non-mechanical (i.e. road surface conditions) components. Such disruptions are shared between CIs; for example, power lines, causing highway closures.	**Emergence of the Cascading Failure:** 1) During the third day of the Storm power lines fall across HWY 417; in response the OPP closes the highway until the lines can be safely removed by hydro crews and other experienced responders.	**Emergence of the Cascading Failure:** 1) The PERP (2008) offers no specific guidance for ensuring that major highways remain clear of debris. **Thus, it is likely that major road closures would again occur. The length of time for the closures would be dependent upon the number of experienced hydro crews available to remove live wires and the extent of damage caused to exposed electrical infrastructure by freezing rain.**
2) The fragile fuel situation: Both the power outage and disruption to Ottawa's transportation infrastructure have put great pressure on a fragile fuel supply that is in high demand.	2) Ottawa's telecommunications are disrupted when a cellular tower loses power	2) **The PERP (2008) looks to incorporate back-up systems that can maintain the service of critical infrastructure. Such systems are dependent upon working generators, and therefore, it is likely that a cascading failure would occur at a moderate to severe degree if both electricity and transportation infrastructures were disrupted by both a storm and each other.**

It is the point of view in this thesis that should an ice storm of similar or greater magnitude occur in eastern Ontario, the disruptions to electricity, transportation, and communications infrastructure would likely outpace infrastructure restoration. This is outlined in Table 5.2 where several specific points during the Ice Storm are used as examples of ANT's forensic capabilities. Leading up to the cascading failure, ANT identifies problems in communication and coordination between emergency managers and key infrastructure stakeholders, namely, EMO and Ontario Hydro. A primary consequence of this miscommunication is revealed in EMO's delayed response during the Storm. Recall that it took several days of freezing rain before EMO coordinated the deployment of generators into Ottawa and the eastern Ontario region. By that point during the Storm, severe disruptions had already been occurring throughout Ottawa's CI and the beginnings of a cascading failure were well underway. Essentially, as an emergency response organisation, EMO's response lagged behind what had been occurring rather than keeping pace with events. For example, when generators were initially needed in Ottawa, individuals, businesses, and ministries could not rely on EMO and instead acquired generators on their own. When EMO eventually caught on to the generator crisis in eastern Ontario, and initiated a coordinated movement of generators into the region, fuel scarcity had already become an emerging crisis. To put it simply, EMO had been continually focused on dealing with yesterday's problems and not today's.

With the current PERP (2008) in place today, and given the memorable imprint that may have been left on emergency managers by the Ice Storm, it is likely that a more efficient response would come from EMO sooner. First, the necessary coordination initiatives between ministries, municipalities, and CI stakeholders are carefully outlined in the PERP (2008). In

1998, coordination was something that Ontario's emergency plans did not take into consideration[120] and emergency planning in Ontario did not truly comprehend due to lack of experience. Today, the PERP (2008) recognizes the potential need for a large coordinated effort between groups and mandates that each group develop coordinated emergency response plans for use during a wide-scale emergency. If these groups were to strictly adhere to the recommendations outlined in the PERP (2008) it is more likely that resources (human and non-human) would be more readily available earlier on during the storm.

Use of ANT in Chapter 4 has shown that sufficient resources (i.e. fuel, generators, hydro workers, etc.) during a prolonged ice storm would hinder the progression of a cascading failure. However, it is important to note that ANT also shows that these resources should be used with the understanding that they are a fragile and temporary solution during an emergency response. The longer back-up systems are in place and relied upon during an abnormal weather event, the more likely it is that a disruption in a CI would occur at some point. This is stated in Table 5.2 under the example of the generator lifeline and the scarcity of fuel supplies. Any break in the network of CIs could hinder the movement of resources. For example, severe transportation disruptions would threaten fuel supply, and in turn generators. Considering the ever increasing interdependence of modern infrastructure and its susceptibility to severe weather, it becomes more likely that given enough time during a storm, there would be a break in the resource chain and greater difficulty managing a failure. Given what ANT reveals about freezing rain, and given the structure of the current PERP (2008), emergency management in Ontario would likely be forced into a position of adaptation more so than to mitigation. The

[120] This is according to Lecomte et al., 1998 & Purcell & Fyfe, 1998.

PERP (2008) could respond to the freezing rain's impact in so far as it can attempt to limit such things as the spread of an electricity failure, or the closure of a major highway.

Unfortunately, the ANT analysis shows that transportation infrastructure would likely experience severe disruptions during another prolonged ice storm. This is largely a case of how cities are built; something the PERP (2008) does not appear to address. For example, tree debris and power lines could still fall onto Ottawa's highways and roadways during a storm. The PERP's (2008) guidance on this matter is that it is up to the MTO to ensure highways remain clear, which is no real change from the responsibilities of the MTO during the Ice Storm. The length of time for future road closures caused by an ice storm is unpredictable; however, the point to make is that this could be the initial point where a cascading failure could occur in a future storm. ANT helped establish that the likelihood of an electricity disruption is high during a severe bout of freezing rain and that generators would be used in greater numbers, particularly with the coordinated resource efforts outlined in the PERP (2008). The ANT analysis also established that a severe disruption in transportation infrastructure puts pressure on fragile fuel supplies with consequences for other CIs such as communications. Thus, it is likely that a cascading failure would occur from a moderate to severe degree if both electricity and transportation infrastructures were disrupted by both the Storm and each other.

<u>**Chapter 6: Conclusion**</u>

When referring to the events that occurred in Ottawa from January 5 to January 10, 1998 this thesis has made use of the term *Ice Storm*. This term is a label and within this label are a multiplicity of meanings related to place, environment, hazards, technology, society, and disaster. Actor-Network Theory (ANT) has been used here to organise a wide array of actors and intermediaries associated with this *Ice Storm* and to show how they together form a network of study. ANT also provided a means for taking a theoretically infinite network and isolating only those pieces that are of the most interest with regards to ice storms and cascading failure in critical infrastructure (CI). Akin to Bruno Latour explaining that ANT is an opening of the metaphorical *black-box*, this thesis has opened the 1998 Ice Storm to illustrate the occurrence of a cascading failure; such failures are initiated by the intersection between a natural hazard and the built-environment made up of CIs.

In accordance with ANT and the notion of translation, this thesis has been presented much like a user-manual. It discussed the 1998 Ice Storm first as a complete whole narrated through series of events that took place, and then by its individual components consisting of actors and their intermediaries (i.e. actions). The primary goal of this has been to demonstrate how an extreme weather phenomenon intersects with the built-environment. As this thesis has shown, such an intersection can result in a cascading failure through a number of CIs. This was followed by adverse outcomes for society and the recognition that modern cities are now at risk of cascading failures in CI, and thus, exposed to complex hazardous events. This argument was made by showing, with the help of ANT, that conditions conducive to a cascading failure are present prior the occurrence of a prolonged and widespread ice storm. The assemblage of actors and intermediaries associated with CI are, by their very presence in the network of study, the instigators and promoters of a cascading failure.

To reach the above conclusion, the thesis began with an in-depth literature review in Chapter 2 on what has been achieved in hazards geography research. Chapter 2 showed that geographers have, over many decades, formulated strong ideas about hazards and disasters, but very little has been done to understand the role of cascading failure in CI. They have shown that natural hazards are integrally linked to a vulnerable society but they have not fully explored how CIs, which have deeply rooted themselves into the urban ecosystem, have influence in a society's risk to extreme hazards. This thesis has showed that cascading disruptions in CI force upon the urban ecosystem described in Chapter 1 a blending of hazards, that when combined with a natural threat, becomes a unique and complex blend of the natural, technological, and social. In this respect, the outcome created is of a highly interdisciplinary nature in research, and so, Chapter 2 also included a discussion on ANT as a means for including the technological, social, and environmental into a single study. Moreover, this theory has been used to help guide the undertaking presented in this thesis; primarily with its key notion of translation. In ANT, translation is a process of identifying key actors, how they are enrolled into a network, and how they work to make the network stable (or unstable). In short, translation is the formation of networks. It is a means for descriptively mapping the cascading failure that occurred during the 1998 Ice Storm. The process of translation identifies actors and traces their intermediaries to show, in the case of this thesis, how a cascading failure can and does occur.

The translation began in Chapter 3, which provides a day-by-day narration of events during the Ice Storm. In accordance with ANT principles, this is the story of the Ice Storm as it was told by media, government reports, weather records, and other secondary data sources. This chapter presented the black-boxed version of the Ice Storm as it describes only what occurred and does not go into a deeper tracing of actors and their association with other actors via intermediaries. To limit the chapter to within the context of this thesis, events were described as they relate to ice storms (forecasting, freezing rain totals, wind), Ottawa's CI (disruptions in electricity, transportation, and communications), and the reactions of emergency managers and other groups (the Ontario Provincial Police (OPP), military, politicians).

Chapter 4 continued the translation by isolating several primary actors from the 1998 Ice Storm including: the freezing rain, electricity infrastructure, transportation infrastructure, and communications infrastructure. With the exception of freezing rain, a diagram has been created for each primary CI actor that measures the level of disruption experienced within each of the named infrastructures on a day-to-day basis during the Storm. These diagrams have been used to examine how each infrastructure reacted to the freezing rain in isolation from one another. In doing so, those actors and intermediaries specifically tied to each infrastructure were identified. Furthermore, an isolated measurement of disruption can be useful for tracing the consequences of each infrastructures failure. However, to be able to trace the cascading failure, all of the primary actors (CIs and freezing rain) were unified into a single disruption diagram. Then, several shaded-boxes were placed at specific locations in the unified disruption diagram from which an analysis was conducted. It was discovered through this analysis that early on in the Storm, disruption in Ottawa's infrastructures occurred largely in isolation from one another, and were likely a direct result of the effects of the freezing rain. The tracing showed that back-up systems in place prior to the Storm were creating barriers that would halt the disruption in electricity from cascading to other infrastructures. Several days into the Storm, when the duration of freezing rain exceeded the capacity of these back-up systems, isolated failures begin to cascade from one infrastructure to the next.

Following the theoretical analysis of Chapter 4, the next chapter applied this theory to emergency management practices in Ontario. The 2008 Provincial Emergency Response Plan (PERP) is an umbrella plan that informs all other emergency plans and practices in Ontario. Although the Plan did not exist in 1998, Chapter 5 speculates as to what would occur with regards to a cascading failure if another ice storm of similar force were to happen today. This chapter argues that the initial disruptions in Ottawa's CI would occur as they did in 1998, largely in isolation from one another. Given enough time, these isolated disruptions in combination with the freezing rain would likely overwhelm back-up systems and a cascading failure would once again be initiated by widespread power outages.

The longer-term and widespread characteristics of the Ice Storm have become a standard from which emergency practices in Ontario are derived. For example, a widespread communications breakdown, a simultaneous, massive, multi-jurisdictional emergency, and highly adept coordinated provincial response were all unique characteristics not seen before the Ice Storm.[121] They were also characteristics that overwhelmed the emergency response and in particular Emergency Management Ontario (EMO). Chapter 5 concluded with a

[121] This statement is supported by the interviews of emergency management personnel conducted by Purcell & Fyfe (1998).

description of how ANT and the notion of translation can be used to update, in accordance with technological and jurisdictional changes among other things, lessons learned from the 1998 Ice Storm. One way this can be done is by inserting new technologies as actors into the current network of CIs and other actors. Another way is to consider how inter-ministerial plans function in a network of study. What actors are they connected to? What intermediaries connect them? What formation does the network adopt when these interactions take place? And is it stable? And finally, with the formation of a stable network, what hazard could be inserted into the network that would cause instability to cascade from actor to actor.

6.1 Limitations and Potential Future Research

There are limitations to the work conducted in this thesis related to the tracing of the cascading failure. First, there are many ways to interpret the scale of the cascading failure. This thesis looked at the failure as it occurred only in Ottawa's urban setting; however, the full Ice Storm scenario also includes rural areas around Ottawa. At times during the research portion of this thesis, the tracing of the cascading failure would lead to rural communities with significant impacts to the population and the economy of these regions. In the interest of staying within the scope of this thesis, tracings outside of Ottawa's urban boundaries had to be closed from the analysis. Yet, considering the impacts the Storm had on farmers and the length of time it took to restore power to some rural areas, it is likely that the consequences may have been more severe for rural populations. In this respect, a future study may look to extend a tracing of the cascading failure analysis from the urban to the rural. Doing so may reveal that cascading failures have origins in urban locations but have a greater impact on rural populations. Furthermore, such a study would contribute to the discussion in hazards geography research on the urban-rural vulnerability divide. Also, it is suggested in the Purcell & Fyfe (1998) report that EMO's delayed response may have been partially attributed to having expended their resource pool early on in the Storm in order to help the much more troubled province of Quebec. In this respect, the cascading failure could be traced outside of Ontario, which also has implications towards the full scale of the failure.

Another limitation imposed on this thesis is the reliance on secondary sources for data regarding the scenario and the failure. ANT is based heavily on interviews as a means for following the actor and tracing the network. However, with the amount of time passed between the Ice Storm and today, it is unlikely that these interviews would be as accurate as they were following the Storm when such researchers as Purcell & Fyfe (1998) or Lacomte et al. (1998) conducted their own interviews. To compensate, this thesis relies heavily on historical data that can also be used justifiably in ANT. This is because these sources have now become part of the Ice Storm network and as actors themselves they are also a part of the tracing that begins with the primary actors. Moreover, historical accounts offer valuable insight into how these actors assert their power over the network of study.

6.2 Linking the Thesis to Hazard's Geography Research

The content explored in this thesis, especially in regards to ANT and cascading failure, have direct links to the hazards geography research discussed in Chapter 2. First, the initial disruptions in electricity, transportation, and communications infrastructure described in Chapter 4 coincide with ideas presented by Cruz (2012) regarding the susceptibility of infrastructure. Cruz (2012) wrote that exposure to natural hazards can damage CI and that electrical power and communications systems tend to be the most susceptible with the highest consequences for the emergency response capability. This thesis supports this claim but also adds that ice storms have an equal if not greater disruption on transportation infrastructure.

Hazards research in geography has long been criticized for lacking a strong theoretical approach to support its views on hazards and disasters. One of the primary challenges has consistently been that disasters are unique on a case-by-case basis. In response, hazards geography research still tends to focus on individual cases even with broader concepts of risk and vulnerability to help create theoretical similarities between hazards and their adverse outcomes. One particular trait geographers may find useful in ANT is that it subscribes to no a priori assumptions. It lets the actors in question form their own network through tracings and therefore is more accepting of differences and uniqueness because it is those things that define the network and reveal power. This is particularly important when one considers the concept of vulnerability and its ties to power; whether it is political power, monetary power, or power over livelihoods. In showing how networks are formed, ANT is also describing how power is exerted and where that power comes from.

Furthermore, cascading failure, when explored through ANT, also offers geographers a means for better linking the broad contextual aspects of hazards. Tracing a failure through multiple systems (i.e. actors and intermediaries) not only reveals how natural hazards exert their power on society or vice-a-versa; but also brings attention to the interdisciplinary nature of hazards research. ANT excludes the need to categorize hazards as technological, human-caused, or environmental. With ANT, such categorizations, which are also used abundantly in hazards geography research, are difficult to make. Instead, a failure occurs throughout a single network that contains all of these domains. It is within this network that actors present themselves as either promoting the failure and growing the hazardous threat, or, hindering the failure and minimizing any threats. It is notable that CIs have a contradictory role within the modern-urban environment: when functioning normally they keep people, their property, and the environment safe from adverse outcomes; however, they also create their own adverse outcomes when normal operations are disrupted and their services cease. As this thesis has shown, the potential for a cascading failure is already present in the network before a natural hazard occurs; this is an unavoidable outcome derived from the structure of the urban ecosystem intersecting with an irregular natural phenomenon. Learning how to recognize where these failures spread can have significant implications to both emergency practices in Canada and hazards geography research.

Further contributing to knowledge on ice storms and cascading failure in critical infrastructure is the idea that transportation infrastructure has been routinely overlooked as a major actor during disaster. This thesis showed that a city's transportation system is also highly susceptible to ice storms and, in combination with other infrastructure failures, can further hinder a city's response capability. Furthermore, the Ice Storm is often thought of as an electricity disaster but given the challenges created by a severely disrupted transportation system, this storm could be (and perhaps should be) re-imagined as something much different.

Finally, this thesis described in Chapter 4 a theoretical link that exists between ANT and the concept of context. ANT’s notions support the exploration of the broader contextual aspects associated with individual disasters and explains how these aspects are connected to form disaster. This is a particularly useful trait when studying the occurrence of a cascading failure where multiple contexts are involved. Progress made in hazards geography research by

White (1945), Hewitt (1983), and Blaikie et al.'s (2004) PAR Model are in part an extension of this link. White (1945) surmised that blame on disasters should be placed largely on the social environment in which the disaster played out. Human decision and management of the natural environment were the determining agents for why disaster occurred. His work had broadened the disaster context from purely natural phenomenon to social phenomenon. In turn, Hewitt (1983) used this perspective to include a more detailed look at how the individual characteristics of a vulnerable population will determine both the occurrence and the extent of disaster. In doing so, Hewitt further broadened the context of disaster, which has since become a significant challenge to research in hazards geography.

At its core, vulnerability has the capacity to expose multiple contextual domains in a disaster ranging from the political, economic, environmental, social, and technological; albeit separately from one another. By incorporating such models as the PAR, these wide ranging domains can be categorized under the label of vulnerability and used to identify populations prone to disaster. For example, infrastructure related vulnerabilities such as a susceptibility to freezing rain or the technocratic vulnerability that describes a population's dependency on electricity both have influence on a population's vulnerability to a natural hazard. Furthermore, vulnerability can be used to explain the impact certain population characteristics such as political freedom or technological dependence have on a society threatened by a natural hazard; however, on its own, the concept of vulnerability does not sufficiently explain the deeper connections that can be found between characteristics. However, ANT can make these connections, and is therefore beneficial to the progression of hazards geography research. For example, the ANT-cascading failure research conducted in this thesis is applicable not only to wealthy regions in North America but in poorer regions in the developing world. This is because ANT offers a means for tracing different contextual aspects that maintain connections and form phenomenon such as a cascading failure. The benefit to hazards geography research is in the ability to remove the theoretical barrier created by the broadening of contextual aspects. Adding ANT into the analysis of hazards means that geographers can research disasters in ways that include the crucial connections between human decision, the natural-environment, and the configuration of the built-environment. These connections can be used to identify conditions which are conducive to the occurrence of a cascading failure in critical infrastructure, which can help strengthen adaptation and mitigation strategies in future emergency plans.

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Appendix A

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