Impact of Climate Change on Winter Road Systems in Ontario’s Far North: First Nations’ and Climatological Perspectives on the Changing Viability and Longevity of Winter Roads

by

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A thesis submitted in conformity with the requirements for the degree of Doctor of Philosophy
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Abstract

Climate change is already being experienced in Ontario’s Far North with implications for First Nations communities that are reliant on winter road systems. The first study of this thesis examined how winter road seasons have been affected historically by particular climate conditions by focusing on the timing of opening dates of the James Bay Winter Road (JBWR). This study established a minimum threshold of 380 freezing degree-days (FDDs) below 0°C, a threshold subsequently used to assess the impacts of climate change on winter road systems in the future using climate change projections. The second study explored the current vulnerability of the Fort Albany First Nation community regarding physical, social/cultural, economic impacts associated with changing winter roads and its seasons, as well as river ice regimes. Through the
analysis of key informant interviews and winter road user surveys on the changes in winter roads and river ice regimes, the six major themes were identified. As a result, the JBWR has now become a critical seasonal lifeline for not only providing a relatively inexpensive land transport of essential goods and supplies, but also reconnecting coastal remote communities by physical, social, and cultural activities during winter. The third study focused on the viability and longevity of winter road systems in Ontario’s Far North for the next century using recent climate model projections using three Representative Concentration Pathway (RCP) scenarios. Using FDD threshold established in the first study as the main metric, climate conditions are expected to remain favourable in Big Trout Lake and Lansdowne House during winter road construction through the end of 2100. However, climate conditions would possibly be unfavourable for winter road construction at Moosonee, Kapuskasing, and Red Lake by 2041–2070. These studies demonstrate that there is an immediate need to develop adaptation strategies in response to impacts of climate change on winter roads in Ontario’s Far North.
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Statement of Co-authorship

A number of chapters were written as standalone manuscripts for publication in peer-reviewed journals at the time of this thesis submission. Chapter 2 to 4 are currently under review in peer-reviewed journals. For each of the manuscripts, I worked as the principal investigator for research project involving study design, community visit and land observation, data collection and analysis, and manuscript writing. My supervisor, Dr. William Gough, provided the necessary supervision and guidance throughout all steps of each research project. Specific contributions of co-authors to each manuscript are described below.

Chapter 2

Chapter 2 is co-authored by Dr. William A. Gough, Dr. Ken Butler, and Dr. Leonard Tsuji. Dr. William Gough and Dr. Leonard Tsuji provided invaluable scientific guidance and expert advice for the research design and editorial input for manuscript preparation. Dr. Ken Butler provided expert advice for the statistical analyses of this research.

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Chapter 1
Introduction and Literature Review

1 Chapter 1

1.1 Introduction

An increase in average surface air temperature has been observed in the Canadian Arctic and subarctic using instrumental records and Indigenous observations (Ford et al., 2006a; Furgal and Prowse, 2008; Hassol, 2004). Climate change scenarios have indicated that the greatest temperature changes are projected to occur in northern Canada, particularly during the fall and winter seasons (Furgal and Prowse, 2008). Thus, the intensified warming will cause a number of significant impacts in the cryosphere, including sea ice, snow cover, glaciers, ice sheets, lake and river ice, and permafrost (Furgal and Prowse, 2008; Gagnon and Gough, 2005b). As the climate over northern Canada continues to change, alteration of human access to northern regions will be a consequence of this climate change.

The most significant impact of climate change on transportation systems in northern Canada is the reduced viability of winter roads and their seasonal nature. Winter roads consist of ice roads over land, frozen lakes, and rivers, and these roads are very common in northern
Canada and Alaska, USA (ACIA, 2005; Adam, 1978). In the Far North of Ontario\(^1\), a network of winter roads links 31 remote First Nations communities to all-season road systems (Government of Ontario, 2015c). These seasonal transportation corridors are critical lifelines for all remote communities, enabling the delivery of essential goods, medical supplies, and heavy building materials (Chiotti and Lavender, 2008; CIER, 2006; Furgal and Prowse, 2008; Hori et al., 2016). They also provide social and cultural opportunities among nearby remote communities during winter months. However, in recent years, there is growing recognition that the length of the winter road season has shortened and the quality of the roads has reduced due to the effects of climate change (ACIA, 2005; Blair and Sauchyn, 2010; CIER, 2006; Hinzman et al., 2005; Hori et al., 2015; Tam et al., 2013). For instance, following the 2015 United Nations Climate Change Conference, i.e., COP 21, held in Paris, Isadore Day, the Ontario Regional Chief for the Assembly of First Nations expressed his concerns about the reliability of the winter road systems in Ontario, Canada:

> I am calling upon our Treaty partners the federal and provincial government to step up now and order a Climate Change Impact Study for the north. We can’t wait any longer. Climate change has dramatically reduced the length of time winter roads are accessible causing shortages of food, fuel and medical supplies and increasing the need to fly-in supplies. This results in higher living costs and potential decreases in quality of life and health. (Chiefs of Ontario, 2015, p.1)

The main objective of this dissertation is to examine the implications of climate change

\(^1\) The term, Far North of Ontario, refers to northern Ontario, as defined by the Far North Act, 2010 (Government of Ontario, 2015a).
on the winter road systems in the Far North of Ontario, and also to investigate current vulnerability and potential adaptability of First Nations regarding physical, social/cultural, economic impacts associated with changing winter road seasons and conditions. The detailed research objectives of this dissertation are provided in Section 1.4.

1.2 Chapter Overview

This dissertation has been divided into five chapters. The first chapter provides a literature review of climate change in northern Canada, sea and river ice regimes, winter roads, and community adaptation in the context of the main objective of the entire dissertation. The detailed research objectives and significance of the research are presented after the literature review. Chapters 2–4 are presented as manuscripts of three different studies. Lastly, Chapter 5 includes a discussion of the key findings from all three studies, concluding with future steps in research. I note that there are sections of writing that are repeated in this dissertation due to a hybrid thesis format, which contains a series of submitted and/or in-preparation articles such that some passages of the literature review of this thesis are the same as those found in the introduction and methods sections of each article.
1.3 Literature Review

1.3.1 Climate Change in Northern Canada

There is strong evidence that northern Canada is undergoing a number of significant changes in its climate (ACIA, 2005; Anisimov et al., 2007; Furgal and Prowse, 2008; Larsen et al., 2014). An increase in average surface air temperatures has resulted from a number of extreme temperatures that have been observed at higher northern latitudes, particularly in the Arctic, by instrumental records and Indigenous observations (Ford et al., 2006a; Furgal and Prowse, 2008). Since the mid-20th century, surface air temperatures in the Arctic region have risen by between 0.5°C and 2°C (Larsen et al., 2014). This region in particular has experienced the most rapid rates of increasing average surface air temperatures compared to the global average temperatures during the last century (ACIA, 2005; Anisimov et al., 2007; Furgal and Prowse, 2008; Hassol, 2004). Thus, the rate of warming in the future for the Arctic is expected to exceed the global rate (Larsen et al., 2014).

The Hudson and James Bay regions, which are located within the Arctic and subarctic regions of Canada, are therefore strongly affected by rising temperatures (Gagnon and Gough, 2002, 2005a; Ho et al., 2005; Laidler and Gough, 2003). For example, the duration of sea-ice cover in the Hudson and James Bay has been decreasing as a consequence of earlier break-up and later freeze-up dates over the past few decades (Gagnon and Gough, 2005b; Gough et al., 2004a; Hochheim and Barber, 2014; Kowal et al., 2015). Gough et al. (2004a) report that the trend towards earlier sea-ice break-up dates for the southwestern region of Hudson Bay and the
northwestern region of James Bay are consistent with increased spring temperatures. On the other hand, the trends in river ice break-up dates in the western James Bay region are statistically weak although average spring and winter temperatures have increased (Ho et al., 2005). One limitation to the study by Ho et al. (2005) is that it lacks a large dataset to identify long-term trends. It is also possible that there may have been significant changes in break-up events in recent years. Ho et al. (2005) suggest that Indigenous knowledge can complement conventional scientific methods in research such as statistical analyses; such knowledge is important in understanding uncertainties with respect to regional climate change. In addition to temperatures increasing in the Hudson and James Bay regions, precipitation has increased in the regions (Gagnon and Gough, 2002). The Moosonee weather station, located in the western James Bay, has experienced an increasing trend in summer and fall precipitation. This trend is statistically significant at the 95 % level of confidence (Gagnon and Gough, 2002).

Such recent regional climate changes have affected many natural and human systems. A longer ice-free season has detrimental effects on local ecosystems, as well as animal and plant populations and distributions (Gagnon and Gough, 2005a, 2005b). For instance, sea ice is an important platform for polar bears to hunt for food (e.g., seals); changes in the annual sea ice cycle of the Hudson and James Bay regions pose a potential threat to the local polar bear population (Gagnon and Gough, 2005a, 2005b; Gough et al., 2004b; Gough and Wolfe, 2001; Stirling et al., 1999). According to the Arctic Climate Impact Assessment (ACIA) (2005) and Canadian Council of Ministers of the Environment (CCCME) (2003), the average weight of polar bears and their number of cubs have declined from 1981 to 1998 in these areas. In addition, waterfowl migration routes have shifted from the coast to inland, so the number of birds following traditional coastal migration patterns has declined for both spring and fall (McDonald
et al., 1997). As spring and fall waterfowl hunts are important harvesting activities for coastal Cree communities on Hudson and James Bay, the decreasing number of coastal migrations has a negative impact on the traditional economy and cultural importance for the communities (Laidler and Gough, 2003). Subsistence fishing is also an important harvesting activity for Cree communities (Berkes et al., 1994, 1995). Hori et al. (2012) reported an extreme event of fish die-offs in 2005, which was linked to observed regional climate changes. Such climatic changes impacted specific fish species of specific age classes, leading to a reduced source of food for nearby communities. With the continued effects of climate change, it is possible that a change in food sources such as fish may lead to food security issues for such communities.

The Canadian North is home to Indigenous peoples who receive a variety of benefits from the natural environment; however, many community members have noted significant changes in the ecological, economic, and social systems (ACIA, 2005; McDonald et al., 1997). Specifically, many have expressed growing concerns for their changing environment and way of life (Anisimov et al., 2007; Ford, 2009; Ford et al., 2006a, 2006b, 2007, 2009; Furgal and Seguin, 2006; Laidler, 2006; Laidler et al., 2009; Laidler and Gough, 2003; Larsen et al., 2014; Tam et al., 2013).

The climate model projections by the IPCC Fifth Assessment Report (AR5) show that by 2100, the global average surface air temperatures are projected to rise by 4.8°C and sea levels will increase by 0.82 m, relative to 1986–2005, under the Representative Concentration Pathways (RCPs) 8.5 scenario (IPCC, 2014). In particular, changes in the variability and intensity of climate events are expected to be significant at high latitudes (IPCC, 2014; Furgal and Prowse, 2008). Furgal and Prowse (2008) report that climate change scenarios for the Canadian Arctic project an increase in temperature ranging from 3.5°C to 12.5°C during the
2071–2100 period; moreover, temperature variability will be at its greatest during fall and winter. As well, most of the scenarios project an increase in annual precipitation varying from 15 to 30% (Furgal and Prowse, 2008). In the Hudson Bay region, the climate change projections present an increase in temperature ranging from 3.9°C to 4.5°C for the 2041–2070 period (2 × CO₂ concentration), as well as from 4.8°C to 8.0°C for the 2071–2100 period (3 × CO₂ concentration) (Gagnon and Gough, 2005a). The greatest warming is expected from October to April over the ocean due to a depletion of the sea ice cover (Gagnon and Gough, 2005a). In addition, annual precipitation in the region is projected to increase 3.2 mm to 7.1 mm per month for the 2041–2070 period and 5.2 mm to 11.3 mm per month for the 2071–2100 period (Gagnon and Gough, 2005a). In the western James Bay region, by 2100, mean air temperatures are projected to increase by approximately 18°C range in summer, 6°C range in fall, and -9°C range in winter, and 0°C range in spring, relative to 1961–1990, from 13.5°C, 2.8°C, -18.6°C, and -3.0°C, respectively (Hori, 2010).

These projections of climate change in northern Canada indicate that the degree of warming in the region will be greater and more intense than other parts of the world. For example, climate variability and the frequency of extremes are expected to increase in the future. Moreover, the intensified warming will cause a number of significant impacts in the cryosphere, including sea ice, snow cover, glaciers, ice sheets, lake and river ice, and permafrost (Furgal and Prowse, 2008). Changes in seasonal snow and ice cycles will have enormous impacts on wildlife, such as marine, terrestrial, and bird species (ACIA, 2005; Furgal and Prowse, 2008; Larsen et al., 2014). The following sections describe some potential implications of climate change for northern environments, focusing on climate variability and extremes, changing sea and river ice regimes, and decreasing vegetation and wildlife.
1.3.1.1 Climate Variability and Extremes

Climate is naturally variable; it has been changing continuously throughout human history. Extreme weather and climate events have been observed in the past few decades. There have been increasing concerns about the possible increase in the degree of climate variability in the future due to anthropogenic-induced climate change (Barrow et al., 2004; Colombo et al., 1999; Easterling et al., 2000). In recent years, a number of climate change impacts and adaptation studies have put more emphasis on the variability of climate, as well as on the frequency and magnitude of climate extremes (Barrow et al., 2004). Climate variability in northern Canada refers to variations from atmospheric, oceanic, and locally generated sources. For example, the main sources of atmospheric variability that affect the Canadian Arctic and subarctic regions are the El Niño Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO) and the closely linked Arctic Oscillation (AO). Using statistical theory of climate extremes, the frequency of extremes is more dependent and sensitive on changes in variability rather than mean climatic values (Brown and Katz, 1995; Colombo et al., 2000; Katz and Brown, 1992). Moreover, as climate events become more extreme, the influence of extremes becomes greater (Colombo et al., 2000; Katz and Brown, 1992).

Climate variability and extremes are the most important and influential aspects of climate change due to direct effects on human health, agriculture, ecosystems, and natural hazards. Although society is greatly concerned with variations in weather, particularly the extremes in weather that have caused profound impacts on both human society and the natural environment, assessments of the socio-economic impacts of climate change have used average climate conditions rather than climate variability and extremes (Katz and Brown, 1992).
It is important to note that Indigenous elders in Cree and Inuit communities are already noticing that some environmental indicators used for interpreting and forecasting weather patterns no longer coincide with current weather conditions (McDonald et al., 1997; Nickels et al., 2006). Local elders have used weather prediction knowledge for understanding wildlife, as well as for interpreting animal distributions, migration patterns, and local vegetation growth. Such traditional knowledge is vital in harvesting traditional/country foods (Laidler and Gough, 2003; Laidler et al., 2009).

1.3.1.2 Changing Sea and River Ice Regimes

Sea ice is a key indicator of climatic changes and trends in the North; however, the annual and decadal-scale variability of sea ice cover and thickness remains poorly understood (ACIA, 2005; Gough and Houser, 2005). Changes in sea ice cycles have enormous implications for the natural and human environments in the North, so several studies have been investigating future changes in sea ice regimes (ACIA, 2005; Furgal and Prowse, 2008). The Hudson and James Bay regions experience a complete annual cryogenic cycle (Gagnon and Gough, 2005a, 2005b; Gough et al., 2004b, 2005; Gough and Wolfe, 2001; Kowal et al., 2015; Laidler and Gough, 2003). Typically, sea ice is formed in November and stays in ice form until June; both bays are generally completely ice-free in August and September (Gagnon and Gough, 2005a, 2005b; Gough et al., 2004a, 2004b; Gough and Wolfe, 2001; Kowal et al., 2015). This cryogenic cycle plays an important role in regional climate, as sea ice cover creates a unique ecosystem that has a diverse range of species (Gagnon and Gough, 2005a; Gough and
Wolfe, 2001). In the northern aquatic ecosystems, for example, marine algae and invertebrates are the base of the marine food web, and their life forms are associated with ice cycles (ACIA, 2005; Furgal and Prowse, 2008). However, a warmer climate may have had profound effects on their survival over the past few decades (ACIA, 2005; Furgal and Prowse, 2008; Gagnon and Gough, 2005a, 2005b). The biological productivity in aquatic ecosystems of the North is relatively low compared to temperate and tropical ecosystems due to low energy flows (Furgal and Prowse, 2008). Thus, as climate change progresses, the marine food web in the Hudson Bay region will inevitably be affected by a longer ice-free season; it is possible that populations, biodiversity and distributions of marine species will be reduced due to the loss of their habitats and forage areas (ACIA, 2005; Gagnon and Gough, 2005a).

The recent AR5-Earth System Models (ESMs) show that by 2050, annual sea ice concentration in the Hudson Bay is projected to decrease by 11.6% and 15.9%, under the RCP 4.5 and RCP 8.5 scenarios, respectively, relative to the present concentration (1986–2005) of 44.3% (Steiner et al., 2015). Also, the AR5-ESMs project a decrease in annual ice cover for the Hudson Bay with a similar loss rate to the Canadian Arctic Archipelago (CAA). Gagnon and Gough (2005a) state that even using the least drastic climate change scenario, the duration of the ice-free season in the Hudson Bay region will be longer because of an earlier break-up and a later freeze-up date. With respect to the latest Canadian regional climate model (CRCM4.2.3) analysis, Joly et al., (2011) show that by 2041–2070, the length of sea ice season in the Hudson Bay is projected to reduce by 7–9 weeks under the IPCC SRES A2 scenario due to a modification in the seasonal variability of water stratification.

Lake and river ice regimes will also have substantive and likely negative consequences for local communities. Winter roads in the western James Bay region run through large estuaries
so that ice bridges are constructed over rivers, creeks and muskegs, which are covered by landfast ice. Landfast ice (or fast ice) typically forms along coastlines and is immobilized by grounded ice ridges (stamukhi), and thus does not move with the ocean circulation (ACIA, 2005; Flato and Brown, 1996; Gagnon and Gough, 2006; Gough et al., 2004b). Although landfast ice often refers to landfast sea ice that occurs in the near shore zone in the presence of sea ice, landfast ice is also formed with freshwater and brackish water in a river delta such as the Mackenzie River Delta (Eicken et al., 2015). Thus, this dissertation describes river–landfast ice interaction rather than landfast sea ice. The presence of landfast ice mediates potential impacts of climate change on various natural and socio-economic systems. For example, it protects unstable coastlines from wave-induced erosion; it provides a safe and fast link to hunting and fishing grounds, and it creates a rich habitat for northern marine and fish species (ACIA, 2005; Dumas et al., 2005). Thus, a reduction in the landfast ice thickness and duration could have a negative impact on northern ecosystems and subsistence lifestyle of the local people.

River ice is also a vital component of the winter roads in the western James Bay region. Specifically, there are three major rivers (the Moose River, Albany River, and Attawapiskat River) that run through the region. Recent changes in the characteristics of river ice freeze-up and break-up have been observed by Cree elders in the region; however, there has been no significant trends between rive ice break-up dates and time (Ho et al., 2005). Changes in river ice freeze-up and break-up trends are complex, though the impacts of climate change on the timing and severity of river ice break-up remain unclear (Beltaos, 2004; Beltaos and Prowse, 2009; Ho et al., 2005). In addition, there appears to have been a recent change in the timing and intensity of flooding in the region due to rapid snowmelt and/or ice jam that may result in earlier springs (Chiotti and Lavender, 2008). Communities in Attawapiskat, Fort Albany and Kashechewan
have experienced major floods in the past, in particular, Kashechewan First Nation has forced a full community evacuation for four consecutive times since 2012 (CBC, 2015). As a consequence of the frequent flood events in the communities, some Fort Albany community members have raised concerns on the issue of mold occurring in home, leading to health risks (Tam, 2012). Thus, such rapid changes of river ice conditions and the links to the impacts of climate change require further research.

1.3.1.3 Decreasing Vegetation and Wildlife

Changes in the regional climate are expected to affect northern vegetation and a range of wildlife significant to the Cree and Inuit communities (ACIA, 2005; Furgal and Prowse, 2008; Laidler and Gough, 2003; McDonald et al., 1997). As for many northern Indigenous people, vegetation and wildlife play a vital role in local diet, traditions and cultures, economics, and spirituality (Furgal et al., 2002; Furgal and Prowse, 2008; Laidler and Gough, 2003).

Indigenous hunters and local residents have reported changes in animal behaviour and health, migration routes, abundance of species, and vegetation growth (Furgal and Prowse, 2008; Laidler and Gough, 2003; McDonald et al., 1997; Pearce et al., 2015). Hori (2010) reports that there is a temporal relationship between an observed fish die-off event and a heat wave in 2005 in the western James Bay region, indirectly impacting food source for many Cree fish harvesters and directly impacting harvesting techniques.

Cree and Inuit elders consider that a combination of a number of factors have led to significant changes in vegetation and wildlife over the recent decades (McDonald et al., 1997).
McDonald et al. (1997) indicate that natural fluctuations of wildlife populations in the Hudson Bay region may occur in response to a number of environmental conditions, such as habitat loss, food availability, reproduction rates, and disturbances caused by weather and humans. However, uncertainty must be taken into consideration when interpreting the presence of long-term and permanent changes of wildlife populations (Laidler and Gough, 2003). For example, a decline in one local population may result in an increase in populations in other areas. Thus, researchers need a better understanding of the possibilities of migration for wildlife species and overall population decreases as a consequence of climate change (Laidler and Gough, 2003). In addition, traditional Cree and Inuit remain dependent on harvesting activities, so they use vegetation and wildlife health as local indicators (Laidler and Gough, 2003; McDonald et al., 1997). Such indicators may provide further insights into the impacts of climate variability and extremes on local plants and animals, as well as show early warning signs of these changes (Laidler and Gough, 2003).

1.3.2 Winter Road Systems

Winter roads in northern Canada consist of ice roads over land, frozen lakes, and rivers (ACIA, 2005). These roads are often found in the northern parts of Northwest Territories, Manitoba and Ontario, though their use becomes less frequent in Yukon, Nunavut, Alberta, Saskatchewan, Quebec, and Newfoundland and Labrador (Andrey et al., 2014). A network of winter roads in the Far North of Ontario connects 31 remote-northern First Nations communities to permanent roads and railways (Government of Ontario, 2015c). In 2014–2015, approximately 3,000 km of winter
roads are constructed and maintained at a cost of $5.0 million (Government of Ontario, 2015c). During late spring to early fall, the port of Moosonee provides a barge transportation service to the Hudson and James Bay coastal communities, which delivers bulk materials and essential goods. These items are then transported to the town of Moosonee by train (Chiotti and Lavender, 2008). During winter, the winter road network that operates for three months each year – January, February, and March – is key to supplying major goods to most communities in the region (Chiotti and Lavender, 2008). Winter roads minimize the cost of goods and services for local residences. A community health study by Tam et al. (2013) on Fort Albany (focusing on the First Nation communities of the western James Bay region) documents that many community members use the winter road to travel to the town of Moosonee to purchase cheaper necessities. As indicated by participants in this study, shipping goods by air or barge are more costly than using ground transportation such as winter roads (Tam et al., 2013).

Winter roads provide not only the transport of heavy machinery and essential goods, such as food, fuel, and medical supplies at a low cost, but they also play important social and cultural roles in northern remote communities (Chiotti and Lavender, 2008; Furgal and Prowse, 2008). A winter road study by Blair and Sauchyn (2010) in Manitoba addresses that winter roads provide access to neighbouring communities. For example, many community members use the roads to visit family and friends, gather for social, cultural, and recreational events, and see the elderly in hospitals or health-care facilities. Moreover, winter roads and trails provide access to some resource areas, such as hunting grounds, harvesting sites, and fishing areas (Blair and Sauchyn, 2010; CIER, 2006).

Particular meteorological factors, such as surface air temperature, precipitation, snowfall, and wind, play a significant role in determining the viable operating season of winter roads
(ACIA, 2005; Knowland et al., 2010). However, in recent years, there has been increasing concern that the average opening date of winter roads has been delayed and the quality of the roads has been reduced due to a warmer climate (ACIA, 2005; Blair and Sauchyn, 2010; Chiotti and Lavender, 2008; CIER, 2006; Furgal and Prowse, 2008; Tam et al., 2013). For example, in Ontario’s Far North during 2005–2006, delays of up to 10 days in opening several sections of the winter roads (Wawatay News, 2005); likewise, construction of winter roads was delayed in Manitoba and Saskatchewan (CIER, 2006). In the Northwest Territories, the average date for opening of the Mackenzie River Ice Road has been delayed by more than 3 weeks since 1996 (ACIA, 2005; CIER, 2006). During the warm winter of 1997–1998, a total cost of $15–18 million was spent for essential supplies to be flown into a number of remote communities in Manitoba and Ontario’s Far North because the winter road season was shortened (Blair and Sauchyn, 2010; CIER, 2006). In December 2012, Kashechewan First Nation in Ontario’s Far North declared a state of emergency due to a lack of fuel (CBC, 2012), which was caused by a short winter road season in the previous year that limited the transportation of diesel fuel (CBC, 2012).

Despite the effects of a warmer climate on the winter road systems, there has been little research in the scientific literature about the effects of climate change on winter roads in northern Canada. A trend analysis of the historical opening and closing dates for winter travel on the Alaskan North Slope was first reported by Hinzman et al. (2005). Opening dates have been delayed from early November in the 1970s to early January in the 2000s, and closing dates have also been changed to approximately three weeks earlier in May. Due to a relatively warmer winter, the duration of the winter travel seasons has decreased from over 200 days in 1970s to only 100 days in 2000s. Likewise, Knowland et al. (2010) identify meteorological features
associated with the opening dates for the winter road near Norman Wells, Northwest Territories during 1982 to 2006. The five extremely late-opening years are well correlated with the El Niño events, whereas no particular correlation is detected between the five extremely early-opening years and the occurrence of climatic events.

There is limited research using climate model projections to analyze the physical and socio-economic implications of winter transportation system in northern Canada. Lonergan et al. (1993) utilize three Global Circulation Models (GCMs) to examine the implications of climate change on the winter roads in the Mackenzie River Valley, Northwest Territories. The three GCMs predict a decrease in the duration of the winter road and an increase in the length of open waters at Norman Wells. The climate models project a shorter winter road season concurrent with a longer barge season that, in turn, will impact the economic component of the transportation systems in the region. However, Lonergan et al. (1993) conclude that the economic impacts on the winter transportation system, particularly winter roads, in the region are relatively minor, as shipping items by barge tends to be cheaper than transportation by truck and air. As described previously, in the western James Bay region of Ontario’s Far North, shipping costs of goods by winter road are the cheapest (Tam et al., 2013). Thus, the competition in the local transport industry should also take into consideration when assessing regional impacts on transportation systems. In another part of Canada, climate model projections by Blair and Sauchyn (2010) in Manitoba indicate that the winter road seasons will become shorter throughout this century by 8 days in the 2020s, 15 days in the 2050s, and 21 days in the 2080s.

To our knowledge, there is no comprehensive trend analysis and climate change impact assessment regarding the winter road seasons in the Far North of Ontario. As an aim of the study is to understand physical, social/cultural, economic impacts associated with changing the
viability of winter roads in the Far North of Ontario, the development of a coherent climate change impact assessment for the region is necessary.

1.3.3 Community Adaptation

A number of explanations for the signs of climate change on human systems have been acknowledged in the literature. Harvesting, traveling by sea ice, and food and diet studies have been conducted with respect to changing weather and climate. The main objective of these studies is to identify potential health impacts of and vulnerabilities resulting from climate change for Indigenous groups in Canadian Arctic (Ford, 2008, 2009; Ford et al., 2006a, 2009; Furgal and Seguin, 2006; Laidler et al., 2009; Newton et al., 2005). These analyses indicate that many Indigenous communities demonstrate significant adaptability to cope with past and present environmental changes although they are often more vulnerable to such changes due to their strong relationship with the environment (Ford et al., 2006a; Furgal and Seguin, 2006; Guyot et al., 2006; Laidler et al., 2009; Lemelin et al., 2010; Tremblay et al., 2008). Many community members have learned to overcome environmental changes through various adaption tools and strategies, such as the sharing of risks and knowledge, community programs, and the use of advanced equipment and new technology (Furgal and Seguin, 2006; Guyot et al., 2006; Laidler et al., 2009; Tremblay et al., 2008).

In the context of climate change adaptation for winter roads and Manitoba First Nations, CIER (2006) addresses seven strategies at the community level and government level. These seven strategies are summarized in Table 1-1. Northern communities in Canada that are
dependent upon winter roads need to undertake long-term planning to develop a robust adaptation strategy. To our knowledge, no systematic assessment and/or research of vulnerability and adaptation regarding impacts of climate change on winter roads have been carried out in the Far North of Ontario.

Table 1-1. List of adaptation strategies at the community and government levels

<table>
<thead>
<tr>
<th>Community-level strategies</th>
<th>Government-level strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Increase the security of winter roads</td>
<td>Increase the security of winter roads</td>
</tr>
<tr>
<td>2 Develop a community climate change action plan</td>
<td>Support a community climate change action plan</td>
</tr>
<tr>
<td>3 Develop a communication strategy</td>
<td>Increase communication with First Nations communities</td>
</tr>
<tr>
<td>4 Increase social and cultural-recreational opportunities</td>
<td>Support social and cultural-recreational opportunities</td>
</tr>
<tr>
<td>5 Increase consumption of local foods</td>
<td>Support consumption of local foods</td>
</tr>
<tr>
<td>6 Enhance community safety</td>
<td>Enhance community safety</td>
</tr>
<tr>
<td>7 Increase funding opportunities for community operations</td>
<td>Increase funding opportunities for community operations</td>
</tr>
</tbody>
</table>

*Note. Adapted from CIER (2005).*
1.4 Research Theme and Objectives

The main theme of this dissertation is to analyze the implications of climate change on the winter road systems in the Far North of Ontario. Understanding current vulnerability of First Nations communities who rely on winter roads is of particular interest. Also, this dissertation identifies any existing adaptation strategies used to address the impacts of a changing winter road system, as well as addresses potential adaptation strategies in response to future change for First Nations communities in the region. The Fort Albany First Nation community in Fort Albany, Ontario is the focal community for examining community vulnerability to changes in winter road conditions. This dissertation comprises of three individual studies. The specific research objectives of this dissertation are as follows:

1. To analyze a temporal trend of meteorological factors in determining the historical opening and closing dates of the James Bay winter road;

2. To explore current vulnerability of First Nations communities regarding physical, social/cultural, economic impacts associated with changing winter road seasons; and

3. To examine the viability and longevity of winter roads in the next century by using climate model projections as part of a climate change impact assessment.

The following sections are a detailed overview of the above specific objectives pertaining to three studies.
1.5 Chapter 2

Chapter 2 forms a fundamental part of this dissertation by the setting context for the winter road study in the Far North of Ontario. This study focuses on the trends of freezing degree-days (FDDs) and landfast ice cover across the western James Bay region in order to investigate whether there is a temporal relationship between seasonal climate trends and the historical opening dates of the James Bay Winter Road. The Mann-Kendall test and the Theil-Sen method are applied to determine the statistical significance of the temporal trends and their magnitude. This study presents a novel finding on the FDD accumulations during the preconditioning months of October to December for James Bay Winter Road. This threshold can be potentially used as a lower threshold for winter roads in the Far North of Ontario.

1.6 Chapter 3

Chapter 3 explores current vulnerability of First Nations communities in the Far North of Ontario regarding physical, social/cultural, economic impacts associated with changing winter road seasons and the viability of the roads, as well as the river ice regimes. This study uses local knowledge and observations that require First Nations participants in order to analyze community vulnerability and adaptability to changes in the winter road and its seasons. Thus, this research requires active involvement of local First Nations communities and organizations such as engagement of community collaborators, recruitment of participants, translation and interpretation of results, commitment to dissemination of results, and continuous communication.
with communities for future research. The major themes that emerged from participant’s responses include current practices of the winter road construction and maintenance, changes in winter road seasons and conditions, and current adaptation to changes in winter road seasons and conditions. This study provides greater insight on community vulnerabilities associated with the changes on winter roads that will contribute to developing adaptation strategies and coping measures among First Nations communities.

1.7 Chapter 4

Chapter 4 includes a regional climate impact assessment for the winter road systems in the Far North Ontario using recent climate model projections from the multi-model ensembles of General Circulation Models (GCMs) and dynamical downscaling of Regional Climate Models (RCMs) under the Representative Concentration Pathway (RCP) scenarios to examine the viability of winter roads and their seasonal nature in the next century. The lowest threshold of FDD accumulations from the James Bay Winter Road is applied to the projected FDDs to assess how climatically favourable to construct winter road systems during October to December in the preceding year of road openings. This study uses five locations in the Far North of Ontario and examines the future FDD accumulations for the three time periods: 2011–2040, 2041–2070, and 2071–2100. For the government organizations and First Nations groups, the results of this study will contribute to creating strong action plan and/or public policy for the impacts of climate change on winter road systems not only in Ontario’s Far North but also in Canada’s North.
1.8 Significance of the Research

A number of studies have addressed the relationship between climate change and human health impacts in the context of harvesting activities and traditional food systems for Inuit communities in the Canadian Arctic (Ford, 2009; Ford and Berrang-Ford, 2009; Ford et al., 2006a, 2008a, 2008b, 2010; Furgal and Seguin, 2006; Laidler et al., 2009; Newton et al., 2005; Statham et al., 2014). However, only a few studies have investigated the implications of climate change to the winter road systems in remote-northern Indigenous communities. Although such studies have examined winter road systems only for Inuit communities in the Canadian Arctic, none have extended the research to consider First Nation Cree communities in the western Hudson and James Bay regions. Moreover, there is no comprehensive scientific analysis of winter road stability and longevity in the Far North of Ontario. Lemelin et al. (2010) indicate that changes of climate and environment affect travel routes including river corridors and winter roads in the western Hudson Bay lowland; however, they did not perform any statistical analysis using meteorological data. Furthermore, no effective adaptation strategy has been assessed or developed in the context of climate change and winter road systems for the James Bay Cree communities. Tam et al. (2013) indicate that the Fort Albany First Nation has exhibited a sense of adaptability and resiliency to adapt the changes in the environment, but their adaptive capacity to climate change in the future is uncertain so that the development of adaptation strategies is necessary.

Lastly, the Chief of Fort Albany First Nation and the Ontario Regional Chief for the Assembly of First Nations have expressed concerns on the impacts of climate change on the winter road systems. Thus, it is expected that the results of this dissertation will inform public
policy and decision-making processes addressing implication of climate change to the stability and longevity of winter roads for First Nations communities.

1.9 Methodological Considerations

One of the research objectives for this dissertation explores current vulnerability of First Nations community to physical, social/cultural, economic impacts associated with the changing of the viability and longevity of winter roads and the river ice regimes. In particular, this dissertation integrates semi-directive interviews and concept mapping as part of the research methods. The following portion of the literature review explores methodological considerations.

1.9.1 Conceptual Framework

The conceptual framework to be used in this dissertation is modified from a climate change impact assessment (CCIA) introduced by Carter et al. (1996). Their guidelines provide a general framework for conducting a CCIA and for evaluating appropriate adaptation strategies. They consist of seven main steps of analysis: 1) define the problem; 2) select method; 3) test method; 4) select scenarios; 5) assess biophysical and socioeconomic impacts; 6) assess autonomous adjustments; and 7) evaluate adaptation strategies. The CCIA concept map (Figure 1-1) is adapted from Gough (2012), which shows the connections of basic elements for assessing the potential impacts of climate change. The concept map was used as the general guideline when
conducting step 1–6 of the CCIA.

An analytical framework for vulnerability and adaptive analyses developed by Ford and Smit (2004) and Ford et al. (2006a) employs case studies of climate change involving northern communities and integrates multiple information for current and future vulnerabilities and adaptations. Figure 1-2 depicts a framework model of vulnerability analysis. Ford and Smit (2004) articulate that the CCIA framework has been widely used but it treats adaptation hypothetically. Such CCIA approach focuses more on the relations between present and future climatic conditions rather than climate-related connections with current experiences of communities. Thus, this dissertation research applied the vulnerability analysis framework when conducting step 7 of the CCIA in order to assess the current vulnerability of the Fort Albany community and possible adaptation options for their community.
Figure 1-1. Concept map of climate change impact assessment (Adapted from Gough, 2012).
1.9.2 Winter Road Concept Map

Concept mapping is a visualization tool for organizing and representing prior knowledge that serves a foundation for future knowledge (Edmondson, 1994). Concept mapping was originally developed by Novak in 1972 as a teaching technique that can enhance learning for students (Novak et al., 2008). A concept is usually represented with boxes or circles, and is connected by lines or arrows, indicating a relationship between concepts. Words or phrases on the line, referred to as ‘linking words’ or phrases, describe the relationships between the concepts. Concept maps differ from flowcharts, which are based on a one-way structure with no important linking words/phrases.
In this dissertation, concept mapping is applied not only to examine interrelationships between winter roads and their potential impacts on First Nations communities but also to gain a holistic view on adaptation strategies to future changes. Figure 1-3 presents the concept map developed for the impacts of climate change on winter roads and the First Nations communities. The concept map was made during the literature review in Chapter 3. The construction of the concept map was to reveal my knowledge and understanding of the main topic, as well as to organize the knowledge as concepts in the form of a concept map. Through many revisions of the concept map, the relationships between key features of the concept map became more evident. Concept mapping was also used to help develop winter road interview and survey guides.
Figure 1-3. Concept map of the impacts of climate change on winter roads and their potential impacts on First Nations communities. The symbols refer to: ↑ increase, ↓ decrease, + positive, - negative. (Created by Y. Hori).

1.9.3 Development of Winter Road Interview and Survey Guides

The collection of local knowledge and observations is imperative to analyze community vulnerability and adaptability in the context of physical, social/cultural, economic impacts associated with the changing of seasonal length and quality of winter roads.
Through the use of the winter road interview and user survey, this dissertation examined the evolution of winter road systems with changing climatic and environmental conditions, as well as the community vulnerabilities associated with a combination of changing climatic conditions and changing the seasonal life of winter roads. The study also analyzed community adaptabilities regarding physical, social/cultural, economic impacts on community life.

The winter road interview and user survey were directed by the winter road interview and survey guide, which contained key research elements with a series of questions. The structure of the guide was adapted from Ford (2006), Ho (2003), Laidler (2007), and Tam (2012), all of which were doctoral and master’s theses that focused on impacts of climate change in northern-remote Indigenous communities. These theses provide a detailed interview guide and interview protocol, aiding in the development of the interview guide used for this dissertation research.

Ethical approval was obtained from the University of Toronto Research Ethics Board (REB) before research was conducted with First Nations communities. Specifically, the winter road interview and survey guide, written informed consent form, telephone script, and email text were submitted and approved by the REB (see Appendix 1A-1D).

1.10 Study Areas

1.10.1 Western James Bay region

The western James Bay region, also known as the Mushkegowuk region, is characterized as
having a subarctic climate with short and fairly warm summers, and long and cold dry winters (Aguado and Burt, 2007). The region is situated along the coastal areas of the James Bay with large river systems including the Moose River, Albany River, and Attawapiskat River. There are approximately 10,000 First Nations people inhabiting the communities of this region (Figure 1-4): Moose Factory; Moosonee; Fort Albany; Kashechewan; Attawapiskat; Peawanuck (formerly Winisk); and Fort Severn (Berkes et al., 1994, 1995; Tsuji and Nieboer, 1999). Fort Severn is the only community that is not a member of the Mushkegowuk Council. Fort Albany, Kashechewan, Attawapiskat, Peawanuck, and Fort Severn are remote, coastal, and fly-in communities; accessible only by plane year round, barge during the ice-free season, and winter roads during the winter season (Ho et al., 2005; Tsuji and Nieboer, 1999; Tsuji et al., 2006). Peawanuck and Fort Severn are the two most northerly and remote Cree communities in Ontario. The residents of these communities mainly speak the Cree language and follow a subsistence lifestyle (Tsuji, 1996a, 1996b; Tsuji and Nieboer, 1999). Moose Factory is also a remote community, located on Moose Factory Island, near Moosonee which is accessible by rail transportation from Cochrane, Ontario. The Cree communities of the western James Bay region are still dependent on wildlife harvesting, predominantly fish and game meat (Berkes et al., 1994, 1995; George et al., 1996; Tsuji et al., 2006).

The western James Bay region has a main winter road network, also known as the James Bay Winter Road (JBWR), connecting remote and coastal communities in the region. The JBWR will be discussed in detail in Section 1.11 of this chapter. In the southwestern regions of Hudson Bay, the Peawanuck winter road links Peawanuck to Fort Severn, and ultimately connects to Shamattawa and Gillam in Manitoba (Government of Ontario, 2015c). Gillam is accessible by rail and highway systems. The winter road is approximately 200 km long, and 120 km of which
runs through the Polar Bear Provincial Park (Government of Ontario, 2015c). The winter road is managed by the band council (Lemelin et al., 2010). There is no winter road network between Attawapiskat and Peawanuck.
Figure 1-4. Map of the western James Bay region, Ontario.
1.10.2 Far North of Ontario

The Far North of Ontario, as defined by the Far North Act, 2010, covers at 452,000 km² which encompasses 42% of the area of the province of Ontario (Government of Ontario, 2015a). Ontario’s Far North consists of two distinct biophysical environments: the Hudson Bay Lowlands and the Canadian Shield (Far North Science Advisory Panel, 2010). The Hudson Bay Lowland is the largest wetland region of North America that supports subarctic wetland habitats, as well as migratory habitats including waterfowl and shorebird populations (Far North Science Advisory Panel, 2010). The presence of permafrost provides unique characteristics of topography in the region such as a palsa (Tam et al., 2014). The Canadian Shield area lies on Precambrian bedrock and glacial sediment which creates an arc-shaped mineral-rich zone that is expected to be commercial forest potential and intensive mineral exploration activities (Far North Science Advisory Panel, 2010).

The Far North of Ontario is home to approximately 24,000 people, 90% of which include First Nations people living in 31 First Nation communities (Government of Ontario, 2015b). The two municipalities in the Far North of Ontario are Moosonee and Pickle Lake, and Moose Factory has a local services board that offers municipal-level services (Government of Ontario, 2015b). The Far North of Ontario currently has only two permanent gravel roads that connect to all-season roads (Far North Science Advisory Panel, 2010). Figure 1-5 shows the current access options to the region. In the western section of the region, the Nungesser Road is from the town of Red Lake to the Berens River, and the Pickle Lake Road is from the town of Pickle Lake to the Musselwhite Mine, and terminates at the Windigo Lake. The Ontario Northland provides rail access from Cochrane to Moosonee in the eastern section of the region. Thus, access to most of
the First Nations communities in Ontario’s Far North is via air, barge and/or a network of winter roads.

Figure 1-5. Map of current available accesses to the Far North of Ontario (Adapted from Far North Science Advisory Panel, 2010).
1.11 Exposure Units

As described previously, this dissertation followed the climate change impact assessment (CCIA) framework. In a CCIA, the impacted subjects such as population, ecosystems and biota to be assessed are labeled as exposure unit(s). The exposure units of this dissertation include the winter road systems and First Nations populations in the Far North of Ontario, specifically, the James Bay Winter Road and the Fort Albany First Nation in Fort Albany, Ontario, were particular focus units for this dissertation.

1.11.1 James Bay Winter Road

The James Bay Winter Road (JBWR) connects the remote communities of Attawapiskat, Kashechewan, Fort Albany, and Moose Factory to Moosonee through the annual operation and maintenance by the Kimesskanemenow Corporation, owned by the First Nations communities of Attawapiskat, Kashechewan, Fort Albany, and Moose Cree (Kimesskanemenow Corporation, 2015). The winter road network spans 320 km in length along the coastline of western James Bay (Government of Ontario, 2015c). The road is constructed to meet a standard of quality set by gross vehicle weight (GVW). Figure 1-6 shows the standard conditions of JBWR. In the last decade, the winter road was open from January to March each year (Kimesskanemenow Corporation, 2015). There is a winter road that connects Attawapiskat to the Victor Diamond Mine (~ 90km) (Whitelaw et al., 2009). Also, Wetum Road, its grand opening in February 2013,
connects Moose Factory to Otter Rapids (~ 170km) (Moose Cree First Nation, 2016). These winter roads are not maintained by Kimesskanemenow Corporation.

The winter road system in the James Bay region was originally built for a tractor train. Roman Catholic missionaries used to haul supplies up along the coastline of James Bay from the town of Moosonee to Winisk, which local people often refer to as ‘missionaries trail’. There still are some marks of missionary trails nearby the current winter roads (Figure 1-7). The missionary trails were often very narrow, and a tractor train with sleighs compacted the snow on the trail resulting in a low-quality trail. In the past, there were several organizations that were in charge of the winter road, such as the Royal Canadian Air Force (RCAF), North American Construction Group, and 981584 Canada Inc. (also known as The Service Company). Since 2007, the JBWR has been operated and managed by the Kimesskanemenow Corporation.
Figure 1-6. Photograph of the standard road condition of JBWR, near Fort Albany, February 27, 2015. Photo taken by Y. Hori.
1.11.2 Fort Albany First Nation

The Fort Albany First Nation, the focus community of this dissertation, has a total population of approximately 2,000 according to the 2011 Census (Statistics Canada, 2015). Fort Albany is located near the mouth of the Albany River in the western James Bay region of Ontario’s Far North. The community residents mainly speak the Cree language and follow a subsistence
lifestyle (Tsuji, 1996a, 1996b; Tsuji and Nieboer, 1999). For example, the Cree communities of the western James Bay region are dependent on wildlife harvesting, predominantly fish and game meat (Berkes et al., 1994, 1995; Tsuji et al., 2006). Dr. Leonard J.S. Tsuji, a committee member of this dissertation research, has conducted a wide range of studies involving the participation of Fort Albany First Nation for over a decade. He has also organized community-based science and technology camps for First Nation students in conjunction with the Mundo Peetabeck Education Authority of Fort Albany First Nation to educate high school students with hands-on activities. Thus, community partnership has been strongly established, which is fundamental for this research; trust, commitment, and support from the communities are necessary.
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Chapter 2
Trends in the seasonal length and opening dates of a winter road in the western James Bay region of Ontario’s Far North, Canada

2 Chapter 2

2.1 Abstract

In northern Canada, winter roads are essential for nearby communities. The seasonal length of the roads depends on particular meteorological conditions. In this study, we investigated whether there is a temporal relationship between seasonal weather trends and the historical opening dates of the James Bay Winter Road in Ontario’s Far North. The statistical significance of the temporal trends and their magnitude are determined by the Mann-Kendall test and the Theil-Sen method. Results showed that the decreasing trends in the freezing degree-days (FDDs) are statistically significant, along with the statistically significant increasing trends of monthly averages of both $T_{\text{min}}$ and $T_{\text{mean}}$ during the winter months in the western James Bay region for the 1961–2014 period. However, there were no statistically significant linkages between opening dates and FDDs detected, largely due the paucity of opening dates data, although early opening dates appear to result from larger FDDs during the last ten years. The FDDs during the months of October through December were more closely linked to opening dates than FDDs that were calculated up the opening date (including January dates) suggesting the key role of preconditioning during late fall and early winter. The lowest FDDs for the months of October to
December that resulted in a viable winter road were 380 degree-days. This threshold can be potentially used as a lower threshold for winter roads.

### 2.2 Introduction

The climate of northern Canada has undergone significant changes in recent years (ACIA 2005; Anisimov et al., 2007; Furgal and Prowse, 2008). The average air temperatures in the Canadian Arctic and subarctic have increased approximately twice as much as that of the global rate during the past century (Anisimov et al., 2007). Also, the impacts of climate change on sea ice cover and ice thickness, permafrost, and weather patterns, including changes in snow, wind and precipitation, have been observed in the Hudson and James Bay regions of Ontario’s Far North (Chiotti and Lavender, 2008; Ford et al., 2009; Furgal and Prowse, 2008; Gagnon and Gough, 2005a; Gough and Leung, 2002; Gough et al., 2004b; Laidler and Gough, 2003). For instance, past studies have shown that both the extent and duration of sea ice cover in Hudson and James Bay have been decreasing as a consequence of earlier break-up and later freeze-up dates over the past few decades (Gagnon and Gough, 2005b; Gough et al., 2004a; Hochheim and Barber, 2014; Kowal et al., 2015).

Many studies show that the effects of climate change in northern Canada are most pronounced. The climate model projections show that temperatures in the Arctic region will warm more rapidly than the global average, and changes in the variability and intensity of weather events are expected to be significant at high latitudes (IPCC, 2014). In the western James Bay region, mean air temperatures are projected to increase throughout the seasons, from
13.5°C to 16–19°C range in summer, 2.8°C to 5–7°C range in fall, -18.6°C to -13°C – -9°C range in winter, and -3°C to -1°C –1°C range in spring by 2100 (Hori, 2010). In addition, annual precipitation in the region is projected to increase from 3.2 mm to 7.1 mm per month by the 2050s and from 5.2 mm to 11.3 mm per month by the 2080s (Gagnon and Gough, 2005a). Moreover, the frequency of extreme temperature and/or precipitation events is expected to increase in the future (ACIA 2005; Anisimov et al., 2007). Even though many Indigenous people in the Canadian North subsist off the land, significant effects of climate change on their ecological, economic, and social systems have affected their lifestyle (ACIA, 2005; Hori et al., 2012; McDonald et al., 1997; Tam et al., 2013). Thus, community members have expressed growing concerns for their changing environment and way of life (Anisimov et al., 2007; Ford et al., 2006a, 2006b, 2009; Furgal and Seguin, 2006; Laidler and Gough, 2003), one of which includes the viability of winter roads (Tam et al., 2013).

During the winter season, there is a winter road network that operates for approximately three months each year, from January to March, in Ontario’s Far North (Chiotti and Lavender, 2008). Winter roads minimize the cost of goods and services for local residents. A community health study showed that many Fort Albany First Nation community members use the winter road to travel to the town of Moosonee to purchase cheaper necessities (Tam et al., 2013). As indicated by participants in the study, shipping goods by air or barge is more costly than using ground transportation such as a winter road (Tam et al., 2013).

Winter roads not only provide the transport of heavy machinery and essential goods such as food, fuel, and medical supplies at a lower cost, but they also play important social and cultural roles in northern remote communities during the winter months (Chiotti and Lavender, 2008; Furgal and Prowse, 2008). For instance, neighboring communities in Manitoba use the
winter road to maintain social networks, including gatherings for social, cultural, and recreational events and visiting the elderly in hospitals or health-care facilities (Blair and Sauchyn, 2010). Winter roads and trails also provide access to certain resource lands such as hunting grounds, harvesting sites, and fishing areas (Blair and Sauchyn, 2010; CIER, 2006).

Meteorological factors such as surface air temperature, precipitation, snowfall, and wind, influence when the winter roads are opened and closed on a daily basis (ACIA, 2005; Knowland et al., 2010). In recent years, there has been growing concern about the average opening date of winter roads, which has been later than in the past, and the quality of the roads, which has been reduced due to a warmer climate (ACIA, 2005; Chioti and Lavender, 2008; Furgal and Prowse, 2008; Tam et al., 2013). For instance, in Ontario during 2005–2006, there were delays of up to 10 days in opening several sections of the winter roads (Wawatay News, 2005). Likewise, construction of winter roads was delayed in Manitoba and Saskatchewan due to thin ice and poor ice texture (CIER, 2006). In 1997–1998, northern Manitoba and Ontario experienced a warmer winter than usual; and as a result, the winter road season was shortened. As many essentials had to be transported via air instead, this resulted in a total cost of $15–18 million spent for air transportation for many communities in Manitoba and Ontario’s Far North (Blair and Sauchyn, 2010; CIER, 2006).

Using climate model projections, Blair and Sauchyn (2010) found that the winter road seasons in Manitoba will become shorter by approximately 8 days in the 2020s, 15 days in the 2050s, and 21 days in the 2080s. Similarly in the Mackenzie River Valley of the Northwest Territories, climate models project a shorter winter road season concurrent to a longer barge season at Norman Wells (Table 2-1), which will impact the economic component of the transportation systems in the region. However, Lonergan et al. (1993) conclude that the
economic impacts on the winter transportation system, particularly winter roads, are relatively minor as shipping items by barge is more cost efficient than ground or air transportation. Tam et al. (2013), on the other hand, have found that the winter road in the western James Bay region of Ontario’s Far North is a more preferred transportation method.

Table 2-1. GCM model predictions of the duration of the winter road and open water season at Norman Wells, Northwest Territories

<table>
<thead>
<tr>
<th>GCM Models (2 x CO₂)</th>
<th>Winter road Mean ± SD (day)</th>
<th>Open water Mean ± SD (day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Historical mean duration (1944-1975)</td>
<td>178 ± 15.1</td>
<td>164 ± 15.3</td>
</tr>
<tr>
<td>Oregon State University (OSU)</td>
<td>148 ± 14.7</td>
<td>183 ± 14.1</td>
</tr>
<tr>
<td>Goddard Institute for Space Studies (GISS)</td>
<td>138 ± 20.6</td>
<td>193 ± 16.5</td>
</tr>
<tr>
<td>Geophysical Fluid Dynamics Lab (GFDL)</td>
<td>132 ± 20.8</td>
<td>206 ± 15.4</td>
</tr>
</tbody>
</table>

*Note.* Adapted from Lonergan et al., 1993.

The Hudson and James Bay regions experience a complete annual cryogenic cycle (Gagnon and Gough, 2005a, 2005b; Gough and Wolfe, 2001; Gough et al., 2004b; Kowal et al., 2015). Typically, sea ice forms in November and stays until June, with ice-free periods during August and September (Gagnon and Gough, 2005a, 2005b; Gough et al., 2004a, 2004b). This cryogenic cycle plays an important role in the regional climate and the sea ice cover of the bays creates a unique ecosystem for a diverse range of species (Gagnon and Gough, 2005a; Gough and Wolfe, 2001).

Winter roads in the western James Bay region run through large estuaries so that ice bridges are constructed across such areas which are covered by landfast ice in winter. Landfast
ice typically forms along coastlines and is immobilized by grounded ice ridges which is called *stamukhi*, meaning it does not move with winds and ocean currents (ACIA, 2005; Dumas et al., 2005; Flato and Brown, 1996). The landfast ice in the Arctic covers approximately 5–50 km from the coast of Alaska, and extends several hundred kilometers from the coast of Siberia (Mahoney et al., 2007a). The presence of landfast ice provides various natural and socio-economic functions. While landfast ice creates a rich habitat for northern marine and fish species, and also it provides a feeding and breeding ground of migratory birds and mammals (ACIA, 2005; Dumas et al., 2005; Petrich et al., 2012), it also serves as a safe and fast link to hunting and fishing grounds for Arctic communities (ACIA, 2005; Dumas et al., 2005; Ford et al., 2009; Laidler et al., 2009; Galley et al., 2012; Petrich et al., 2012). Landfast ice also protects unstable coastlines from wave-induced erosions and winter storms (ACIA, 2005; Dumas et al., 2005; Mahoney et al., 2007b). For example, it mitigates the erosional effects caused by wave action in the coastlines of Tuktoyaktuk, Northwest Territories, and it helps to form the winter road between Tuktoyaktuk and local communities of the Mackenzie River (Galley et al., 2012).

Several studies have examined the historical trends and future projections of landfast ice thickness and duration in the Canadian Arctic. Dumas et al. (2005) examined the landfast ice thickness on load limits of ice roads in Tuktoyaktuk, Northwest Territories using climate change scenarios. This study found that the mean landfast ice thickness decreases by approximately 25–40 cm when annual mean temperature increases by 4°C and the snow accumulation rate is also increased by 20–100%, reducing the period of ice duration by 3 weeks (Dumas et al., 2005). Moreover, Dumas et al. (2005) found that if the sea ice model includes the increased Mackenzie River discharges in the spring due to earlier melt of landfast ice as a result of climate warming, the model would also indicate a shorter duration of ice roads.
The long-term trends of landfast ice thickness in the Hudson Bay region have been studied by Gagnon and Gough (2006) and Gough et al. (2004b). There was a statistically significant trend toward a thickening of the annual ice cover at three of the sites on the western region of Hudson Bay: Coral Harbour, Moosonee, and Big Trout Lake; on the other hand, there was a statistically significant thinning trend of the ice cover on the eastern side of Hudson Bay (Gagnon and Gough, 2006). These east-west asymmetric trends of the ice cover correspond to trends of warmer air temperature and earlier freeze-up and later break-up dates of sea ice. However, the results of Gagnon and Gough (2006) are in contrast to the reduced thickness and duration of the landfast ice observed in other Arctic regions (Gough et al., 2004b).

In this study, we focused on the James Bay Winter Road located in the western James Bay region of Ontario’s Far North, Canada. The main objectives of this study were to examine if winter road seasons have been affected by climate conditions and identify the potential effects of climate change, focusing on opening dates of the road. The James Bay Winter Road runs through several rivers and muskeg areas across the western James Bay coast; thus, changes in the length and timing of the river and/or muskeg ice are of particular climatic interest. However, no datasets for river and/or muskeg ice freeze-up were found to exist, so landfast sea ice was used as a proxy for the river and muskeg ice freeze-up in the western James Bay region. To our knowledge, no previous studies have carried out a comprehensive analysis of winter road records in Ontario’s Far North.
2.3 Methods

2.3.1 Study area

The western James Bay region is characterized as having a subarctic climate with short and fairly warm summers, and long and cold dry winters (Tam and Gough, 2012). There are approximately 10,000 First Nations inhabiting the communities of this region (Figure 2-1): Moose Factory; Moosonee; Fort Albany; Kashechewan; Attawapiskat (Tsuji and Nieboer, 1999). The residents of these communities mainly speak the Cree language and follow a subsistence lifestyle (Tsuji, 1996a, 1996b; Tsuji and Nieboer, 1999). The Cree communities of the western James Bay region are dependent on wildlife harvesting, predominantly fish and game meat (Berkes et al., 1994, 1995; Tsuji et al., 2006). The locations, Moose Factory, Fort Albany, Kashechewan, Attawapiskat, are remote, coastal, and fly-in communities; accessible only by plane year round, barge during the ice-free season, and winter roads during the winter season (Ho et al., 2005; Tsuji and Nieboer, 1999; Tsuji et al., 2006). Moosonee is accessible by rail transportation.
Figure 2-1. Map of Ontario’s Far North, including First Nations, the town of Moosonee, and the James Bay Winter Road.
2.3.2 James Bay Winter Road

The James Bay Winter Road runs through several rivers and streams as well as muskeg areas across the western James Bay coast. In the Hudson Bay Lowlands, approximately 80 percent of the region consists of muskeg or peat forming wetlands (Adam, 1978). The winter road network spans 320 km in length along the coastline of the Hudson-James Bay (Government of Ontario, 2014). During winter, the winter road connects the remote communities of Attawapiskat, Kashechewan, Fort Albany, and Moose Factory to Moosonee through the annual operation and maintenance by the Kimesskanemenow Corporation, owned by the First Nations communities of Attawapiskat, Kashechewan, Fort Albany, and Moose Cree (Kimesskanemenow Corporation, 2014). In the last ten years, the construction of winter road began as early as December (Kimesskanemenow Corporation, 2014).

Winter roads are made up of various types of peatlands and bodies of water when they freeze, though the methods of winter road construction vary by such frozen bodies. Winter road construction on frozen lakes, rivers, and open muskegs begins with initial compacting of snow for frost penetration, typically starting when the snow depth reaches 30–50 cm (Campbell and Bergeron, 2012; Kimesskanemenow Corporation, pers. comm., 2015). Snowmobiles are used to compact snow depth, which reduces its insulating effects and promotes deeper frost penetration (Adam, 1978; Campbell and Bergeron, 2012; Lefebvre, 1979). Once the ice thickness reaches approximately 15–25 cm in the muskegs and approximately 25–30 cm for lakes and rivers, snow removal and surface flooding begin to increase ice thickness naturally and rapidly until it can support full loads (Adam, 1978; Campbell and Bergeron, 2012). Creek and stream crossings are also filled with snow and flooded, creating a ramp between land and water (INAC, 2010;
Kimesskanemenow Corporation, pers. comm., 2015). For ice bridges across major rivers, the minimum ice thickness for a full weight (GVW 55,000 kg) is at least 1.09 m (43 inch) with a road width of 30–60 m (100–200 feet) (Adam, 1978; Kimesskanemenow Corporation, pers. comm., 2015). Testing and measuring ice thickness during construction and maintenance of winter road are recorded regularly until the official road closure. Over the last decade, the James Bay Winter Road haul season normally ran from January to March (Kimesskanemenow Corporation, 2014).

2.3.3 Data

2.3.3.1 Meteorological data

The opening and closing dates of the James Bay Winter Road were collected from local news media and the Kimesskanemenow Corporation for the period 2005–2015. Daily temperature maximum ($T_{\text{max}}$), temperature minimum ($T_{\text{min}}$), and temperature mean ($T_{\text{mean}}$) data were obtained from climate datasets maintained by the National Climate Data and Information (NCDI) Archive of Environment Canada (Environment Canada, 2014a). The Moosonee weather station (51.3°N, 80.7°W; Environment Canada, 2014a) was selected because this is the only station located in the Hudson-James Bay area, with an extended and intact temperature record since the 1960s; the other weather stations such as Moose Factory, Fort Albany, Attawapiskat have been operational only for short periods of time and the data are incomplete (Environment Canada, 2014a). Due to a lack of snowfall data from the NCDI, monthly total snowfall data for Moosonee were obtained.
from the Adjusted and Homogenized Canadian Climate Data (AHCCD) of Environment Canada (Mekis and Vincent, 2011).

2.3.3.2 Ice data

Ice data were obtained through ice concentration charts. Ice thickness data for the Hudson Bay region are available through the Canadian Ice Service (CIS) of Environment Canada as part of the Canadian Ice Thickness Program, though only for the years, 1961–1990 (Gagnon and Gough, 2005b; Gough et al., 2004b) due to the end of the program (Environment Canada, 2014b). Thus, we used ice concentration charts instead. Weekly ice concentration charts, typically used for commercial navigation purposes, were obtained from CIS of Environment Canada. These charts provide ice conditions in Canada’s waters starting in 1971, except during the winter months (January to May) (Environment Canada, 2014b). The ice concentration charts follow an advanced coding system, i.e., “Egg Code”, which was introduced by CIS in April 1982. This coding system is based on high quality spatial resolution through improved satellite technology. Thus, landfast ice data from 1982 to present were obtained for this study.

The weekly regional ice charts in Hudson and James Bays were used and the dates of fast ice for each year with an accuracy of ± 1 week, following the methodology of Gagnon and Gough (2005b), were determined. On each ice concentration chart, we identified fast ice through the Egg Code (code 8=fast ice) and the ice chart (black/grey areas=fast ice) (CIS, 2005). As the James Bay Winter Road runs alongside the coastline of western James Bay, three shoreline locations near Attawapiskat, Fort Albany, and Moosonee were chosen to identify the appearance
of fast ice. Attawapiskat is located along the northern shore of James Bay while Moosonee is located near the southern shore. For each location, we identified the first date of when fast ice appeared on the ice chart, which for the purposes of the study, was considered as the landfast onset date.

2.3.4 Freezing degree-days

Freezing degree-days (FDDs) have been used to determine the severity of winters and their trends (Assel, 1980). As previously mentioned, the James Bay Winter Road has officially opened in January during the last ten years. To determine a minimum threshold of FDDs that is required to open the winter road, two periods of FDD accumulations were examined from October 1 to December 31 as a preconditioning period of winter road seasons and from October 1 to the opening dates.

The FDDs are calculated as a sum of the daily mean temperature below the freezing point (0°C) for a specific time period with units in °C·days (Assel, 1980; 1990; 2003). In this study, the FDDs are defined as the departure of the daily $T_{\text{mean}}$ below a given temperature threshold:

$$\text{FDDs} = \sum (T_{\text{threshold}} \, ^\circ\text{C} - \text{daily } T_{\text{mean}} \, ^\circ\text{C}) \quad [1]$$

where the FDDs are the sum of the degrees of the number of days below a certain temperature threshold. For example, if daily $T_{\text{mean}}$ is above 0°C, the FDDs are indicated as negative values while if daily $T_{\text{mean}}$ is below 0°C, the FDDs are expressed as positive values. The FDDs are accumulated for each day. Knowland et al. (2010) reported a critical temperature for the ice
bridge construction at Norman Wells, Northwest Territories. Initial ice forms on freshwater lakes at a daily mean temperature of less than -5°C with a weak wind. The strength of ice continues to increase as temperatures reach -18°C; the ice strength becomes fairly constant below this threshold. This present study examined temperature thresholds at 0, -5, and -18°C which were adapted from the critical temperature thresholds developed for the Norman Wells study (Knowland et al., 2010). A total of seven months was chosen from October 1st to April 30th. The accumulations of FDDs for each temperature threshold were analyzed by a trend analysis detailed in the next section.

2.3.5 Statistical approach

Climate and landfast ice data were analyzed by using the non-parametric Mann-Kendall correlation and the Theil-Sen method in order to identify the statistical significance and magnitude of the trends. These techniques of trend analysis have been used in several sea ice studies of the Hudson Bay region by Gagnon and Gough (2002, 2005b, 2006) and Gough et al. (2004a). The Mann-Kendall test determines the statistical significance of a trend at α=0.05 (Helsel and Hirsch, 2002). The Mann-Kendall test was chosen as this test avoids the assumption of normality of the observations and handles the effects of outliers and missing values (Helsel and Hirsch, 2002). However, the Mann-Kendall test does not provide an estimate of the magnitude of significant trends; thus, the Theil-Sen method was applied for this purpose. The Theil-Sen method is also non-parametric and provides more robust estimate of a slope than the
methods of least-squares since the median of the sets of slopes is less affected by outliers or gross errors in the time series (Hirsch et al., 1982; Sen, 1968).

To assess the relationship of the FDD accumulations with temperature thresholds on the opening dates of winter road, Pearson’s product-moment correlation coefficient (Pearson’s $r$) was performed. The Student’s $t$-test statistic was used to determine the statistical significance of Pearson’s $r$ at the 95% confidence levels.

2.4 Results and discussion

2.4.1 Temperature trend analyses

Monthly averages of $T_{\text{max}}$, $T_{\text{min}}$, and $T_{\text{mean}}$ and the results of the trend analyses for Moosonee for 1961–2014 are summarized in Table 2-2. Trend analyses revealed that monthly averages of both $T_{\text{min}}$ and $T_{\text{mean}}$ have significantly increased for the months of January to April, with trends varying from a minimum 0.6°C per decade to a maximum 1.0°C per decade for $T_{\text{min}}$, as well as from a minimum 0.4°C per decade to a maximum 0.7°C per decade for $T_{\text{mean}}$. Although no statistically significant trend was identified for both $T_{\text{min}}$ and $T_{\text{mean}}$ from October to December, the Theil-Sen slopes did indicate relatively slight warming trends.

Monthly averages of $T_{\text{min}}$ from January to April reflect a greater warming than $T_{\text{max}}$, and statistically highly significant warming trends ($p<0.01$) were observed for $T_{\text{min}}$ in both January and February. These results are consistent with the findings of Vincent and Mekis (2006) that
show more significant warming trends among $T_{\text{min}}$ indices, such as frost days, than $T_{\text{max}}$ in Canada. The trend analyses also revealed that monthly averages of $T_{\text{max}}$ have warmed throughout the months of October to April; however, a statistically significant warming trend was only observed in January. In January, statistically significant warming trends were observed for all three temperature metrics among the seven months examined. An increase in temperatures, as found in the present study, may have significant implications for the winter roads. Specifically, warming trends in January or the preconditioning months of October to December may lead to negative effects on the winter road opening dates such as later openings, longer construction period, and/or lower quality of winter roads. In fact, Tam et al. (2013) noted that many Fort Albany First Nation community members who use winter roads indicated that the usability and stability of the roads have been decreased due to warmer winters.

Monthly averages of $T_{\text{mean}}$ have also significantly increased in the western James Bay region. These trends are similar to the seasonal air temperature trends at Moosonee in the sea ice studies by Gagnon and Gough (2005b, 2006). Gagnon and Gough (2005b) observed that the trends in air temperatures from October to April have increased, though the increase in temperatures was statistically significant only in December and January (where temperatures have warmed by more than 1.0−2.0 °C per decade). In this present study, statistically significant warming trends were observed in four months from January to April, which have shown the extended warming months until April although the trend in December was not statistically significant, and the magnitudes of warming in both December and January were less than 1.0 °C per decade. This discrepancy may be due to different times series analyzed. The present study examined approximately 50 years of data (1961–2014) while Gagnon and Gough (2005b) examined 30 years of data (1971–2001).
Table 2-2. Monthly averages of $T_{\text{max}}$, $T_{\text{min}}$, and $T_{\text{mean}}$ (°C), the Mann-Kendall (MK) test, and the Theil-Sen (TS) slopes (°C/10 y)

<table>
<thead>
<tr>
<th>Month</th>
<th>$T_{\text{max}}$</th>
<th>MK</th>
<th>TS slope</th>
<th>$T_{\text{min}}$</th>
<th>MK</th>
<th>TS slope</th>
<th>$T_{\text{mean}}$</th>
<th>MK</th>
<th>TS slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>October</td>
<td>8.2</td>
<td>0.073</td>
<td>0.21</td>
<td>-0.1</td>
<td>0.123</td>
<td>0.25</td>
<td>4.1</td>
<td>0.110</td>
<td>0.21</td>
</tr>
<tr>
<td>November</td>
<td>-0.4</td>
<td>0.137</td>
<td>0.25</td>
<td>-8.1</td>
<td>0.176</td>
<td>0.50</td>
<td>-4.3</td>
<td>0.174</td>
<td>0.40</td>
</tr>
<tr>
<td>December</td>
<td>-9.9</td>
<td>0.144</td>
<td>0.50</td>
<td>-20.4</td>
<td>0.172</td>
<td>0.73</td>
<td>-15.2</td>
<td>0.159</td>
<td>0.68</td>
</tr>
<tr>
<td>January</td>
<td>-13.8</td>
<td>0.196 *</td>
<td>0.57</td>
<td>-25.9</td>
<td>0.240 **</td>
<td>0.78</td>
<td>-19.9</td>
<td>0.228 *</td>
<td>0.65</td>
</tr>
<tr>
<td>February</td>
<td>-11.3</td>
<td>0.154</td>
<td>0.44</td>
<td>-25.2</td>
<td>0.268 **</td>
<td>1.03</td>
<td>-18.3</td>
<td>0.225 *</td>
<td>0.73</td>
</tr>
<tr>
<td>March</td>
<td>-4.4</td>
<td>0.137</td>
<td>0.36</td>
<td>-18.7</td>
<td>0.212 *</td>
<td>0.94</td>
<td>-11.5</td>
<td>0.189 *</td>
<td>0.64</td>
</tr>
<tr>
<td>April</td>
<td>3.9</td>
<td>0.128</td>
<td>0.24</td>
<td>-8.2</td>
<td>0.240 *</td>
<td>0.60</td>
<td>-2.2</td>
<td>0.202 *</td>
<td>0.42</td>
</tr>
</tbody>
</table>

Note. Significance at *< 0.05; **< 0.01

2.4.2 Freezing degree-days trend analyses

Trend analyses of the freezing degree-days (FDDs) are provided in Table 2-3, which include the average FDDs and the Mann-Kendall test results with threshold measures of the seven months (i.e., October to April) for each year during 1961–2014, estimated by the Theil-Sen slope. Monthly averages of FDDs for all temperature thresholds were highest in January, and the second and third highest in February and December, respectively. This coincides with monthly temperature averages being the coldest in January, followed by February and December, respectively.
Trend analyses of the FDDs or all temperature thresholds revealed negative trends for all months. At the 0°C threshold, statistically significant decreasing trends were observed in October and the months of January to April. The Theil-Sen slopes have shown decreasing trends, varying from -2.26 to -0.14 FDDs per year, although trends in November and December were not statistically significant. Similarly at the -5°C threshold, statistically significant decreasing trends were detected for the months of January to April, with Theil-Sen slopes varying from -2.15 to -0.64 FDDs per year. No statistically significant decreases in the months of October to December were observed. At the -18°C threshold, statistically significant decreasing trends were detected from the months of December to February, with Theil-Sen slopes ranging from -1.38 to -1.02 FDDs per year. All other months were not statistically significant for the -18°C threshold.

Results of trend analyses for FDDs coincide with the nature of ice formation. Ice begins to form at the surface of fresh water when air temperatures fall below 0°C, and the salt water freezes at slightly lower temperatures. As found in the present study, October was the first month when the amount of FDDs below the 0°C threshold started to accumulate. A statistically significant decreasing trend was also identified for the FDDs at a threshold of 0°C in October, though it was of lower magnitude (Theil-Sen slope= -0.14 FDDs/yr). Furthermore, initial ice formation develops on freshwater lakes when daily mean temperatures are less than -5°C with a weak wind (Knowland et al., 2010; Williams and Stefan, 2006). Similarly, statistically significant decreasing trends were observed for both 0°C and -5°C thresholds from January to April, which coincide with the months of the winter road operating season. However, there was no statistically significant decrease for both thresholds in December, which is typically a crucial month for winter road construction. These trends are consistent with the monthly averages of $T_{\text{mean}}$, which have shown statistically significant warming trends from January to April. This
indicates that decreasing trends of FDDs during the operation season of the winter road may result in a significant impact on the opening dates of the winter road, as well as the road conditions. As found in Manitoba, warm winters lead to a delay in freezing among muskeg areas, resulting in delayed winter road construction (CIER, 2006). Thus, decreasing trends of FDDs due to warmer temperatures may reduce the rate of initial ice growth in muskeg regions, impacting the majority of the James Bay Winter Road route. According to Knowland et al. (2010), daily mean temperatures below the -18°C are crucial for ice bridge construction. As found in the present study, the amount of FDDs below the -18°C threshold increases in December, allowing for almost a month of ice bridge construction before winter road openings in January. As shown in Table 2-3, most FDDs below the -18°C threshold accumulated during the months of December to February; thus, decreasing trends of FDDs during these months may have a significant influence on construction and maintenance of ice bridges over river and creek crossings.

Throughout all months, trend results for FDDs indicated statistically significant decreases for all temperature thresholds. For example, results of the FDDs for the 0°C threshold show that there was approximately -550 FDDs reduction over time since 1961. We used a Lowess curve to depict such decreasing trends (Figure 2-2). A Lowess curve carries out a locally weighted regression so that it is prone to the effects of outliers (Cleveland, 1981). As shown in Figure 2-2, the Lowess curve exhibited a steep reduction in the 1980s, which continues until present time. Such patterns were detected in all threshold measures. In fact, Gagnon and Gough (2005b) observed that there was a temporal pattern in the historical temperature records in the Hudson Bay region. Since 1975, the significant warming period was observed in Moosonee and the warming continued thereafter. Results of the present study indicate that due to the higher
monthly averages of FDDs before the 1980s, it is possible that the winter road may have opened earlier than current time. Indeed, Adam (1978) has reported that in the 1970s, the winter road construction from Moosonee to Attawapiskat was usually completed and opened to traffic by January 1st. Likewise, local residents have noted that the average opening date of the James Bay Winter Road was around late December to January 1st in the 1970s and 1980s (Moosonee Transportation Limited, pers. comm., 2015; Wawatay News, 2012). Such local observations of winter road openings are also documented with the effects of warming in winter such as shorter winter, less snow and later ice freeze-up (Ho, 2003; Tam et al., 2013).

Table 2-3. Monthly averages of FDDs, the Mann-Kendall (MK) test, and the Theil-Sen (TS) slopes

<table>
<thead>
<tr>
<th>Month</th>
<th>FDD</th>
<th>MK</th>
<th>TS slope</th>
<th>FDD</th>
<th>MK</th>
<th>TS slope</th>
<th>FDD</th>
<th>MK</th>
<th>TS slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>October</td>
<td>11.0</td>
<td>-0.20*</td>
<td>-0.14</td>
<td>0.7</td>
<td>-0.17</td>
<td>0.00</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>November</td>
<td>150.7</td>
<td>-0.18</td>
<td>-1.00</td>
<td>64.5</td>
<td>-0.14</td>
<td>-0.45</td>
<td>1.5</td>
<td>-0.07</td>
<td>0.00</td>
</tr>
<tr>
<td>December</td>
<td>471.6</td>
<td>-0.17</td>
<td>-2.09</td>
<td>326.8</td>
<td>-0.16</td>
<td>-2.16</td>
<td>64.9</td>
<td>-0.23*</td>
<td>-1.02</td>
</tr>
<tr>
<td>January</td>
<td>611.8</td>
<td>-0.25**</td>
<td>-2.26</td>
<td>460.5</td>
<td>-0.24*</td>
<td>-2.15</td>
<td>129.0</td>
<td>-0.24*</td>
<td>-1.38</td>
</tr>
<tr>
<td>February</td>
<td>511.4</td>
<td>-0.23*</td>
<td>-2.14</td>
<td>376.1</td>
<td>-0.25**</td>
<td>-2.08</td>
<td>87.4</td>
<td>-0.29**</td>
<td>-1.17</td>
</tr>
<tr>
<td>March</td>
<td>365.5</td>
<td>-0.20*</td>
<td>-1.98</td>
<td>235.2</td>
<td>-0.20*</td>
<td>-1.58</td>
<td>27.3</td>
<td>-0.10</td>
<td>-0.18</td>
</tr>
<tr>
<td>April</td>
<td>110.6</td>
<td>-0.24*</td>
<td>-1.03</td>
<td>40.8</td>
<td>-0.27**</td>
<td>-0.64</td>
<td>0.3</td>
<td>-0.18</td>
<td>0.00</td>
</tr>
<tr>
<td>Oct–Apr</td>
<td>2232.8</td>
<td>-0.34***</td>
<td>-10.16</td>
<td>1505.3</td>
<td>-0.33***</td>
<td>-8.93</td>
<td>310.8</td>
<td>-0.34***</td>
<td>-3.74</td>
</tr>
</tbody>
</table>

Note. The TS slopes are displayed in FDDs per year. Significance at *< 0.05; **< 0.01; ***< 0.001
Figure 2-2. Time series of the FDDs at the 0°C threshold for seven months in total from October to April during the 1961–2014 period. The solid line represents Lowess curve.

2.4.3 Snowfall

Monthly total snowfall and trend analyses for 1961–2014 are presented in Table 2-4. As shown in Table 2-4, snowfall totals are high from November to January. With the exception of October, trend analyses indicated that there was no significant change in snowfall. Moreover, the Theil-Sen slope indicated smaller positive and negative trends for each month. Snowfall trends for October showed statistically significant decreases (p<0.05) over time since 1961. This is consistent with the Vincent and Mekis (2006) findings, where total snowfall has significantly decreased in Moosonee for 1950–2009; though the present study showed almost no change in slope for November. Vincent and Mekis (2006) also observed significantly decreased trends in
spring snowfall for Moosonee; however, the present study showed no statistically significant changes in total snowfall in both March and April.

**Table 2-4.** Monthly total snowfall (mm), the Mann-Kendall (MK) test, and the Theil-Sen (TS) slopes (mm/y)

<table>
<thead>
<tr>
<th>Period</th>
<th>Month</th>
<th>Snowfall</th>
<th>MK</th>
<th>TS slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>1961-2014</td>
<td>October</td>
<td>14.3</td>
<td>-0.24 *</td>
<td>-0.19</td>
</tr>
<tr>
<td></td>
<td>November</td>
<td>52.5</td>
<td>-0.04</td>
<td>-0.06</td>
</tr>
<tr>
<td></td>
<td>December</td>
<td>55.5</td>
<td>0.06</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>January</td>
<td>50.9</td>
<td>-0.04</td>
<td>-0.08</td>
</tr>
<tr>
<td></td>
<td>February</td>
<td>37.8</td>
<td>0.13</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td>March</td>
<td>38.5</td>
<td>-0.01</td>
<td>-0.01</td>
</tr>
<tr>
<td></td>
<td>April</td>
<td>26.3</td>
<td>0.04</td>
<td>0.03</td>
</tr>
</tbody>
</table>

*Note.* Significance at *< 0.05

2.4.4 Relationship of FDDs to opening dates of winter road

The mean opening date for the James Bay Winter Road is January 16 from 2004−2005 to 2014−2015, with two missing years (2006−2007 and 2007−2008). Results of the two periods of FDD accumulations and Pearson correlation coefficients between FDD accumulations and opening dates are presented in Tables 2-5 and 2-6. From October 1 to December 31 as a preconditioning period of winter road seasons, the minimum FDD accumulation at the 0°C temperature threshold was 376 FDDs (°C·days). Also, FDDs have decreased with lowering temperature thresholds (Table 2-5). The correlations between FDD accumulations during the preconditioning period and opening dates for all temperature thresholds exhibited negative
correlations, which coincide with earlier opening dates as a result of larger FDD accumulations (though these trends were not statistically significant, most likely attributed to a small sample) (Table 2-5, Figure 2-3A). Thus, the minimum FDD accumulation at the 0°C threshold, which is approximately 380 FDDs (°C·days), may be a conservative estimate of the minimum threshold of FDDs. This indicates that if the FDD accumulations in the preconditioning period exceed 380 FDDs (°C·days) at the 0°C threshold, this would provide a more favourable (climate) construction period and earlier opening dates.

As expected, from October 1 until the opening dates, the minimum FDD accumulation below the 0°C threshold was 746 FDDs (°C·days), which was larger than FDDs from October to December (Table 2-6). This indicates that over the last ten years, a minimum of 750 FDDs (°C·days) may have been required to properly construct and open the winter road. In agreement with this, temporal trend analyses on monthly averages of FDDs at the 0°C threshold in January showed statistically significant decreasing trends over recent years. As a result of decreasing FDDs, it is possible that there may be a delay in the opening of the winter road (possibly delayed to February) due to the amount of time required to meet the minimum FDD accumulations (i.e., 750 FDDs (°C·days) below the 0°C threshold). Nonetheless, this may be negligible as the FDD accumulations and opening dates were weakly correlated (Table 2-6, Figure 2-3B). We note the small sample size of opening dates (9 years) because the opening and closing dates of winter roads have been recorded since the roads have to accommodate large transport trucks to haul heavy machinery, fuel, and supplies to the Victor Diamond Mine. Comparing the Pearson correlation coefficients for the two periods of FDD accumulations, it can be seen that the FDD accumulations during the preconditioning period have lower $p$ values than the FDD accumulations from October 1 until the opening dates. Specifically, $p$ value at the 0°C threshold
during the preconditioning period is close to confidence level of 90% \((p=0.109)\). This may be an indication that the amount of FDD accumulations during the preconditioning period has more significant effects on the opening dates of winter roads.

**Table 2-5.** FDD accumulations from October 1 to December 31, and Pearson correlation coefficients for FDD accumulations vs. opening dates

<table>
<thead>
<tr>
<th>T threshold</th>
<th>FDDs</th>
<th>FDDs, Opening Date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Max</td>
</tr>
<tr>
<td>&lt; 0°C</td>
<td>595.3</td>
<td>814.7</td>
</tr>
<tr>
<td>&lt; -5°C</td>
<td>370.3</td>
<td>566.1</td>
</tr>
<tr>
<td>&lt; -18°C</td>
<td>53.7</td>
<td>132.6</td>
</tr>
</tbody>
</table>

**Table 2-6.** FDD accumulations from October 1 until opening dates, and Pearson correlation coefficients for FDD accumulations vs. opening dates

<table>
<thead>
<tr>
<th>T threshold</th>
<th>FDDs</th>
<th>FDDs, Opening Date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Max</td>
</tr>
<tr>
<td>&lt; 0°C</td>
<td>895.2</td>
<td>1085.6</td>
</tr>
<tr>
<td>&lt; -5°C</td>
<td>587.3</td>
<td>762.4</td>
</tr>
<tr>
<td>&lt; -18°C</td>
<td>100.6</td>
<td>184.0</td>
</tr>
</tbody>
</table>
Figure 2-3. Linear regression of the opening dates on FDD accumulations from October 1 to December 31 (A), and FDD accumulations from October 1 to opening dates (B).
2.4.5 Landfast ice dates

The average onset dates of landfast ice for the years, 1982–2013, in Attawapiskat, Fort Albany, and Moosonee are December 14, 22, and 23, respectively. It should be noted that data from Moosonee were limited (we were only able to obtain data for the past 18 years, which is approximately half the size of the datasets of Attawapiskat and Fort Albany). Time series results of landfast onset dates of Attawapiskat, Fort Albany, and Moosonee are presented in Figure 2-4. Trend analyses revealed no statistically significant trends for the landfast onset dates at the three sites, although slope analyses indicated a trend towards earlier onset of landfast ice for Fort Albany and Moosonee. This is due to the earlier onset dates of landfast ice at the both sites, particularly since 2001. No apparent trends in landfast onset dates were evident for Attawapiskat.

The trends toward earlier onset of landfast ice for Fort Albany and Moosonee are in agreement with a sea ice study by Gagnon and Gough (2005b), who identified earlier freeze-up trends for the James Bay region, though also lacking statistical significance. For the Hudson Bay region, however, later freeze-up trends were found in all regions, with statistically significant trends ($p \leq 0.05$) in northern and northeastern regions of the bay. In addition, statistically significant trends ($p \leq 0.05$) toward later onset of landfast ice were found in the Canadian Arctic Archipelago. More specifically, landfast onset days have been delayed by one to three weeks per decade in the Beaufort Sea and eastern regions of the Canadian Arctic Archipelago (Galley et al., 2012). In addition, trends in the duration of landfast ice season have decreased over time in most regions of the Canadian Arctic (Galley et al., 2012).
Gagnon and Gough (2006) studied trends of landfast ice thickness for Moosonee during the time period, 1960–1990. The study showed that there was a significant increase in maximum ice thickness over time for Moosonee ($p<0.05$). At the moment, there is no measurement for ice thickness in the area since 1990s because the Canadian Ice Thickness Program which recorded ice thickness data has ended (Environment Canada, 2014b). Though, it has been observed that the ice thickness of freshwater waterways in the region that the winter road crosses has been artificially enhanced. In fact, the Albany River has caused local flooding to nearby communities in the vicinity, such as Fort Albany and Kashechewan (CBC, 2015). In recent years, spring flooding has increased in magnitude and frequency, increasing the risk to flood damage for many community members (Ho et al., 2005; McCarthy et al., 2011). Thus, though this study found that an earlier onset of landfast ice may lead to increase ice thickness (and benefit the winter road), increased warming may also cause earlier springs, rapid snowmelt and/or ice jam, and an increase in the frequency and intensity of flooding.

![Figure 2-4](image)

**TS slope = 0.00 (AT), -0.33 (FA), -0.46 (MO)**

**Figure 2-4.** Time series of landfast onset dates for the 1982–2013 period at Attawapiskat (AT), Fort Albany (FA), and Moosonee (MO). LOWESS curve is indicated by a dashed line.
2.5 Conclusion

This study is the first to report on climate change impacts on the winter road seasons in Ontario’s Far North with a particular focus on the climatological factors related to the historical opening dates of the James Bay Winter Road. Climate data, including air temperature, precipitation, and snowfall, as well as the dates of landfast ice were analyzed to advance our understanding of a changing climate on the viability and longevity of the winter road. The warming trends in the monthly averages of both $T_{\text{min}}$ and $T_{\text{mean}}$ are statistically significant from January to April, 1961–2014. Also, the decreasing trends in the FDDs are statistically significant from October to April. The FDDs during the months of October through December as a preconditioning period of winter road seasons show more significant effects on the construction period and opening dates of winter road.

We acknowledge that other climatic variables such as wind speed and direction may alter natural ice growth. For instance, ice grows faster if wind is able to blow snow cover off the frozen surface of water to reduce the insulation effect of the snow (Williams and Stefan, 2006). Changes in wind patterns have been observed in the Hudson-James Bay region by Indigenous observations (McDonald et al., 1997); however, there is a lack of wind data for the local weather stations to determine regional changes of the winds. It should be noted that the results for the relationships of minimum FDD accumulations to the opening dates of James Bay Winter Road should be taken with caution, given the small sample size of opening dates. However, the results do point to the importance of the preconditioning period of October to the end of December. For
the available data, a minimum threshold of 380 FDDs (°C·days) with a 0°C threshold was established and is potentially useful for climate change projections.

We note that the use of present landfast ice data to detect the changes of ice freeze-up is a difficult task because if the stage of development of landfast ice and/or the area in question cannot be identified, the area will be “blackened-in” to label as a landfast ice (CIS, 2005). In recent years, warming weather results in delayed construction of winter roads in muskeg areas due to later freeze-up of water (CIER, 2006). Ice growth in muskeg areas may be slow due to gases that are produced by the muskeg (Saskatchewan Ministry of Highways and Infrastructure, 2010). Such warming effects may affect the gases in muskeg and may cause natural ice formation at a much slower rate.

We also note that the techniques used to construct and maintain winter roads have changed substantially due to integration of modern technology and perhaps an increase in funding. These factors have improved road quality, such as wider, straighter and smoother roads along with an increase in load-bearing capacity. Moreover, the winter road safety and liability have become major priorities since the rapid expansion of mining and transportation sectors that have used the road to move fuel and heavy equipment. Such factors for winter road development are surely important to consider not only for the historical opening dates of the winter roads but also for the usability and stability of the roads in the future.

This study is part of a broader project that is developing effective adaptation strategies for remote-northern Indigenous communities in Ontario regarding the effects of climate change on seasonal transportation systems. Knowledge of warming trends such as decreasing FDDs and increasing air temperature will aid in the development of climate change impact assessments,
long-term planning, and adaptation strategies for Indigenous communities who rely on winter roads. Continued monitoring of ice cover in rivers, creeks, and muskeg areas in the Hudson-James Bay region is needed to allow for a more comprehensive study of winter road meteorology. Further research is required to gain a better understanding of the effects of climate change on the winter road systems throughout the Far North of Ontario.
2.6 References


Chapter 3
Community vulnerability to changes in the winter road viability and longevity in the western James Bay region of Ontario’s Far North

3 Chapter 3

3.1 Abstract

A network of winter roads that consists of snow-ice roads over land, muskeg, frozen lakes, and rivers has been, and continues to be, a critical seasonal lifeline in remote-northern First Nations communities in Ontario’s Far North. This study examines current vulnerability of the Fort Albany community to physical, social/cultural, and economic impacts associated with the changing of the viability and longevity of winter roads and its seasons, as well as the river ice regimes. Semi-directive interviews with key informants (n = 8) and structured surveys with winter road users (n = 54) were conducted to gather local knowledge about the evolution of winter roads and climatic and environmental changes in winter road conditions and seasons. Trends in the river ice break-up and flood events for the Moose River, Albany River, and Attawapiskat River were also examined. The results of this study indicate that climatic factors, particularly air temperature and snowfall, have directly affected the construction and maintenance of the James Bay Winter Road, which plays an important role in the Fort Albany community. Trend analyses of spring flooding for the three rivers exhibit statistically significant increases ($p \leq 0.01$) over the past few decades; thus, flooding in nearby communities has become
a more significant threat in recent years. A few short- and medium-term adaptation strategies
have been initiated in response to the impacts of climate change on winter roads; however,
developing long-term planning and feasible adaptation for remote-northern communities in
Ontario’s Far North is necessary.

3.2 Introduction

3.2.1 Background on the winter road systems in northern Canada

Winter roads provide critical transportation routes in northern Canada. Winter roads can be
defined as any type of roads that are made of snow and/or ice that remain functional during the
winter months (Adam, 1978). In northern Canada and Alaska, USA, winter roads that consist of
ice roads over land, frozen lakes, and rivers are frequently used (Adam, 1978; ACIA, 2005).
Since the 1950s, a seasonal network of winter roads that sometimes link to all-season road
systems was implemented in remote-northern communities in Canada (Prowse et al., 2009). In
1999, the Government of Ontario spent $2.7 million to construct and maintain over 2,700 km
winter roads in Ontario’s Far North; in 2014–2015, they invested $5.0 million for the 3,160 km
winter road system connecting 31 remote-northern communities to a highway or railway system
(Dore and Burton, 2001; Government of Ontario, 2015b). Ontario’s Far North, as defined by the
Far North Act, 2010, refers to the northern portion of Ontario that covers 42% of the province’s
land mass (Government of Ontario, 2015a). The winter road network in Ontario’s Far North
typically operates for three months each year (i.e., January, February, and March), and is integral
in providing access to major goods to most communities in the region (Chiotti and Lavender, 2008). Thus, winter roads have minimized the cost of goods and services for local residences. In addition to such economic benefits, these corridors also facilitate social and cultural connections among nearby remote-northern communities (Chiotti and Lavender, 2008; Furgal and Prowse, 2008).

3.2.2 Climate factors to the winter road systems

The seasonal length of the winter roads depends on particular climatic factors, such as surface air temperature, precipitation, snowfall, and wind. These climatic conditions also influence the initial ice development that includes ice freeze-up, growth, and thickness before road construction begins (ACIA, 2005; Hori et al., 2015; Knowland et al., 2010). However, the warming of the Earth’s climate system is unequivocal (IPCC, 2007b), and climate change is projected to increase the Earth’s surface temperature at an unprecedented rate (IPCC, 2014); the implications of climate change to the winter road systems is of a concern. In recent years, an increase in mean air temperature has been observed at higher northern latitudes by both instrumental records and Indigenous observations (Ford et al., 2006; Furgal and Prowse, 2008; Hassol, 2004). With an increase in mean temperatures, there has been increasing concerns with delayed opening dates of the winter roads and a decline in the quality of the roads (ACIA, 2005; Chiotti and Lavender, 2008; Furgal and Prowse, 2008; Tam et al., 2013). As climate change scenarios project a continual rise in winter air temperatures in the western James Bay region
(Hori, 2010), there is the concern that the winter road will not be able to withstand the transport of heavy materials, food, and fuel among remote-northern communities.

3.2.3 Implications of river ice regime to winter road systems

As reported by Hori et al. (2015), it has been observed that ice thickness of freshwater waterways including rivers and muskegs in the western James Bay region has been artificially enhanced. Winter roads in the western James Bay region run through large estuaries of three major rivers so that ice bridges are constructed across such areas. Surface flooding or spray-ice techniques have been commonly used to maximize the ice thickness of ice bridges (Prowse et al., 2009); thus, such methods artificially increase ice thickness of winter roads in the region. An increase in temperatures not only affects the winter road systems in the Far North of Ontario, but may also impact environmental phenomena, such as spring floods and ice jams. Warmer temperatures, for instance, have significant implications to the timing and intensity of spring floods and ice jams (Chiotti and Lavender, 2008). Communities of the western James Bay regions in Ontario’s Far North are located in flood plain regions and as a result, have been affected by a number of spring floods in the past (Chiotti and Lavender, 2008; McCarthy et al., 2011). Unfortunately, an increase in the magnitude and frequency of spring floods has been observed in recent years, adding to increased risks to flood damage among these communities (Ho et al., 2005; McCarthy et al., 2011).

Changes in river ice freeze-up and break-up trends are also complex, though the impacts of climate change on the timing and severity of river ice break-up are less well known in contrast
to changes in Arctic sea ice characteristics (Beltaos, 2004; Beltaos and Prowse, 2009; Ho et al., 2005). As an example, Ho et al. (2005) reported that no river ice break-up occurred in 1999–2002 for the Moose River, Albany River, and Attawapiskat River in the western James Bay region due to break-up changes being too gradual to measure. In 2004, however, a major break-up event in Attawapiskat caused severe floods, forcing a full community evacuation (Ho et al., 2005). Such rapid changes of river ice pattern and conditions and the links to winter road systems and climate change are of interest.

3.2.4 Study objectives

The remote-northern First Nations communities in Ontario’s Far North are particularly vulnerable to climate variability and climate change. However, there remain significant knowledge gaps regarding the vulnerability of these communities to climate change (Chiotti and Lavender, 2008; Tam et al., 2013). Improved understanding of community vulnerability and the related determinants should therefore be a priority to help identify feasible adaptation strategies to the risks associated with climate change (Ford and Smit, 2004). Therefore, the main objective of this study was to explore the vulnerability of James Bay Cree communities (i.e., physical, social/cultural, and economic impacts) to changes in the winter roads. Also, trends in river ice break-up and flooding were examined to provide insight into the links to the current practices of winter roads. An understanding on the impacts of climate change on the winter road systems is of particular importance to First Nations in the Hudson-James Bay region due to the potential impacts on everyday lifestyle. Thus, a broader understanding of regional climate change impacts
on local infrastructure will allow the remote-northern Indigenous communities to develop feasible adaptation strategies and coping measures. To our knowledge, there is no comprehensive scientific analysis of the viability and longevity of winter roads in Ontario’s Far North in current literature.

3.3 Vulnerability framework

The IPCC (2007a) defines vulnerability as “a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity” (p. 21). In order to analyze community vulnerability and adaptability to climate change, Ford and Smit (2004) developed an analytical framework for vulnerability analysis. They conceptualized vulnerability as a function of exposure sensitivity and adaptability to deal with climatic stresses (Ford and Smit, 2004). This vulnerability framework and conceptualization were employed by a number of case studies of climate change involving Indigenous communities in Canada’s Arctic and subarctic (e.g. Ford et al., 2010). These case studies indicate that many Indigenous communities demonstrate significant adaptability to cope with past and present environmental changes, although they are often more vulnerable to such changes due to their strong relationship with the environment (Ford et al., 2006; Furgal and Seguin, 2006; Guyot et al., 2006; Laidler et al., 2009; Lemelin et al., 2010; Tam et al., 2013; Tremblay et al., 2008). They have learned to overcome environmental changes through various adaptation tools and strategies, such as the sharing of risks and knowledge, community programs, and the use of advanced equipment and new technology (Furgal and Seguin, 2006; Guyot et al., 2006; Laidler
et al., 2009; Tam et al., 2014; Tremblay et al., 2008). The present study utilizes the aforementioned vulnerability framework (Ford and Smit, 2004) to assess current vulnerability of the Fort Albany community to the changes of winter road systems and river ice regimes, also taking into consideration local observations, experiences and knowledge.

3.4 Study area and community

The western James Bay region of Ontario’s Far North is classified as having a subarctic climate, which typically includes short and cool summers, and long and cold dry winters (Hori et al., 2012). The James Bay Winter Road (JBWR) runs through several rivers, streams, and muskeg areas across the western James Bay coast. In the Hudson Bay Lowlands, approximately 80 percent of the region consists of muskeg or peat forming wetlands (Adam, 1978). Because of this, an all-season road is unsuitable due to great environmental damage and high maintenance costs that would come from building on muskeg and wetlands (Campbell and Bergeron, 2012).

The winter road network spans 320 km in length along the coastline of the Hudson-James Bay (Government of Ontario, 2015b). During the winter season, the winter road connects the coastal and remote fly-in communities of Attawapiskat, Kashechewan, Fort Albany, and Moose Factory to the town of Moosonee, which is the northern terminus of the railway in the region. The JBWR is currently operated and maintained by the Kimesskanemenow Corporation, owned by the First Nations communities of Attawapiskat, Kashechewan, Fort Albany, and Moose Cree (Kimesskanemenow Corporation, 2015). The name *Kimesskanemenow* is a Cree language, which means ‘our road’.
The Fort Albany First Nation, the focus community of this study, has a total population of approximately 850 Cree (Tsuji et al., 2006). Fort Albany First Nation was chosen among remote communities of the western James Bay region, because it is approximately midway on the JBWR, and our research team has a long-standing ties with the community. The residents of the community mainly speak Cree and follow a subsistence lifestyle (Tsuji, 1996a, 1996b; Tsuji and Nieboer, 1999). For example, the Cree communities of the western James Bay region are dependent on wildlife harvesting, predominantly fish and game meat (Berkes et al., 1994, 1995; Tsuji et al., 2006).

3.5 Methods

3.5.1 Data collection

3.5.1.1 River ice break-up data

River ice break-up data for the three major rivers (the Moose River, Albany River, and Attawapiskat River) of the western James Bay region were used to examine the temporal trends of river ice patterns of the region and the links to the current practices of winter road construction and maintenance. The methods to determine break-up dates in each river are outlined in Ho et al. (2005). Break-up data for each of the three rivers were obtained from the
Ministry of Natural Resources and Forestry for the period 1950–2014. The data also indicated major flood events in each river.

### 3.5.1.2 Interviews with key informants

A semi-directed interview is a standard method for gathering local knowledge through an open-ended format, and it has been commonly used in the context of northern research (Ford et al., 2008a, 2008b; Huntington, 1998; Laidler et al., 2009). Semi-directive interviews were conducted with eight key informants in February 2015. The eight key informants were from three First Nations communities and non-First Nation individual (Moose Cree First Nation = 2, Fort Albany First Nation = 4, Kashechewan First Nation = 1, non-First Nation = 1). The ages of the key informants ranged from 31 to 78 years old (mean = 50). The key informants were purposively recruited based on their knowledge and experience with the construction and maintenance of JBWR. Specifically, former/current managers and employers of JBWR were recruited as the key informants. The aim of the key informant interviews was to understand how the winter road systems have evolved with changing climatic and environmental conditions as well as to document past and current practices for construction and maintenance of the winter road. Moreover, collecting local knowledge and observations of the winter road system provides insight on intricate environmental changes not found in scientific observations. The community-based research coordinator helped in identifying, contacting, and recruiting participants to interview for this study. All interviews were conducted in English, although a Cree interpreter was available upon request. Interviews lasted from 20 to 60 minutes and were conducted at a
convenient location and time for the participants. With the participant’s permission, interviews were audio recorded and/or detailed notes were taken.

3.5.1.3 Winter road user survey

Fifty-four winter road user surveys with Fort Albany First Nation were conducted from February to April 2015. The ages of the winter road users ranged from 18 to 69 years old (mean = 35). The winter road users were purposively selected from a household list of Fort Albany by the community-based research coordinator, and one eligible person was invited to participate from a household. Eligibility criteria for the community members were as follows: 1) the participant must be self-identified as Aboriginal, ≥ 18 years old; 2) the participant must have been living in Fort Albany for the majority of their life; 3) the participant must currently reside in their community at the time of the survey; and 4) the participant is a main driver in his/her household. The aim of the winter road group surveys was to document current and future vulnerabilities of the Fort Albany community, including winter weather and climate, ice and water conditions, winter road use and its conditions, and spring flooding. The survey consisted of 28 questions that divided into seven sections. Written consent (informed) was obtained from each participant after being informed of the purpose of the study. Ethical approval for the study was obtained through the University of Toronto Research Ethics Board.

3.5.1.4 Land survey
A land survey was carried out approximately one week in February 2015. This included traveling on the JBWR, experiencing and observing winter road use and its conditions, winter road features (e.g., river and creek crossings and muskeg areas), and local ice features (e.g., river freeze-up and landfast ice). These observations were guided by the community-based research coordinator who is highly knowledgeable on the winter road systems and its environments. These experiences promote a better understanding of local knowledge and perspectives that were brought up by participants during the interviews (Laidler et al., 2009). Visual documentation (e.g., photographs and videos) and detailed notes were taken in order to record relevant observations and experiences.

3.5.2 Data analysis

3.5.2.1 River ice break-up data

River ice break-up data were analyzed by using the non-parametric Mann-Kendall correlation and the Theil-Sen method in order to identify any statistically significant trends between year and date of break-up. These statistical techniques are typically used in sea ice studies (ice freeze-up and break-up dates) of the Hudson Bay region by Gagnon and Gough (2002, 2005, 2006) and Gough et al. (2004) since time series trends are not necessarily linear. The Mann-Kendall test determines the statistical significance of the trends at a selected significance level (Helsel and Hirsch, 2002); thus this study used $\alpha=0.05$ for the test. The Mann-Kendall test, however, does not estimate the slope of a trend, so the Theil-Sen method was applied for this purpose. The
Theil-Sen method is also non-parametric and provides a more robust estimate of a slope than the methods of least-squares, since the median of the sets of slopes is less affected by outliers or gross errors in the time series (Hirsch et al., 1982; Sen, 1968).

In order to examine the relationship between year and flood event, Pearson’s product-moment correlation coefficient (Pearson’s $r$) was performed. All statistical analyses were performed using R (R version 2.15.3, R Development Core Team).

### 3.5.2.2 Interviews and surveys

Key informant interviews and open-ended survey responses were recorded by hand and a voice-recorder (only for those who provided participant approval), and records were transcribed verbatim. Qualitative data were then analyzed using QSR NVivo, a computer software program. A thematic content analysis has commonly been performed on interview data to identify common groups or categories relating to environmental and human impacts in northern communities (e.g. Ford et al., 2009; Furgal and Seguin, 2006; Tam et al., 2013). Thus, this study employed a thematic analysis approach to identify themes or patterns from the interview transcriptions and open-ended survey responses. The analysis of observation notes and secondary sources, including newspaper articles, books, and government reports, was also used to examine how the JBWR has evolved with First Nations communities over time. Concept mapping was then applied, not only to examine interrelationships between the winter road and its potential impacts on First Nations communities, but also to gain a holistic view on possible adaptation
strategies. Descriptive statistics were used to analyze the closed-ended survey responses and the most frequently occurring words and concepts in open-ended survey responses.
3.6 Results and discussion

3.6.1 River ice break-up and flood event trends

Statistical trend analyses of river ice break-up and major flood events (1950–2014) for the Moose River, Albany River, and Attawapiskat River are provided in Table 3-1. Trend analyses revealed that only the Moose River has shown potentially significant ($p \leq 0.1$) earlier break-up dates, although such trend is minimal according to the Theil-Sen slope (-0.08/day). There was no statistically significant change in both Albany River and Attawapiskat River. Ho et al. (2005) observed that the trends in the river ice break-up date for the three rivers during 1950–2002 (some data end in 1998 or 2001). The Albany River and Attawapiskat River have shown statistically significant changes in break-up dates over time; however, due to a lack of a statistical variance, they concluded that the statistical results were considered to be inconclusive.

The flooding data for the three rivers revealed that flooding events have exhibited statistically significant correlations between major flooding events and time. Moose River and Attawapiskat River showed a highly statistically significant increasing ($p \leq 0.001$) trend. Similarly, Albany River indicated a statistically significant increasing ($p \leq 0.01$) trend over time. As aforementioned, the JBWR runs through several rivers and muskegs so that river and creek crossings are enhanced to cross these areas. The ice thickness of freshwater waterways, such as rivers and muskegs in the western James Bay region, has been artificially increased, which may be attributed to the application of water layers to reach a critical ice thickness for the winter road. This may be an indication that not only increased warming, but also artificially increased ice
thickness when it melts have resulted in increased intensity and frequency of spring flooding in recent years. The majority of winter road users (81%) reported that spring flooding is an issue in the Fort Albany community, and they commented that warming may lead to more snow, earlier and quick spring melt and/or ice jam. Only 9% of those indicated that the ice is thicker than before and such thickness may also cause flooding when it melts; however, none of them mentioned the use of water to increase the ice thickness on the winter road.

Table 3-1. The average date of river ice break-up, the Mann-Kendall (MK) test, and the Theil-Sen (TS) slopes in days, as well as Pearson correlation coefficients for flooding from 1950–2014

<table>
<thead>
<tr>
<th>River ice break-up</th>
<th>Average break-up date</th>
<th>MK</th>
<th>TS slope</th>
<th>R value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moose River</td>
<td>April 29</td>
<td>-0.144 •</td>
<td>-0.08</td>
<td>0.430 ***</td>
</tr>
<tr>
<td>Albany River</td>
<td>May 1</td>
<td>-0.087</td>
<td>-0.06</td>
<td>0.365 **</td>
</tr>
<tr>
<td>Attawapiskat River</td>
<td>May 4</td>
<td>0.112</td>
<td>0.07</td>
<td>0.400 ***</td>
</tr>
</tbody>
</table>

*Note.* Significance at •< 0.1; *< 0.05; **<0.01; ***<0.001

3.6.2 Themes

The vulnerability framework was used to understand and present a characterization of how changes in winter road systems and river ice regimes were experienced by community members. The thematic analysis revealed six major themes and related sub-themes from key informant interviews, winter road user group surveys, and land survey.
3.6.2.1 Evolution of the James Bay Winter Road

Initially, the winter road systems were built for winter-road tractor trains. As a result, the quality of the roads was often poor; however, as a mining company moved into the area, there was a dramatic change in the quality of the roads and its main uses.

Until 1950s, the communities in the western James Bay region were only accessible by boat during the summer season and by dog teams during the winter season (Laguerrie, 1994). In the early 1950s, the JBWR was first built for the construction of the Mid-Canada Radar Line sites (McCarthy et al., 2010). In the past, there were several organizations that were in charge of the winter road. Since 2007, the JBWR has been operated and managed by the Kimesskanemenow Corporation.

The majority of key informants indicated that the initial construction of the winter road was different than current practices of the JBWR. Snow on the winter road was first compacted by a tractor train with sleighs, which brought fuels and building supplies to the communities. Roman Catholic missionaries used to haul supplies up along the coastline of James Bay from Moosonee to Winisk, often referred to as ‘missionaries trail’. The missionaries came into the communities with the first tractor train. Based on participants’ accounts, the initial winter road was very narrow and the road quality was poor. As indicated, the winter roads were mainly built by compaction of snow using any available tractor, roller, and/or bulldozer. Such practices have changed since De Beers Canada Inc. started their mining project in the western James Bay region. Specifically, the Victor Diamond Mine, an open-pit diamond mine, is located approximately 90 km west of Attawapiskat (Whitelaw et al., 2009). This mine construction
commenced in 2006, and as a result, a new section of the winter road was built to connect Attawapiskat to the mine site (Whitelaw et al., 2009). As key informants stated:

In my knowledge, when I start working 25 years ago, it was a very small road. When you passed vehicles, it sometimes gets stuck, sometimes won’t get stuck. But when the mine came in, roads were bigger, big ice roads. (Participant #1)

We just pulled and dragged, let it freeze, that’s it. On the snow, that was it, no water. It’s not that long time ago, changes came when the DeBeers came around. (Participant #5)

...if you see the road, probably the last 20–30 years, like I say the first 20 years was narrow, very rough, not very good like here [now], that’s good, that’s very good road. About eight years, we have built it to that standard there. (Participant #1).

3.6.2.2 Current practices of the winter road construction and maintenance

For the last ten years, the construction of the winter road typically began in early December (Kimesskanemenow Corporation, 2015). Under the management of Kimesskanemenow Corporation, the JBWR is divided by four sections to construct and maintain the road and the four First Nations communities of Attawapiskat, Kashechewan, Fort Albany, and Moose Cree take responsibility for each section (Kimesskanemenow Corporation, pers. comm., 2015). The JBWR construction on frozen lakes, rivers, smaller waterways, and open muskegs starts with initial compacting of snow for frost penetration, typically starting when the snow depth reaches about knee height (Kimesskanemenow Corporation, pers. comm., 2015). In each section of the road, about 5–10 snowmobiles are used to compact snow depth, which reduces its insulating effects and promotes deeper frost penetration (Kimesskanemenow Corporation, pers. comm., 2015). Once the ice thickness reaches approximately 15–25 cm in the muskegs and approximately 25–30 cm for lakes and rivers (Adam, 1978; Campbell and Bergeron, 2012), a
small and/or medium size bulldozer is used to plow the snow and drag tires to smooth and strengthen the surface (Kimesskanemenow Corporation, pers. comm., 2015). In order to increase the durability of the road that can support full loads, surface flooding is done by a water truck to create an ice cap on top of the road surface (Kimesskanemenow Corporation, pers. comm., 2015). Creek and stream crossings are also filled with snow and flooded, creating a ramp between land and water (INAC, 2010; Kimesskanemenow Corporation, pers. comm., 2015). For ice bridges across major rivers, the minimum ice thickness for a full weight (GVW 55,000 kg) is at least 1.09 m (43 inch) with a road width of 30–60 m (100–200 feet) (Adam, 1978; Kimesskanemenow Corporation, pers. comm., 2015). Testing and measuring ice thickness during construction and maintenance of winter road are recorded regularly until the official road closure in the end of March (Kimesskanemenow Corporation, pers. comm., 2015).

3.6.2.3 Importance of climatic indicators for the winter road

The majority of key informants noted the importance of air temperature and snowfall for the construction and maintenance of the winter road. Many noted that it is important to have very cold temperatures before and during the construction period. As one key informant stated:

_We get around anything under double digits, really cold like -20 to -40°C. That range...is good for the road. Colder the start is better because first we have to run 10 snowmobile machines to pack the snow down, so water comes up and then frost starts going down. The machines go on top, so they won’t fall through. That is what we do the first._ (Participant #1)

This observation coincides with past findings that the freezing degree-days during the month of October through to December (preconditioning period of the winter road) play a key role in
providing a more climatically favourable construction period and earlier opening dates (Hori et al., 2015). Knowland et al. (2010) reported a critical temperature threshold for flooding ice bridges at Norman Wells, Northwest Territories, which is that 5 cm of water will freeze successfully overnight at a daily mean temperature of -18°C and 9 cm will freeze overnight with a daily mean temperature of -31°C or lower. Although none of the key informants indicated any required temperature thresholds for constructing ice bridges, one key informant indicated, “the ideal situation is quick freeze” (Participant #2).

Second, many participants noted that there should be sufficient snow cover to pack the snow and build creek and stream crossings. One key informant stated that “with snow, again, you want some snow but not too much, so you want minimum snow during the ice construction” (Participant #2). At least 10 cm of the packed snow is required on the winter road surface in order to maintain a high albedo as well as to protect the ground surface from tracks and vehicles (INAC, 2010; Knowland et al., 2010). If there is heavy snow cover on the ice before the construction period, it may cause unsafe ice conditions throughout the winter road season (Knowland et al., 2010). Another key informant described how snow affects the rate of ice growth: “…we look at how [it] freezes, [if] the lots snow in December, be very thin, [if] no snow in December, be thick because [of] cold, snow is blanket and insulated” (Participant #1).

Other climatic indicators, such as wind speed and direction may alter natural ice growth of the winter road. For instance, ice grows faster if wind is able to blow snow cover off the frozen water surface to reduce its insulating effects (Williams and Stefan, 2006). The moon and tides may also alter natural ice formation and growth. Two key informants indicated that major river crossings are affected by the tidal currents, because the tides can cause ice to rise and/or
fall. Also, one key informant noted their perception on the association between moon activity and weather:

*Sometimes [when it's] warm, water comes up from the bottom, like slush ice in muskeg, water comes out, we get stuck on the winter road. December, sometimes in January, very warm sometimes. Maybe the moon does that, getting full moon, water comes, lots slush (Participant #7).*

The correlations between climate variations and lunar cycles are of interest to scientists; however, such mechanisms have been unclear (Royer, 1993).

**3.6.2.4 Current practices of winter road use**

The JBWR has become a critical route connecting remote fly-in communities in the western James Bay region. Key informants stated that it used to only be used by snowmobiles, and at times, small trucks, on the winter road approximately 20 years ago. Today, all types of vehicles, from a small passenger car to a large transport truck, travel across the winter road. Based on key informants’ accounts, approximately 30–50 vehicles travel on the winter road per day, though this tends to increase on weekends and social events. Key informants also mentioned that the numbers of pickup trucks, in particular, have increased rapidly:

*We didn’t have enough vehicles long time ago in this town, nobody hardly using any pickup trucks to go to Moosonee, roads are too soft, lots of snow, sometimes they fall, they stuck, so they didn’t use those. It wasn’t meant for vehicles back then, just getting supplies then. Gas, fuels, groceries, lumber, that’s why we were doing that, just building that road all the way to Moosonee, get that train loaded it up come back with full loads, that’s it. Now I noticed that when we worked here we can use pickup trucks come back home do it again every day (Participant #5).*
For winter road users in Fort Albany, the majority (76%) of respondents indicated that they use winter road a few times during the winter road season. Almost half (48%) of winter road users drive on the winter road in the morning due to better road conditions (i.e., easy to travel, colder in the morning, stable ice) and purchase groceries and necessary supplies at the local stores in Moosonee. The results of descriptive statistics of current winter road use are summarized in Table 3-2. The winter road users in Fort Albany described the JBWR as an important social and cultural lifeline. In summary, the majority (93%) of winter road users reported that the JBWR is important to them due to financial (i.e., cheaper to travel), social (i.e., visit family and friends), and mental (i.e., feel less isolated) reasons. These responses are consistent with past research reporting the impact of changes in cold weather, ice conditions, winter roads and trails, and wildlife on the five First Nations communities in northern Manitoba (CIER, 2006). For example, community members indicated that the winter roads, access trails, and frozen water bodies play a vital social and cultural role in their communities. A shorter winter road season and increase in unreliable road conditions decreased opportunities to participate in social and cultural activities, as well as to travel outside of the community; while also increasing financial costs, feelings of social isolation, and accidents along the winter roads and/or trails. A community health study by Tam et al. (2013) in Fort Albany documented that many community members have less chance to travel to Moosonee to purchase cheap necessities, when the winter road season is shorter due to warmer climate conditions, thereby increasing financial challenges.
Table 3-2. Responses by winter road users for social and cultural roles of the current winter roads

<table>
<thead>
<tr>
<th>Items</th>
<th>Agree (n %)</th>
<th>Neither agree nor disagree</th>
<th>Disagree (n %)</th>
<th>Don’t know (n %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shop in Moosonee</td>
<td>48 (92)</td>
<td>0 (0)</td>
<td>2 (4)</td>
<td>2 (4)</td>
</tr>
<tr>
<td>Visit friends and family</td>
<td>47 (92)</td>
<td>0 (0)</td>
<td>3 (6)</td>
<td>1 (2)</td>
</tr>
<tr>
<td>Gather at social events (e.g., marriages, birth and funerals)</td>
<td>46 (90)</td>
<td>1 (2)</td>
<td>3 (6)</td>
<td>1 (2)</td>
</tr>
<tr>
<td>See significant others in hospitals or care centres</td>
<td>42 (86)</td>
<td>2 (4)</td>
<td>3 (6)</td>
<td>2 (4)</td>
</tr>
<tr>
<td>Participate in recreational activities (e.g., bingos and hockey games)</td>
<td>32 (65)</td>
<td>2 (4)</td>
<td>12 (24)</td>
<td>3 (6)</td>
</tr>
<tr>
<td>Hunt/trap animals and/or fish</td>
<td>29 (59)</td>
<td>3 (6)</td>
<td>14 (29)</td>
<td>3 (6)</td>
</tr>
<tr>
<td>Work</td>
<td>24 (49)</td>
<td>6 (12)</td>
<td>15 (31)</td>
<td>4 (8)</td>
</tr>
</tbody>
</table>

Note. Numbers may not add up to the total numbers of participants due to blank responses.

3.6.2.5 Changes in winter road seasons and conditions

The majority of key informants and winter road users described the effects of warming on construction and maintenance of the winter road, and its seasons and conditions over time. One key informant stated that a long time ago, winter temperatures were about -50 °C and -60 °C in December. Today, most key informants and winter road users (85%) reported that the winter weather as being warmer now compared to the past. Moreover, 60–70% of winter road users felt that air temperature, rain, and snow have showed a marked change in recent years, such as an increase in rain during the winter season. Key informants believe that snowfall has decreased; however, winter road users have found that there has been an increase in snowfall over the recent years.
These weather observations align with past studies addressing how the Fort Albany community has been affected by changing climatic conditions (Ho et al., 2005; Hori et al., 2012; Tam et al., 2013). An increase in monthly mean temperatures has been observed in the western James Bay region by instrumental records and Indigenous observations (Gagnon and Gough, 2005; Hori et al., 2012; Hori et al., 2015; Tam et al., 2013). Hori et al. (2015) reported that statistically significant warming trends in air temperature ($p < 0.05$) were observed from January to April for the period 1961–2014. Historical temperature data in regions over Hudson Bay and the Canadian Arctic also indicated statistically significant warming during the winter and spring months, and similar local observations were made in northern Manitoba and some regions in the Canadian Arctic (CIER, 2006; Gagnon and Gough, 2005; Laidler et al., 2009; Statham et al., 2014).

The effects of such warming have been observed in the timing and quality of ice freeze in the water bodies (i.e., lakes, rivers, creeks, and muskegs), before and during the construction period. For example, waters used to freeze early before snowfalls, waters in rivers and lakes do not freeze to the same extent as before, and/or ice in muskegs is too thin. As one key informant expressed concerns about the ice of the road when flooding, because of such unstable ice freeze conditions:

*You see when it freezing and flooding on top, when you need to freeze because sometimes it won't freeze enough and get the shell ice and you get pockets of water, then in the end just going back. What has been doing lately, it will freeze and break up, stop, freeze, so when we make a road, when we drill, there’s a pocket of air and a pocket of water in that ice (Participant #1).*

Almost half (47%) of winter road users also noticed changes in coastline, river, and muskeg due to changes in winter climate. Such observations include more water and slush in coastline and river, thinner ice in river and muskeg and partially frozen areas. In particular, changes in the
timing of river ice freeze and melt have observed by the majority (70%) of winter road users. These observations include that the river freezes later or not completely at all, river ice melts faster, and river ice break-ups earlier. This is consistent with past research findings that have found delayed freezing of water bodies and decreased ice thickness (CIER, 2006; Ho et al., 2005; McDonald et al., 1997; Tam et al., 2013). CIER (2006) reported that the construction of winter roads in northern Manitoba was delayed due to late ice freeze-up, weaker ice, and thinner ice in some muskeg areas. Sixty-five percent of winter road users also stated that the timing of the freezing and melting cycles is harder to predict now due to warmer, different, and/or unpredictable weather. Cree elders from the western James Bay region have noticed that the timing of river ice freeze has been delayed in recent years so that the prediction of the river ice freeze/thaw cycles has become more difficult (Ho et al., 2005). The majority (78%) of winter road users reported that spring melt has changed in recent years, such as earlier thaw, melt, and break-up due to warmer springs. This is consistent with local observations in 2003 and 2010 that spring melt occurred earlier with infrequent traditional river ice break-up (Ho et al., 2005; Tam et al., 2013).

Three key informants related changes in the strength, frequency, and severity of wind and snowstorm during the construction and operation periods. As they mentioned:

Wind gets weaker too over the years, not like a long years ago, I couldn’t see hundred of miles because it’s blown snow, can’t see. I’ve never seen those kinds of storms anymore, just weak storms [now] (Participant #5)

One week, sometimes you can’t go – Stormy. Now is different. Storm now is just a day. Storm today, you can probably go out tomorrow because we get better machines today, clear the road, but before, we have nothing, we [only] have a tractor, [it] took longer to maintain the road. Storms last longer too, [and] more snow too… Storms are affecting everything in the past, even if train tracks. Train came once a week before, now everyday now (Participant #3)
Lately, we have not gotten snowstorms until March. Normally, we [are] getting in December, or January, or February... I remember 5 years ago, we closed for one week because it stormed for 3 days. We used lots machines, day and night 24/7 to get it open, took 3 days to get it open (Participant #1).

Changes in wind patterns have been observed in the Hudson-James Bay region by local observations (McDonald et al., 1997). Two winter road users in Fort Albany indicated that blizzards used to be more intense, but now, they are weaker and occur later in the winter season (e.g., March). This supports local observations that snowstorms and blizzards are now less frequent in some communities in northern Manitoba (CIER, 2006).

The majority (65%) of winter road users stated that such changes in air temperature, ice freeze, and wind have affected the winter road, resulting in shorter winter road seasons and unstable ice conditions. Changes in the winter road conditions have been observed by winter road users in recent years (Table 3-3). As shown in Table 3-3, 59% of respondents agreed changes in the winter road conditions while 22% of respondents answered “don’t know” for all items that were on the table. These respondents are relatively young age ranging from 18 to 33 years old and the majority of them are female (male = 4; female = 8). All of these respondents use winter road only once or twice during the season.

Although most key informants stated changes in the weather and the effects of warming during the winter road construction and maintenance periods, two key informants indicated that impacts of climate change on the road construction may not be clear; rather, they described that there is a climatic cycle of constant change. As one key informant asserts:

Over the years, I haven’t really seen any change. Up and down a bit, but it’s more like a cycle, you know, climate change as such [is] not affected our [road], you know, construction or longevity of the road. What I found, say 40 years ago even, you know, you had the same condition we have now, nothing really change, you get warmer and colder days, next winter slow warm and so on, and then the cycle seems to repeat itself every 4
or 5 years, but on the average, it hasn’t changed much, you know, I haven’t seen [the] effects of climate change (Participant #2).

This is in contrast to the majority (74%) of winter road users who stated the effects of climate change on the winter road seasons and its conditions. Kimesskanemenow Corporation also mentioned in a local newspaper interview in 2012 that the impacts of climate change are reducing the construction season and the road’s lifespan (Coyle, 2012).

Changes in the length and timing of winter road season have also observed by the four key informants. They stated that the opening dates of winter roads in the past were earlier than now because of colder temperature and more snowfall, as well as lower quality of the roads due to the relatively simple construction techniques that were applied before. In the 1970s and 1980s, the average opening date of winter road was around late December to January 1st (Moosonee Transportation Limited, pers. comm., 2015; Wawatay News, 2012) while the average opening date for the last ten years is Jan 16 (Hori et al., 2015). Also, the closing dates of the winter road were later in the past. It should be noted that the opening dates for the last decade were for light traffic (GVW 7,500 kg), and the process of ice-capping is continued until it can support full weight (GVW 55,000 kg). Public access is allowed before and after the JBWR officially opens and closes; however, the road is ‘drive at your own risk’. Although the winter road users have noticed changes in the winter road conditions, only 26% of winter road users have noticed changes in the reliability of winter road. This may because the current JBWR has been constructed and maintained with modern technology and techniques that enhance road quality, durability, and ice thickness. Also, the winter road safety and liability have become major priorities since the rapid expansion of mining and transportation sectors that have used the road to move fuel and heavy equipment. Although such modifications of winter road maximize road
conditions and load-bearing capacity, melting of ice events can reduce usability and longevity of winter road and its seasons.

**Table 3-3.** Observations of winter roads users for changes in the winter road conditions

<table>
<thead>
<tr>
<th>Items</th>
<th>Agree</th>
<th>Neither agree nor disagree</th>
<th>Disagree</th>
<th>Don't know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shorter winter road season</td>
<td>36 (67)</td>
<td>2 (4)</td>
<td>4 (7)</td>
<td>12 (22)</td>
</tr>
<tr>
<td>Delayed winter road season</td>
<td>33 (61)</td>
<td>3 (6)</td>
<td>5 (9)</td>
<td>13 (24)</td>
</tr>
<tr>
<td>More earth patches/potholes</td>
<td>33 (61)</td>
<td>2 (4)</td>
<td>3 (6)</td>
<td>16 (30)</td>
</tr>
<tr>
<td>More white ice (or weaker ice) on the road</td>
<td>30 (56)</td>
<td>2 (4)</td>
<td>4 (7)</td>
<td>18 (33)</td>
</tr>
<tr>
<td>Increased slush on the road</td>
<td>29 (54)</td>
<td>3 (6)</td>
<td>6 (11)</td>
<td>16 (30)</td>
</tr>
<tr>
<td>Thinner and weaker ice (or less blue ice) on the road</td>
<td>29 (54)</td>
<td>2 (4)</td>
<td>6 (11)</td>
<td>17 (31)</td>
</tr>
</tbody>
</table>

**3.6.2.6 Current adaptation to changes in winter road seasons and conditions**

The Fort Albany community members demonstrate some capabilities to adapt to changes of the winter road seasons and conditions. When the length of the winter road season has shortened due to the effects of warming, 50% of winter road users commented that there would be less necessities and building supplies available in the community, leading to increased costs. However, the majority (81%) of winter road users indicated that they would be able to adapt to such shorter winter road seasons: 61% of respondents indicated that they would use alternate travel options, such as air charter and snowmobile and/or barge during the ice-free seasons, although some noted that such alternatives are expensive. Tam et al. (2013) reported that shipping goods by air or barge is more costly than using ground transportation on the winter
roads. There is a sense of adaptability and resiliencies to the effects of climate change within the Cree communities of the western James Bay region (Lemelin et al., 2010; Tam et al., 2013). Because of their long history of resourceful adaptation to changing climatic and environmental conditions in their homeland, many participants expressed confidence in their ability and strength to adapt to the effects of climate change on their traditional lifestyles (Lemelin et al., 2010; Tam et al., 2013).

Key informants identified some strategies that are now being used to address unstable winter road condition and a shorter winter road seasons due to the implications of climate change. Currently, taking winter road safety training is mandatory for all winter road construction and maintenance workers. As one key informant mentioned, “there is a very high standard for safety on the road” (Participant #2). Safety is of fundamental importance when working on the winter road, although two key informants said that there was no such training and/or orientation for all workers approximately 20 years ago. An increase in funding in order to meet the need of construction and maintenance costs can increase the usability and durability of the winter roads. One key informant stated that:

For the construction time, of course, there is the variance you need the colder, and just a right amounts of snow makes a big difference, but on average the construction is governed by the amounts of money had been spent to do the actual [construction], you know, creeks... initial compaction so on, you know, the more money they have and spend, you know, what I mean, the fast they get the road ready... (Participant #2).

For the JBWR, not only the Government of Ontario but also De Beers Canada Inc. has provided funding due to the Victor Diamond Mine that needs to use the JBWR for transporting heavy equipment and machinery from Moosonee.
Developing alternative winter road routes in order to avoid certain creeks and installing permanent bridges on the Bay have also been discussed previously; however, these may create potential negative environmental impacts. Transportation alternatives, all-weather roads in particular, have long been considered among the First Nations communities. The Mushkegowuk Tribal Council has examined the feasibility of an all-weather road to link the western James Bay communities with the Ontario highway 11 (Mushkegowuk Council, 2015). Although the costs of constructing and maintaining all-weather roads are considerably more expensive (Dore and Burton, 2001), as well as the risk of significant disturbance to the natural environment (Ontario Ministry of Natural Resources, 1990), nevertheless, almost half (46%) of winter road users indicated that all-weather roads may bring socio-economic opportunities into the community. By contrast, an airship (also known as blimp or dirigible), which is one of the transportation alternatives, has less environmental impacts and more economically potentials compared with conventional air transportation (CIER, 2006; Prentice and Turriff, 2002). One key informant asserted that:

*It will be so much easier in the environment — number one, and it will great cost saving to the people who reside in the northern communities. Their cost of livings is horrendous, you know. It would certainly I think that is the way to go, airships (Participant#2).*
3.7 Conclusion

This study commenced with a partnership between the authors and the Fort Albany First Nation community. Without such community partnerships and contributions, we would not be able to comprehensively examine the vulnerability and adaptability of the communities to climate change. This study has provided greater insight on the effects of climate change on the winter road system, which is a critical seasonal lifeline in Ontario’s Far North. In the western James Bay region, the JBWR has now become an important asset for not only providing a relatively inexpensive land transport of supplies, but also facilitating social and cultural interactions during the winter season among remote communities. The results of this study indicate that the construction and maintenance of the winter road have been directly affected by climatic factors, in particular, air temperature and snowfall. Thus, increased warming will significantly impact current practices of the winter road construction and maintenance, as well as winter road use. Trend analyses of flooding events for the Moose River, Albany River, and Attawapiskat River exhibit statistically significant increases over time; thus, major flooding in nearby communities has posed an imminent threat in recent years. Such changes in the frequency of flooding may be in part due to anthropogenic activities that maximize ice growth and thickness of freshwater waterways by water layers on winter road when the ice of winter road has melted. Although a few winter road users noticed that thicker ice may cause floods when melting, none of them related such observations to the water use on winter road. This study shows that the Fort Albany First Nation community has some capabilities to adapt to changes in winter road seasons and conditions that may have already been compromised by modifications of winter road using modern technology and techniques, as well as funding from government agencies and private
sectors. Future research should include working with other First Nations communities who are reliant on the JBWR to understand their risks to winter road changes as local adaptability differs among communities. Some adaptation strategies in response to the current climatic changes on winter road have been incorporated into the road construction and maintenance as a short and medium term planning; however, the focus in long term planning and adaptation is necessary to reduce vulnerability and enhance adaptability within the community. Suggestions from community members include construction of all-season roads. In summary, results of this help to inform public policy and decision-making processes addressing physical, social/cultural, and economic impacts associated with changing winter road longevity and river ice regimes.
3.8 References


Chapter 4
Implications of climate change on winter road systems in the Far North of Ontario based on climate model projections

4 Chapter 4

4.1 Abstract

Understanding climate change impacts on winter road systems in the Far North of Ontario is particularly critical due to the high dependence on such seasonal corridors by local residences, particularly among remote First Nations communities. In recent years, a warmer climate results in a shorter winter road season and an increase in unreliable road conditions; thus, limiting access to remote communities. This study focused specifically on examining the future freezing degree-days (FDDs) accumulations during the preconditioning period of the winter roads at five locations throughout the Far North of Ontario using recent climate model projections from the multi-model ensembles of General Circulation Models (GCMs) and dynamical downscaling of Regional Climate Models (RCMs) under the Representative Concentration Pathway (RCP) scenarios. The Statistical DownScaling Model (SDSM) was applied to validate the baseline climate. The results of CMIP5 ensemble and CanRCM4 models showed that by 2100, the CanRCM4 model projected the largest decreasing rates of the FDD accumulations under the RCP4.5 scenario while the CMIP5 ensemble simulated the greatest declines of the FDD accumulations under the RCP8.5 scenario, relative to the baseline period of 1981–2010. Results
of the FDD threshold measure indicated that climate conditions would possibly be unfavourable
during the winter road construction period by mid-century (2041–2070) for Moosonee and
Kapuskasing, and for Red Lake by the end of century (2071–2100). For Big Trout Lake and
Lansdowne House, on the other hand, climate conditions are expected to remain favourable for
winter road construction through the end of 2100. Thus, effective adaptation strategies and action
plans in response to potential climate change impacts on winter roads are necessary.

4.2 Introduction

There is growing evidence that climate change is occurring and that impacts are already being
experienced in natural and social systems of northern Canada (ACIA, 2005; Furgal and Prowse,
2008; Larsen et al., 2014). Projections of future climate trends in northern Canada have indicated
that changes in the variability and intensity of climate conditions are expected to be greater than
in other parts of the world. As a result, the intensified warming will cause a number of
significant impacts in the cryosphere, including sea ice, snow cover, glaciers, ice sheets, lake and
river ice, and permafrost (Furgal and Prowse, 2008; Gagnon and Gough, 2005). The most
significant impact of climate change on transportation in the Far North of Ontario is the reduced
viability and longevity of winter roads. Ontario’s Far North covers the northern portion of
Ontario, as defined by the Far North Act, 2010 (Government of Ontario, 2015a). In 2014–2015,
the Ontario government invested $5.0 million for the 3,160 km winter road systems connecting
29 remote-northern communities to all-season road systems (Government of Ontario, 2015c).
Winter roads commonly used in northern Canada and Alaska consist of ice roads over land and
frozen lakes, rivers, and creeks (ACIA, 2005; Adam, 1978). Such seasonal roads provide not only the transport of heavy equipment, fuel, and cargo at a low cost, but they also facilitate social and cultural interactions among nearby remote communities (Chiotti and Lavender, 2008; Furgal and Prowse, 2008; Hori et al., 2016). Moreover, they provide access to certain hunting and fishing grounds for many First Nations members during winter months. However, it has been reported that the length of the winter road season has declined in northern Canada and Alaska due to the effects of a warmer climate (ACIA, 2005; CIER, 2006; Hinzman et al., 2005; Hori et al., 2015; Tam et al., 2013).

The seasonal length of the winter roads depends on a cold climate, in particular, the construction and maintenance of the winter roads are directly affected by climate factors such as surface air temperature, precipitation, snowfall, and wind. Knowland et al. (2010) analyzed meteorological conditions associated with early- and late-opening dates of the winter road between Tulita and Norman Wells, Northwest Territories. During November in early-opening years, colder daily mean temperatures, higher snowfall, and greater frequency of northwesterly surface winds than those of the late-opening years have been observed. In the late-opening years, a greater frequency of southerly winds has been associated with the deeper Aleutian low during the preceding November. Thus, the month of November may provide signals of meteorological conditions that would be either favorable or unfavorable for the winter road constructions in the Norman Wells region. Similar indicators of the preceding months of winter roads are also reported for the western James Bay region of the Far North of Ontario by Hori et al. (2015). Specifically, freezing degree-days (FDDs), calculated from mean air temperatures, have been used to define the severity of winters and their trends (Assel, 1980). The FDD accumulations below 0°C during the month of October through to December, i.e., the preconditioning period of
the winter roads, play an important role in providing a more climatically favourable construction period, also contributing to earlier opening dates for the winter roads.

In order to assess the impacts of climate change on the longevity of winter roads in the future, climate models are the most common tools used to project climate change over the next century. Blair and Sauchyn (2010) used climate model projections to understand the impacts of climate change on the winter road systems in Manitoba. They found that the winter road seasons will become shorter by approximately 8 days in the 2020s, 15 days in the 2050s, and 21 days in the 2080s (Blair and Sauchyn, 2010). Similarly, climate models project a shorter duration of winter road season concurrent to a longer open water season at Norman Wells, Northwest Territories, which will directly affect the shipment sectors of the region (Lonergan et al., 1993).

In the western James Bay region, mean air temperatures are projected to increase from -18.6°C to -11°C in winter by 2100 (Hori, 2010). Stephenson et al. (2011) applied the Arctic Transport Accessibility Model (ATAM), which is a new transportation modelling framework that adapts climate and sea-ice model projections for the areas lying northward of 40 °N. By 2060, the Arctic region is projected to have significant reductions in total land area where climate conditions are favourable for winter road construction, causing shorter transportation seasons due to delayed openings and earlier closures of the winter roads.

To our knowledge, there is limited research examining the viability and longevity of winter roads in the Far North of Ontario in the next century using current climate model projections. Thus, the present study focused on examining future FDD accumulations during the preconditioning period of the winter roads over the Far North of Ontario by recent climate model projections. The main objectives of the present study were to construct plausible local-scale climate model projections in the Far North of Ontario and to project future FDD changes until
the end of 2100. Hori et al. (2015) indicate that the lowest threshold of FDDs during the preconditioning period of the James Bay Winter Road, which leads to a climatically viable winter road construction, was 380 degree-days. Therefore, in order to examine the effects of climate change on the winter road construction in a future period, we applied this threshold to the winter road systems throughout the Far North of Ontario.

4.3 Methods

4.3.1 Study area

The Far North of Ontario is situated within two continental landscapes; the Canadian Shield in the western part and the Hudson Bay Lowlands in the eastern part of the Far North (Far North Science Advisory Panel, 2010). The Hudson Bay Lowlands is the largest wetland region of Canada which provides moist ecosystems to 138 types of animals and 36 plant species (McDonald et al., 1997). In addition, the presence of the various states of permafrost (i.e., sporadic, discontinuous, and continuous) creates unique topographic features of the Far North of Ontario. Based on the Köppen climate classification, Ontario’s Far North is classified as having a subarctic climate (Köppen Dfc climate), which includes year-round precipitation, short and cool summers, and long and cold dry winters. (Aguado and Burt, 2007). There is no all-season road within the Far North of Ontario except for two permanent inter-community gravel roads and one railway to the town of Moosonee (Far North Science Advisory Panel, 2010). Thus, the network of winter roads that links 31 remote, coastal, and fly-in First Nations communities to a
permanent highway or railway system is a critical seasonal lifeline in the region (Government of Ontario, 2015c).

### 4.3.2 Climate data

Five weather stations in Ontario’s Far North; Big Trout Lake, Lansdowne House, Moosonee, Red Lake, and Kapuskasing, were selected to cover the winter road systems in Ontario’s Far North (Figure 4-1). Although Red Lake and Kapuskasing are located below the Far North boundary (Government of Ontario, 2015b), they were chosen due to limited climate data of nearby stations. It is important to analyze the climatological baseline with at least 30-years of observed climate data from the study region (IPCC-TGICA, 2007). Adjusted and Homogenized Canadian Climate Data (AHCCD) of Environment Canada provides a second generation of homogenized surface air temperature data for climate trend analysis (Vincent et al., 2012). Daily homogenized temperature mean ($T_{\text{mean}}$) data from 1981–2010 were obtained as baseline climate data for the five locations. Though the homogenized data have adjusted for inhomogeneities such as changes in site relocation and instrumentation, there were a number of missing dates in the dataset for the 1981–2010 period: Big Trout Lake (181), Lansdowne House (450), Moosonee (280), and Red Lake (1). Daily homogenized $T_{\text{mean}}$ data for the 1981–2010 period were used to define the freezing degree-days (FDDs) and applied as local predictands (observations) for downscaling.
Figure 4-1. Map of Ontario’s Far North, including the First Nations communities and the winter road systems.
4.3.3 Statistical analysis of climatological baseline

Freezing degree-days (FDDs) are used as the climatological baseline. FDDs are calculated by a sum of the daily mean temperature below the freezing point (0°C) of fresh water for a given time period with units in °C·days (Assel, 1980; 1990; 2003). For example, if daily $T_{\text{mean}}$ is above 0°C, the FDDs are indicated as negative values while if daily $T_{\text{mean}}$ is below 0°C, the FDDs are expressed as positive values. This present study examined the FDD accumulations from October 1 to December 31 as a preconditioning period of winter road seasons, and the lowest threshold of 380 FDDs (°C·days) (Hori et al., 2015) was chosen for this study.

The non-parametric Mann-Kendall correlation test and the Theil-Sen method were used to identify any statistically significant trends between FDDs and time. Since time series trends are not necessarily linear, these statistical techniques are commonly applied to several sea ice studies of the Hudson Bay region by Gagnon and Gough (2002, 2005, 2006), Gough et al. (2004) and Kowal et al. (2015). The Mann-Kendall test measures the statistical significance of the trends in a time series at a selected significance level (Helsel and Hirsch, 2002); thus, $\alpha=0.05$ is used for the test. The Theil-Sen method is also non-parametric and estimates the slope of a trend that is less affected by outliers (Hirsch et al., 1982; Sen, 1968).

4.3.4 Climate model projections

4.3.4.1 General circulation models (GCMs)
There are a number of types of climate models that are widely accepted as methods of constructing future climate. The most common approaches to simulate the responses in the physical components of the global climate system (atmosphere, ocean, land and sea ice) to changes in greenhouse gas concentrations use General Circulation Models (GCMs) (DDC, 2013; Flato et al., 2013). The Fifth Phase of the Coupled Model Intercomparison Project (CMIP5) model was used to coordinate climate model experiments leading to the Fifth Assessment Report (AR5) by the Intergovernmental Panel on Climate Change (IPCC) (Tayler et al., 2012). The CMIP5 projections of climate change are driven by the Representative Concentration Pathways (RCPs) which are new scenarios that have designed a more complete representation of future forcing pathways (Moss et al., 2010; Tayler et al., 2012). The four RCP scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) were used in CMIP5. RCP8.5 represents a high emissions scenario and somewhat higher than the SRES A2 scenario, and RCP6.0 and RCP4.5 are midrange mitigation emissions scenarios and close to SRES A1B and B1, respectively. RCP2.6 is a low emissions scenario and lower than all SRES scenarios (Flato et al., 2013). The Canadian Climate Data and Scenarios (CCDS) offer twenty-nine CMIP5 models with three RCP scenarios (RCP 2.6, 4.5, and 8.5) (CCDS, 2015). A full list of model details is provided in Table 4-1. The CMIP5 model projections have interpolated model outputs with different horizontal resolutions to a common $1^\circ \times 1^\circ$ global grid (CCDS, 2015). An ensemble approach has been designed to evaluate different model performance since the IPCC Fourth Assessment Report (AR4) (Flato et al., 2013); thus, this approach was utilized in the present study.

**Table 4-1.** List of the twenty-nine The Fifth Phase of the Coupled Model Intercomparison Project (CMIP5) models
<table>
<thead>
<tr>
<th>Model Name</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCC-CSM1.1</td>
<td>Beijing Climate Center, China Meteorological Administration</td>
</tr>
<tr>
<td>BCC-CSM1.1(m)</td>
<td>Beijing Climate Center, China Meteorological Administration</td>
</tr>
<tr>
<td>BNU-ESM</td>
<td>Beijing Normal University</td>
</tr>
<tr>
<td>CanESM2</td>
<td>Canadian Centre for Climate Modelling and Analysis</td>
</tr>
<tr>
<td>CCSM4</td>
<td>US National Center for Atmospheric Research</td>
</tr>
<tr>
<td>CESM1-CAM5</td>
<td>National Science Foundation, Department of Energy, National Center for Atmospheric Research</td>
</tr>
<tr>
<td>CESM1-WACCM</td>
<td>National Science Foundation, Department of Energy, National Center for Atmospheric Research</td>
</tr>
<tr>
<td>CNRM-CM5</td>
<td>Centre National de Recherches Meteorologiques</td>
</tr>
<tr>
<td>CSIRO-Mk3.6.0</td>
<td>Queensland Climate Change Centre of Excellence and Commonwealth Scientific and Industrial Research Organisation</td>
</tr>
<tr>
<td>EC-EARTH</td>
<td>EC-EARTH consortium</td>
</tr>
<tr>
<td>FGOALS-g2</td>
<td>LASG (Institute of Atmospheric Physics) - CESS (Tsinghua University)</td>
</tr>
<tr>
<td>FIO-ESM</td>
<td>The First Institute of Oceanography, SOA, China</td>
</tr>
<tr>
<td>GFDL-CM3</td>
<td>NOAA Geophysical Fluid Dynamics Laboratory</td>
</tr>
<tr>
<td>GFDL-ESM2G</td>
<td>NOAA Geophysical Fluid Dynamics Laboratory</td>
</tr>
<tr>
<td>GFDL-ESM2M</td>
<td>NOAA Geophysical Fluid Dynamics Laboratory</td>
</tr>
<tr>
<td>GISS-E2-H</td>
<td>NASA Goddard Institute for Space Studies USA</td>
</tr>
<tr>
<td>GISS-E2-R</td>
<td>NASA Goddard Institute for Space Studies USA</td>
</tr>
<tr>
<td>HadGEM2-AO</td>
<td>National Institute of Meteorological Research/Korea Meteorological Administration</td>
</tr>
<tr>
<td>HadGEM2-ES</td>
<td>UK Met Office Hadley Centre</td>
</tr>
<tr>
<td>IPSL-CM5A-LR</td>
<td>Institut Pierre-Simon Laplace</td>
</tr>
<tr>
<td>IPSL-CM5A-MR</td>
<td>Institut Pierre-Simon Laplace</td>
</tr>
<tr>
<td>MIROC-ESM</td>
<td>University of Tokyo, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology</td>
</tr>
<tr>
<td>MIROC-ESM-CHEM</td>
<td>University of Tokyo, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology</td>
</tr>
<tr>
<td>MIROC5</td>
<td>University of Tokyo, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology</td>
</tr>
<tr>
<td>MPI-ESM-LR</td>
<td>Max Planck Institute for Meteorology</td>
</tr>
<tr>
<td>MPI-ESM-MR</td>
<td>Max Planck Institute for Meteorology</td>
</tr>
<tr>
<td>MRI-CGCM3</td>
<td>Meteorological Research Institute</td>
</tr>
<tr>
<td>NorESM1-M</td>
<td>Norwegian Climate Centre</td>
</tr>
<tr>
<td>NorESM1-ME</td>
<td>Norwegian Climate Centre</td>
</tr>
</tbody>
</table>

4.3.4.2 Downscaling techniques

Simulations driven by GCM outputs are restricted in their usefulness for assessing implications for climate at local and regional scales because the spatial resolution of GCMs is too coarse (approximately 50,000 km²) to resolve topographic features and cloud processes (Flato et al.,
Thus, statistical and dynamical downscaling techniques have been employed to evaluate potential impacts of climate change on local and regional scales.

Dynamical downscaling through the use of Regional Climate Models (RCMs) has been greatly improved its resolution over the last decade (Flato et al., 2013; Laprise, 2008; Lemmen & Warren, 2004). RCMs provide a higher spatial resolution (25–50 km) so that they are able to resolve complex orographic features and climate processes such as cloud-radiation forcing (Flato et al., 2013; Wang et al., 2004). Such high-resolution RCMs are driven by large-scale lateral and lower boundary conditions from GCM outputs with a one-way nesting method (Flato et al., 2013; Laprise, 2008; Wang et al., 2004). Although there has been a remarkable progress in the spatial detail produced by RCMs, RCMs require greater computational strength; fewer RCM scenarios are currently available compared to GCMs. Moreover, RCM scenarios are sensitive to the inputs of boundary conditions (e.g., soil moisture) (Lemmen & Warren, 2004; Wilby et al., 2002). However, dynamical downscaling such as RCMs has been recognized as an important tool for analyzing climate change and adaptation studies (Flato et al., 2013).

The development of statistical downscaling has been vigorous since the AR4 (Flato et al., 2013). Statistical downscaling is based on the conditions that local and regional climate information is derived by two factors: large-scale atmospheric variables (predictor) and local/regional variables (predictand) (Wilby et al., 2004). The large-scale GCM outputs are fed into the statistical models to estimate local and regional climate characteristics (Wilby et al., 2004). The major strength of this statistical downscaling technique is that they can provide station-scale climate information which would be useful for regional climate change studies (Wilby et al., 2002). The main theoretical weakness of this technique is that they are sensitive to
the choice of predictor and predictand variables in order to provide suitable predictor-predictand relationships.

In the present study, we used the CMIP5 ensemble based on a group of GCMs, as well as the Canadian Regional Climate Model (CanRCM4) and the Statistical DownScaling Model (SDSM) as downscaling techniques. The Canadian Centre for Climate modelling and Analysis (CCCma) offers a new regional climate model, CanRCM4, with two RCP scenarios (RCP4.5 and RCP8.5) (Scinocca et al., 2015). The SDSM is a free software package that assesses local and regional climate change impacts using a robust statistical downscaling technique (Wilby et al., 2002). The SDSM was used to simulate daily $T_{\text{mean}}$ for the baseline period of 1981–2010 at five locations in the study region. For the future period of 2011–2100, the present study utilized projection results from the CMIP5 ensemble, which contain multiple GCMs, since there are only a few GCM simulations that can be used as inputs to the SDSM. The SDSM version 5.2 was used for this study.

### 4.3.5 Data analysis of climate model projections

To use the SDSM, the predictand variables (in this study daily $T_{\text{mean}}$ for 1981–2010) for each location were first collected. The predictor variables were then obtained from the National Centers for Environmental Prediction (NCEP) re-analysis dataset which are available at the SDSM website (http://co-public.lboro.ac.uk/cocwd/SDSM/data.html). The standard suite of NCEP re-analysis predictor variables is listed in Table 4-2. The SDSM is a hybrid of a stochastic weather generator and regression-based downscaling method so that past and future daily climate
data can be simulated by statistically calculating predictor–predictand relationships (Wilby et al., 2002). The procedure of downscaling large-scale climate data with a downscaling model consists of seven discrete processes: (1) quality control and data transformation, (2) screening of predictor variables, (3) model calibration, (4) weather generation using observed predictors, (5) statistical analysis of observed and downscaled data, (6) graphing model output, and (7) scenario generation using climate model predictors. Detailed technical details of the SDSM are provided by Wilby et al. (2002) and Wilby and Dawson (2007). For analyses in the present study, the following procedures were adapted. First, proper predictor variables were selected and suitable predictor–predictand relationships were then developed. Second, the SDSM-simulated $T_{\text{mean}}$ daily data for 1981–2010 were reproduced. In this step, the weather generator was used to infill missing data in predictands. Third, the projected future $T_{\text{mean}}$ data were reproduced by CMIP5 ensemble and CanRCM4 models. This study used the delta change method (also known as change factor) which is a common approach to deal with climate model inadequacies such as coarse spatial resolution of GCMs (Diaz-Nieto and Wilby, 2005; Hay et al., 2000). The delta change method computes changes between past and future climate model variables and add these differences to the observed baseline climate (Diaz-Nieto and Wilby, 2005; Hay et al., 2000). In this study, the delta change method is defined as:

$$\Delta \text{Projected } T_{\text{mean}} = \text{Projected future } T_{\text{mean}} - \text{Projected historical } T_{\text{mean}}$$  \[1\]

where projected future $T_{\text{mean}}$ represents the climate model (CMIP5 or CanRCM4) outputs for mean temperatures from 2011–2100, and projected historical $T_{\text{mean}}$ represents the climate model (CMIP5 or CanRCM4) outputs for mean temperatures from 1981–2010. The CMIP5 ensemble outputs were reproduced as monthly $T_{\text{mean}}$ while the CanRCM4 outputs were daily $T_{\text{mean}}$. For the CMIP5 ensemble, once changes in projected $T_{\text{mean}}$ ($\Delta$ CMIP5 monthly $T_{\text{mean}}$) were calculated,
SDSM-simulated daily $T_{\text{mean}}$ values are added to these changes to reproduce the future daily $T_{\text{mean}}$ for 2011–2100. This can be calculated by the following equation:

$$\text{CMIP5 future daily } T_{\text{mean}} = \Delta \text{CMIP5 monthly projected } T_{\text{mean}} + \text{SDSM-simulated daily } T_{\text{mean}}$$  \[2\]

As mentioned, the calculation of FDDs requires daily $T_{\text{mean}}$; thus, the results of CMIP5 future daily $T_{\text{mean}}$ were applied to calculate projected FDDs for 2011–2100. For the CanRCM4, since the CanRCM4 outputs were daily $T_{\text{mean}}$, these values were directly applied to calculate the changes in projected FDDs ($\Delta$ CanRCM4 projected FDDs). Once $\Delta$ CanRCM4 FDDs were obtained, observed FDDs are added to these changes to reproduce the future FDDs until 2100. This can be calculated as:

$$\text{CanRCM4 future FDDs} = \Delta \text{CanRCM4 projected FDDs} + \text{observed FDDs}$$  \[3\]
Table 4.2. List of the National Centers for Environmental Prediction (NCEP) re-analysis variables used by the Statistical DownScaling Model (SDSM)

<table>
<thead>
<tr>
<th>Predictors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean temperature at 2 m</td>
</tr>
<tr>
<td>Mean sea level pressure</td>
</tr>
<tr>
<td>850 hPa geopotential height</td>
</tr>
<tr>
<td>500 hPa geopotential height</td>
</tr>
<tr>
<td>Near surface westerly wind</td>
</tr>
<tr>
<td>Westerly wind at 850 hPa</td>
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<tr>
<td>Westerly wind at 500 hPa</td>
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<tr>
<td>Near surface southerly wind</td>
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<tr>
<td>Southerly wind at 850 hPa</td>
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<tr>
<td>Southerly wind at 500 hPa</td>
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<tr>
<td>Near surface wind strength</td>
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<tr>
<td>Wind strength at 850 hPa</td>
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<tr>
<td>Wind strength at 500 hPa</td>
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<tr>
<td>Near surface vorticity</td>
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<tr>
<td>Vorticity at 850 hPa</td>
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<tr>
<td>Vorticity at 500 hPa</td>
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<tr>
<td>Near surface divergence</td>
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<tr>
<td>Divergence at 850 hPa</td>
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<tr>
<td>Divergence at 500 hPa</td>
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<tr>
<td>Near surface-specific humidity</td>
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<tr>
<td>Specific humidity at 850 hPa</td>
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<tr>
<td>Specific humidity at 500 hPa</td>
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<tr>
<td>Near surface relative humidity</td>
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<tr>
<td>Relative humidity at 850 hPa</td>
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<tr>
<td>Relative humidity at 500 hPa</td>
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<tr>
<td>Near surface-specific humidity</td>
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<tr>
<td>Specific humidity at 850 hPa</td>
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<tr>
<td>Specific humidity at 500 hPa</td>
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<tr>
<td>Near surface relative humidity</td>
</tr>
<tr>
<td>Relative humidity at 850 hPa</td>
</tr>
<tr>
<td>Relative humidity at 500 hPa</td>
</tr>
</tbody>
</table>

Note. Adapted from Wilby and Dawson, 2012.

4.3.6 Climate model projections and FDD threshold

Trends in future projected FDDs were then assessed for the following time periods: 2011–2040, 2041–2070, and 2071–2100. The lowest threshold of FDD accumulations during the preconditioning period of the James Bay Winter Road was 380 FDDs (°C·days) (Hori et al., 2015). This present study applied the lowest threshold that was determined by the work of Hori et al. (2015) to assess how climatically favourable to construct winter road systems during October to December at the selected five locations in the Far North of Ontario until the end of 2100.
4.4 Results

4.4.1 Climatological baseline analysis

Results of the 30-year average of FDD accumulations and statistical trend analyses at each location during the preconditioning period of the winter road season (October 1 to December 31) for the baseline period of 1981–2010 are provided in Table 4-3. As shown in Table 4-3, Big Trout Lake has the highest FDD accumulations while Moosonee has the lowest FDD accumulations. Trend analyses of the FDDs indicated negative trends for all locations.

Of the five locations, a statistically significant decreasing ($p$≤0.01) trend was detected at Moosonee. The Theil-Sen slope of Moosonee reflected a higher magnitude (-8.52 FDDs/yr) which was approximately 250 FDDs reduction over the last 30 years. For Big Trout Lake, Lansdowne House, Red Lake, and Kapuskasing, trend analyses revealed no statistically significant change for FDD accumulations although the Theil-Sen slope indicated a moderately decreasing trend for the four locations.

Table 4-3. 30-year (1981–2010) average of FDD accumulations (°C·days) from October 1 to December 31, the Mann-Kendall (MK) test, and the Theil-Sen (TS) slopes

<table>
<thead>
<tr>
<th>Location</th>
<th>FDDs</th>
<th>MK</th>
<th>TS slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big Trout Lake</td>
<td>872.6</td>
<td>-0.225</td>
<td>-5.80</td>
</tr>
<tr>
<td>Lansdowne House</td>
<td>749.6</td>
<td>-0.075</td>
<td>-1.30</td>
</tr>
<tr>
<td>Moosonee</td>
<td>505.7</td>
<td>-0.378**</td>
<td>-8.52</td>
</tr>
<tr>
<td>Red Lake</td>
<td>679.1</td>
<td>-0.182</td>
<td>-5.24</td>
</tr>
<tr>
<td>Kapuskasing</td>
<td>541.1</td>
<td>-0.177</td>
<td>-4.22</td>
</tr>
</tbody>
</table>
**Note.** The TS slopes are displayed in FDDs per year. Significance at **< 0.01

### 4.4.2 Climate model projections

#### 4.4.2.1 Calibration and validation of SDSM

Daily homogenized $T_{\text{mean}}$ data for the 1981–2010 period at each location were taken as predictands. All of the 25 predictors from the NCEP re-analysis dataset were used to investigate the percentage of variance explained by each predictor–predictand combination. Ten predictors which were identified for a predictand described as follows: Downward shortwave radiation (dswr); Mean sea level pressure (mslp); 500 hPa geopotential height (p500); 850 hPa geopotential height (p850); Surface zonal velocity ($p_{\text{u}}$); 850 hPa zonal velocity (p8_u); Surface meridional velocity ($p_{\text{v}}$); Surface vorticity ($p_{\text{z}}$); 500 hPa vorticity (p5_z); and 850 hPa vorticity (p8_z). Five relevant predictors were identified for a predictand at each location. The calibration and validation periods of the SDSM were 30 years from 1981 to 2010. The values of coefficient of determination ($R^2$), standard error (SE) and Durbin-Watson between the observed and SDSM-simulated $T_{\text{mean}}$ data for each month of the year were produced as calibration and validation results. The values of $R^2$ at all locations showed a strong correlation between the observed and SDSM-simulated FDDs: Big Trout Lake ($R^2 = 0.9265$), Lansdowne House ($R^2 = 0.8507$), Moosonee ($R^2 = 0.719$), Red Lake ($R^2 = 0.9112$), and Kapuskasing ($R^2 = 0.9671$). Figure 4-2(a-e) show the scatter plot of the observed and SDSM-simulated FDDs for the baseline period of 1981–2010 of the five study locations. These results indicate that the ability of
the SDSM is sufficient for accurately downscaling $T_{\text{mean}}$ for the baseline period in the study region. Thus, the downscaled $T_{\text{mean}}$ results were used for reproducing the future $T_{\text{mean}}$ for 2011–2100 using CMIP5 ensemble and CanRCM4 models.
Figure 4-2. Scatter plot for correlation between observed and SDSM-simulated FDDs at (a) Big Trout Lake, (b) Lansdowne House, (c) Moosonee, (d) Red Lake, and (e) Kapuskasing for the 1981–2010 period.
4.4.2.2 Projected FDDs for the 2011–2100 period

The projected FDDs using CMIP5 ensemble and CanRCM4 models for the future periods of 2011–2100 at all locations were calculated by the delta change method. The time series for the FDDs using CMIP5 ensemble and CanRCM4 models are presented in Figure 4-3(a-j). Both climate model projections indicated decreasing trends of FDDs over the future period at all locations. Though the magnitude of decreasing trends differs from each RCP, the greatest declines were observed under RCP8.5 for both CMIP5 ensemble and CanRCM4 models while the least decreasing was identified under RCP2.6 in CMIP5. It can be also seen that the variability in the FDDs using CMIP5 ensemble was more pronounced than that in the FDDs by CanRCM4. Such patterns were detected at all locations.
Figure 4-3. Time series of the projected FDDs for the 2011-2100 period at five locations (a-e CMIP5 ensemble, f-j CanRCM4 model).

4.4.3 FDD Threshold analysis

The projected FDDs for the three future periods of 2011–2040, 2041–2070, and 2071–2100 in the CMIP5 ensemble under RCP2.6, RCP4.5, and RCP8.5 scenarios are reported in Figure 4-4(a-c). In the CMIP5 ensemble projection, the 30-year average of SDSM-simulated FDDs values for
the baseline period of 1981–2010 at Big Trout Lake, Lansdowne House, Red Lake, Moosonee, and Kapuskasing were 868.9 FDDs, 771.0 FDDs, 675.3 FDDs, 564.1 FDDs, and 538.6 FDDs, respectively. The differences between the SDSM-simulated FDDs results and observed FDDs for the five locations were as follows: -3.7 FDDs at Big Trout Lake; +21.3 FDDs at Lansdowne House; -3.8 FDDs at Red Lake, +58.4 FDDs at Moosonee; and -2.5 FDDs at Kapuskasing. The trends of FDDs under RCP2.6 indicated that the FDDs for all locations were projected to remain above the lowest threshold through to the end of 2100. Under the RCP2.6 scenario, it should be noted that the trends of FDDs continue to decrease during the periods of 2011–2040 and 2041–2070; however such decreasing trends became somewhat flattened or weakened during the 2071–2100 period. These trends were observed for each location. FDD trends under RCP4.5 were also projected to remain above the lowest threshold during the periods of 2011–2040 and 2041–2070 at all locations. By the end of the century (2071–2100), the RCP4.5 scenarios showed that the decreasing trends of FDDs were projected to be somewhat weakened for all five locations. For Moosonee and Kapuskasing, the trends of FDDs were projected to decrease below the lowest threshold with the FDDs at 373.5 and 356.4, respectively. Under the RCP8.5 scenario, the strongest and most continuous decreasing of FDDs were projected until the end of 2100. By mid-century (2041–2070), the trends of FDDs at Moosonee and Kapuskasing were projected to decrease below the lowest threshold with the FDDs at 353.4 and 335.7, respectively. By the end of the century for Red Lake, the FDDs was projected at 339.7 which is below the lowest threshold.

The projected FDDs in the CanRCM4 under RCP4.5 and RCP8.5 are presented in Figure 4-4(d) and 4-4(e). Under the RCP4.5 and RCP8.5 scenarios, the trends of FDDs were projected to remain above the lowest threshold during 2011–2040 at each location. By mid-century for
Moosonee, the trends of FDDs under RCP4.5 and RCP8.5 were projected to decrease below the lowest threshold with the FDDs at 332.7 and 324.7, respectively. By the end of the century, the FDDs for Kapuskasing under RCP4.5 was projected to decrease below the lowest threshold at 354.3, and the FDDs for Red Lake and Kapuskasing under RCP8.5 were projected at 340.5 and 306.1, respectively, which are both below the lower threshold.
Figure 4-4. The projected FDDs for the three time periods of 2011–2040, 2041–2070, and 2071–2100 under (a) RCP2.6, (b) RCP4.5, and (c) RCP8.5 scenarios in the CMIP5 ensemble and under (d) RCP4.5 and (e) RCP8.5 in the CanRCM4. Dashed lines show the lowest FDDs threshold.
4.5 Discussion

4.5.1 Present to future climate conditions for the winter road construction period

Statistical analyses of climatological baseline for the five study locations revealed that Moosonee has experienced statistically significant decreases of FDD accumulations over the past three decades. This is consistent with the findings by Hori et al. (2015) that monthly average of FDDs has significantly decreased in Moosonee during the cooler months from October to April since 1961. Gagnon and Gough (2005) observed that there was a temporal pattern in historical temperature records in the Hudson Bay region. For example, since 1975 the significant warming period was observed at Moosonee and Churchill and the warming continued thereafter. Such warming trends have linked to the rapid change of sea ice conditions in Hudson-James Bay. Kowal et al. (2015) reported that the trends toward a later sea ice freeze-up and earlier break-up dates in Hudson-James Bay have been accelerated in the most recent decade; thus, the rate of ice-free season has indicated a strong increasing trend in recent years.

The capability of the SDSM was examined to reproduce regional climate features such as observational temperatures in the Far North of Ontario. Results of $R^2$ values between the observed and SDSM-simulated FDDs at all locations indicated a strong correlation, varying from 0.97 to 0.72. Thus, the observed FDDs during the baseline period of 1981–2010 were well simulated by the SDSM. Past research has shown that SDSM output accurately simulated observed mean annual air temperatures (MAAT) at Big Trout Lake and Lansdowne House for
Results of the projected FDDs using CMIP5 ensemble and CanRCM4 models for the 2011–2100 period at five locations showed that both climate models projected deceasing trends of FDDs under all RCPs. Of the RCP scenarios, the magnitude of the trends of CMIP5 ensemble outputs based on RCP8.5 was the largest while ensemble outputs based on RCP2.6 was the smallest for all stations. This is consistent with the theoretical basis of the RCP emission scenarios, where RCP8.5 represents the highest emission scenario while RCP2.6 represents the lowest (Flato et al., 2013). Moreover, there was greater variability in the FDD trends produced by the CMIP5 ensemble when compared to CanRCM4. This could be attributed to the ensemble approach that is used for the CMIP5 projections, which include twenty-nine CMIP5 models. Another possible factor could be that CanRCM4 is driven by one parent global climate model, CanESM2 (Scinocca et al., 2015). Using the GCM- and RCM-based temperature projections under the SRES scenarios, Ruosteenoja et al. (2007) addressed that if RCM projections are driven by a single GCM, the RCM-projected temperature trends would generally be much smaller than trends from GCM projections. This disparity between GCMs and RCMs could be reduced by applying several driving GCMs for RCMs although the number of RCMs is currently limited (Ruosteenoja et al., 2007).

This present study further analyzed the trends of projected FDDs for three time periods using the lower threshold of FDD accumulations as climatically favourable conditions for the winter road construction in Ontario’s Far North. Based on the climatological baseline data from 1981–2010, climate condition during the month of October to December as the preconditioning period were favourable for winter road construction at all five study locations. The SDSM-
simulated FDDs for the CMIP5 ensemble projection were in reasonably good agreement with the observed FDDs although the differences between simulated and observed results for Lansdowne House and Moosonee showed relatively larger than other locations. This is likely due to the values of $R^2$ at two locations which were relatively lower than other locations. Thus, in the CMIP5 projection, the 30-year average of FDDs for Moosonee was the second lowest FDD accumulations among other locations during the baseline period of 1981–2010 while Moosonee ranked the lowest due to the observed FDDs that were used as the baseline climate for the CanRCM4 projection.

Results of the projected FDDs using CMIP5 ensemble and CanRCM4 projections revealed that the magnitude of the decreasing trends differed for each RCP scenario and time period. This indicates that there is an increasing number of projected warming days in the near future, though such warming trends may vary, depending on the RCP scenario and time period. Under the RCP2.6 scenario in the CMIP5 ensemble projection, the smallest decreasing rates of FDDs were projected among other RCPs at all locations through to the end of 2100; still, such declines remain above the lowest threshold. Thus, climate conditions were favourable for winter road construction period for all locations through 2100. Compared with RCP4.5 and RCP8.5, the decreasing trend under RCP2.6 became somewhat flattened or weakened during the 2071–2100 period. This is parallel to the theoretical basis of RCP2.6 emission scenario, which has a peak radiative forcing of 3 W/m$^2$ before declining to 2.6 W/m$^2$ by the end of 2100 (Moss et al., 2010). RCP2.6 is also designed to limit the increase of global mean temperature below 2 °C (van Vuuren et al., 2011).

Under the RCP4.5 and RCP8.5 scenarios in both the CMIP5 ensemble and CanRCM4 projections, the projected FDDs for Big Trout Lake and Lansdowne House suggest that climate
conditions would be favourable for winter road construction through to the end of 2100. These two locations will continue to accumulate sufficient FDDs by low temperatures during the winter road construction period. However, projected FDDs for Moosonee, Red Lake, and Kapuskasing project changes in climate conditions for 2041–2070 and 2071–2100. For Red Lake, climate conditions would possibly be unfavourable by the end of the century under RCP8.5 in both climate model projections. Similarly, based on the CMIP5 ensemble projection, Moosonee’s climate conditions would possibly be unfavourable during the winter road construction period by the end of the century under RCP4.5; however, in the CanRCM4, climatically unfavourable conditions would possibly be occurred in the earlier period, 2041–2070. This may be because the decreasing trend of FDDs under RCP4.5 with the CanRCM4 projection for Moosonee is relatively steeper than the CMIP5 projection during 2041–2070.

Under the RCP8.5 scenario, both climate model projections for Moosonee suggested to have unfavourable climate conditions within the 2041–2070 period. For Kapuskasing, both climate model projections suggested to have unfavourable climate conditions by the end of the century under RCP4.5. Under RCP8.5 in the CMIP5 ensemble projection, climate conditions would possibly be unfavourable within the 2041–2070 period; however, with the CanRCM4, unfavourable conditions could occur in the later period, which is in 2071–2100. This may result in the relatively steep decreasing trend of projected FDDs under RCP8.5 in the CMIP5 projection for Kapuskasing during the 2041–2070 period.

In comparison with the trends of FDDs in both climate model projections under RCP4.5, CanRCM4 projects the largest decreasing rates of FDDs at all locations. By 2100, the FDDs are projected to decrease by -296.6 at Big Trout Lake, by -264.2 at Lansdowne House, by -210.1 at Moosonee, by -235.1 at Red Lake, and by -186.9 at Kapuskasing, relative to the baseline period.
of 1981–2010. Under RCP8.5, on the other hand, CMIP5 ensemble projects the largest deceasing rates of FDDs at most of the locations. By 2100, the largest decreasing rates of FDDs are projected for Big Trout Lake by -425.0, for Lansdowne House by -388.6, for Moosonee by -307.9, and for Kapuskasing by -295.5 under RCP8.5 in the CMIP5 ensemble, and for Red Lake by -338.6 under RCP8.5 in the CanRCM4, relative to the baseline period of 1981–2010.

4.5.2 Limitations

This study acknowledges that the lowest threshold of FDD accumulations that is applied for this present study was determined by the relationship between the opening dates of James Bay Winter Road and the FDD accumulations. It should be noted that techniques of winter road constructions vary by the types of winter roads on land and water and the use of roads so that the opening dates may be different due to these factors. Thus, the lowest threshold of FDD accumulations may differ according to each winter road system. In addition, winter roads in the Far North Ontario are most likely operated by the nearby First Nations communities and/or private companies; thus, detailed information on the annual opening and closing dates of winter roads are not public. This study also recognizes the limited availability and quality of climate data in the Far North of Ontario. This region has the vast landscape although there are only three weather stations that are located above the Far North boundary and have sufficient climate records for a climate change impact assessment.

This study further indicates the uncertainty of climate projections that may arise with time due to three major factors: the internal variability of the climate system, model uncertainty,
and scenario uncertainty (O’Sullivan et al., 2015). Although the CMIP5 models are new so that less published work available, the internal variability in CMIP5 is generally constant through time; however, other uncertainties arise with time, but at different rates (Flato et al., 2013; Miao et al., 2014). For climate model and scenario uncertainties, an ensemble approach that was used for CMIP5 models in this present study gives equal weight to each climate model so that the data from CMIP5 cannot be considered from independent models (CCDS, 2015; Miao et al., 2014). In addition, Regional Climate Models (RCMs) are currently limited; thus, more RCMs need to be developed for the long-term climate model projections. Lastly, further research need to be done to incorporate projections of precipitation (snow and rain) and wind since the winter road construction has directly affected by air temperature, snowfall, and wind.

4.6 Conclusions

This present study has shown the future FDD accumulations at five locations throughout the Far North of Ontario with climate model projections from multi-model ensembles of GCMs and dynamical downscaling of RCMs under the RCP scenarios. For Moosonee and Kapuskasing, climate conditions would possibly be unfavourable during the winter road construction period by mid-century (2041–2070), and for Red Lake by the end of century (2071–2100). For Big Trout Lake and Lansdowne House, on the other hand, climate conditions are expected to remain favourable for winter road construction through to 2100. A network of winter roads in Ontario’s Far North has been, and continues to be, a critical seasonal lifeline, particularly for remote First Nations communities in order to not only transport for the essential goods and services, but also
facilitate social and cultural interactions among remote communities. However, given the results of climate model projections in this present study, the viability and longevity of winter roads and its seasons in the future are uncertain. Thus, long-term planning and adaptation strategies in response to the implications of climate change on winter roads are necessary at the community and government levels.
4.7 References


5  Chapter 5

5.1  Summary and Discussion

The research presented in this dissertation makes significant contributions to understanding the impacts of climate change on the winter road systems in the Far North of Ontario, as well as the current vulnerabilities of First Nations communities (i.e., physical, social/cultural, economic impacts) to changes in the winter road conditions and their seasonal nature. The results of this dissertation provide the basis for future investigations into climate change adaptation for the First Nations communities regarding the changes of winter road viability and longevity in the future.

Chapter 2 presents novel findings of regional climate change impacts on the winter road seasons in the Far North of Ontario with a particular focus on the climatological factors related to the present opening dates of the James Bay Winter Road (JBWR). From 1961 until now, the warming trends in monthly averages of both temperature minimum ($T_{\text{min}}$) and temperature mean ($T_{\text{mean}}$) are statistically significant for the months of January to April, when the winter roads are typically fully operational. Concurrently, the decreasing trends in the freezing degree-days (FDDs) are statistically significant for the months of October to April, where the amount of FDDs below 0°C starts to accumulate in October. Given the results of the relationship between the FDD accumulations to opening dates of winter road, it appears that the FDD accumulations
during the months of October to December are more closely linked to opening dates than the FDD accumulations that include few more days and/or weeks until the opening dates in January. Thus, the amounts of FDDs during the months of October to December as a preconditioning period of winter road seasons indicate more significant climatological effects on the construction period and opening dates of winter roads. This is consistent with the work of Knowland et al. (2010) on the effects of relevant meteorological conditions in early- and late-opening dates of the winter roads at Norman Wells, Northwest Territories. Knowland et al. (2010) highlight that the month of November may provide meteorological signals that would either be favorable or unfavorable for the winter road constructions in the Norman Wells region.

With the climatological linkages between the FDD accumulations and the opening dates of winter roads, this chapter establishes a minimum threshold of 380 FDDs (°C·days) below 0°C which would be potentially useful to assess the impacts of climate change on winter road systems in the future using climate model projections.

This chapter notes that the climate factors are also linked with variation in the closing dates of the winter roads. However, Knowland et al. (2010) address that non-climatic factors such as annual shipping demands, community re-supply needs, and other economic issues that have likely contributed to the timing of the closing dates of the winter roads. Also, compared to the closing dates, there is normally more pressure to open the winter roads as early as possible, so the climate factors are key to determining the opening dates. For the JBWR, the closing dates were less reported by the Kimesskanemenenow Corporation and local news media.

This chapter also notes that methods of winter road construction involve modern technology and techniques to build more durable roads to accommodate heavy vehicles. In
particular, rapid ice thickness for ice bridges over the rivers is achieved by surface flooding or spray-ice techniques that are similar to creating outdoor ice skating rinks (Prowse et al., 2009; Robertson et al., 2005). In addition, an increase in funding to meet the need of such construction and maintenance costs has seen in the last decade. In 2003–2004, the Government of Ontario spent $3.0 million for winter roads program; this winter (2014–2015), they invested $5.0 million for 29 First Nations organizations and the town of Moosonee to build and operate winter roads connecting 31 remote First Nations communities to a permanent highway or railway system (Government of Ontario, 2004, 2015). Such non-climatological/environmental factors that contribute to winter road seasons and its conditions are also of interest in Chapter 3.

Chapter 3 provides an overview of the current vulnerability of the Fort Albany community (i.e., physical, social/cultural, economic impacts) to changes in winter roads and its seasons, as well as river ice regimes. Through the analysis of key informant interviews and winter road user surveys based on local knowledge and observations on the changes in winter roads and river ice regimes, six major themes emerged: 1) Evolution of the JBWR; 2) Current practices of the winter road construction and maintenance; 3) Importance of climatic indicators for the winter road; 4) Current practices of winter road use; 5) Changes in winter road seasons and conditions; and 6) Current adaptation to changes in winter road seasons and conditions.

With these six major themes, it appears that the JBWR has now become a critical seasonal lifeline for not only providing a relatively inexpensive land transport of essential goods and supplies, but for also reconnecting remote communities with social and cultural activities during the winter season. Moreover, the JBWR plays a significant role in the health (i.e. physical, social and cultural, mental, and financial) of individual community members. In addition, the results indicate that the construction and maintenance of the JBWR have been
directly affected by air temperature and snowfall which are recognized by key informants as
important climatic factors. Thus, an increase in air temperature and inconsistent patterns of
snowfall will significantly impact current practices of the winter road construction and
maintenance, as well as its use.

Chapter 3 also addresses changes in frequency and intensity of flooding events at three
major rivers in recent years. This may be in part due to rapid ice growth and thickness of river
crossings by water layers and creek crossings by snow layers when manufactured ice and snow
layers on winter roads have melted. The surface flooding techniques used to form an ice cap on
top of the packed snow/ice on winter roads, as also mentioned in Chapter 2, are recommended by
winter road construction and maintenance guides (Adam, 1978; GNWT Transportation, 2007;
INAC, 2010; Saskatchewan Ministry of Highways and Infrastructure, 2010). Though, water
requirement for ice-capping depends on each road type and condition, Adam (1987) notes that
2.5 cm (1 inch) of water is generally required to create an ‘ice-cap’ on a snow road. For example,
it requires approximately 300,000 L (66,000 gallons) of water to create an ice-cap on a road of
about 7 m (24 foot) wide and 1.6 km (1 mile) long. This study could not obtain information of
the required water quantity and use from Kimesskanemenow Corporation due to the violation of
corporate accountability although this corporation receives permission from the Natural
Resources Canada every year (Kimesskanemenow Corporation, pers, comm., March 2, 2015).

Results of landfast ice dates in Chapter 2 have shown a trend towards earlier onset of
landfast ice that benefits winter road stability in the western James Bay region. However, an
increase in warming may cause earlier springs, rapid snowmelt and/or ice jam, which may lead
to flooding. On top of this, the melting of artificially ice and naturally grown landfast ice may
have increased the frequency and intensity of spring flooding in recent years. First Nations
communities in the western James Bay region are therefore more vulnerable to annual spring river ice break-ups occurring on major rivers. Thus, this chapter provides greater knowledge on community vulnerabilities associated with the changes on winter roads and river ice regimes that will contribute to the development of effective adaptation strategies and coping measures among First Nations communities.

Chapter 4 focuses on the viability and longevity of winter road systems in the Far North of Ontario for the next century using the latest climate model projections from the CMIP5 ensemble models based on a group of General Circulation Models (GCMs) and the CanRCM4 model as dynamical downscaling of Regional Climate Models (RCMs) under the three Representative Concentration Pathway (RCP) scenarios; RCP8.5, RCP4.5, and RCP2.6. The SDSM is applied to validate the baseline climate of 1981–2010. The lowest threshold of FDD accumulations that was determined by the current openings of James Bay Winter Road is applied to the projected FDDs to assess how climatically favourable to construct winter road systems during the preconditioning months at the selected five locations in the Far North of Ontario.

All locations are projected to experience decreasing trends of FDDs through the end of 2100, simulated by the CMIP5 ensemble and CanRCM4 models under all RCPs. In comparison with the trends of FDDs in both climate model projections, by 2100, the CanRCM4 model projected the largest decreasing rates of the FDD accumulations under the RCP4.5 scenario while the CMIP5 ensemble simulated the greatest declines of the FDD accumulations under the RCP8.5 scenario, relative to the baseline period of 1981–2010. The results of the lower FDD threshold measure indicate that climate conditions are expected to remain favourable for Big Trout Lake and Lansdowne House during winter road construction through the end of 2100. However, changes in the climate conditions for winter road construction are expected at
Moosonee, Kapuskasing, and Red Lake by mid-century (2041–2070) as the earliest future 30-year period. Although there are certain factors that contribute to the uncertainty of climate model projections, the results can provide an indication of what may be expected regionally whether climatically favourable or unfavourable for winter road construction through the end of this century. This chapter seeks to contribute to the development of strong action plan and/or new public policy for the impacts of climate change on winter road systems not only in Ontario’s Far North but also in Canada’s North.

In conclusion, the combination of the three research studies provides a regional climate change impact assessment on the winter road systems in the Far North of Ontario and the vulnerability to climate change in First Nations communities who are reliant on winter roads. When the winter road systems become impractical, there certainly will be a need for alternative transportation routes. As stated in Chapter 1, climate models project a decrease in sea ice concentration and thickness for the Canada’s four sub-basins; Beaufort Sea, Canadian Arctic Archipelago, Baffin Bay, and Hudson Bay (Gagnon and Gough, 2005; Joly et al., 2011; Steiner et al., 2015; Stephenson et al., 2011). Thus, such continued reduction of sea ice has gained significant attention as it relates to an increase in marine shipping activities (Pizzolato et al., 2014; Stephenson et al., 2011). In the western James Bay region, increased use of the barge might be possible; however, Tam et al. (2013) indicate that shipping goods by barge is more costly than using land transportation such as winter roads.

All-weather roads as alternative transportation routes have long been considered among the First Nations communities in the Far North of Ontario although the costs of constructing and maintaining all-weather roads are significantly more expensive. For example, Dore and Burton (2001) note that the construction of all-weather roads will cost at least $85,000 per km and the
bridge construction will cost between $65,000 and $150,000 per bridge in Ontario’s Far North. In addition, the construction of all-weather roads can cause significant disturbance to the natural environment (Ontario Ministry of Natural Resources, 1990). If winter roads are able to be replaced by all-weather roads, there still remain some issues to be discussed. The various states of permafrost are present in the Far North of Ontario (Far North Science Advisory Panel, 2010); thus, changes in the distributions of permafrost due to climate change may lead to all-weather road damages (Dore and Burton, 2001). Also, the Chief of Fort Albany mentioned that his communities need to be prepared to open up their territories with an all-weather road (Carpenter, 2015). Thus, an all-weather road is not a silver bullet; however, half the current winter road users in the Fort Albany community expect that all-weather roads may bring social and economic opportunities into the community.

The Mushkegowuk Tribal Council is currently undertaking a feasibility study to construct all-weather roads to link the western James Bay communities with the Ontario highway 11 (Mushkegowuk Council, 2015). They propose a couple of route options as the preliminary results (Figure 5-1). The estimated total cost will be between $350–450 million for the inland routes while the coastal route will cost between $250–350 million (Carpenter, 2015). Community consultations took place in four First Nations communities and the town of Moosonee from July to September 2015. Communities are also informed through local media in order to ensure that all community members understand the pros and cons of all-weather roads (Carpenter, 2015). To date, there has been no comprehensive study on climate change impacts on winter roads in the western James Bay region, except for this dissertation study; thus, this dissertation contributes to the planning and decision-making process in regards to winter-road impacts on northern First Nations communities.
Figure 5-1. Map of the preferred routes for an all-weather road by the Mushkegowuk Tribal Council (Adapted from Mushkegowuk Council, 2015).

5.2 Recommendations for Future Research

This dissertation has demonstrated the importance of future research for the impacts of climate
change on winter road systems in the Far North of Ontario. Disseminating the key findings of this dissertation to the western James Bay communities is a vital component of community-based research including this type of study. Thus, community dissemination will be a short-term research goal. Key findings will be presented at Fort Albany by delivering a poster presentation. Where possible, findings will be also presented through a local radio and/or newspaper.

As long-term research directions of this dissertation, future research objectives include 1) understanding community vulnerability to climate change and winter roads throughout the Far North of Ontario; 2) investigating associated opportunities for adaptation and establishing robust adaptation strategies and policies for individual community; 3) and delineating such adaptation strategies and policies for all communities in the Far North of Ontario as well as for government and non-governmental organizations across Canada.

Arctic community case studies conducted by Ford et al. (2006a, 2006b) have focused on small, remote, and Indigenous northern communities who rely on livelihoods that are affected by climate change. They articulate that vulnerability to climate change is inherently dynamic so that it varies among communities as well as among different groups in the communities (Ford, 2009; Ford et al., 2008). Thus, the ability to adapt to such climate-related changes may also vary among communities and their individual groups. In the Far North of Ontario, where there is a vast landscape with intact ecosystems, there are 34 resource-based First Nations communities who inhabit remotely (Chiotti and Lavender, 2008; Far North Science Advisory Panel, 2010). Comprehensive analysis of current vulnerability and adaptation by each community and/or within subpopulation (i.e. hunters and young First Nations) is needed, though a challenge for researchers.
Delineating adaptation strategies and policy suggestions to climate change is necessary for First Nations communities as well as for government and non-governmental organizations. Stakeholder engagement, community-based monitoring, education, and partnership building are the key elements that are commonly required in adaptation strategies and policy plans (Chiotti and Lavender, 2008). Effective adaptation policies should be formed by decision-makers who understand such challenges and have a solid understanding of climate change impacts and risks to First Nations communities. With this in mind, reducing community vulnerability to climate change in the Far North of Ontario is an important goal.
5.3 References


winter-roads-program.html


Appendix 1-A: Winter road interview and survey guides

These questions are used as a guide during semi-directed interviews. The winter road user survey was formed by this guide.

Introduction / context:
1. Where were you born?
2. How long have you been living in this community?
3. Do you use winter roads?

Important conditions (current vulnerability) – weather and climate:
1. How is the weather today compared to long time ago?
2. Over the past recent years, do you feel that air temperature, rain, snow, and wind have changed?
3. How does a change in the weather affect river ice conditions?
4. How does a change in the weather affect wildlife in winter?
5. Have you noticed changes in the coastline, river ice, or snow because of changes in the weather?
6. Has weather affected the winter road?

Important conditions (current vulnerability) – ice and water condition:
1. Are the river freeze-thaw cycles different today than they were long time ago?
2. Is the timing of the freeze-thaw cycles harder to predict now?
3. Have water levels and currents in the river changed in recent years?
4. Has spring melt changed in recent years?

Important conditions (current vulnerability) – Winter road construction and maintenance:
1. Is there any temperature threshold for constructing ice bridges?
2. How do air temperature, precipitation, wind, and snowfall affect the rate of ice growth?
3. Which vehicles are commonly used on the winter road (e.g. track, passenger car, snowmobile)?
4. How often do the winter roads temporarily closed? Are they similar or different each year?
5. Have you noticed any changes in the winter road seasons?

Important conditions (current vulnerability) – Winter road condition:
1. Have you noticed changes in the winter road conditions?

<table>
<thead>
<tr>
<th></th>
<th>Yes</th>
<th>No</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less blue ice</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>More white ice</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Weaker and thinner river ice</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Shorter winter road season</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Delayed winter road season</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Increased slush on winter road</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Presence of hanging ice</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Presence of earth patches/potholes</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>More accidents on road</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>
2. Have you noticed changes in the reliability of winter roads?
   a. What do you think are the causes of such changes?
   b. Does this impact your daily life (physical, socio-economic, cultural roles)?
3. Do you, or have you predicted the opening and closing dates of winter roads?

**Important conditions (current vulnerability) – Winter road use:**
1. How are winter roads important to you?
2. Do people use winter road today in the same ways that they did long time ago?
3. How do you use for winter roads in your community today?

<table>
<thead>
<tr>
<th>to shop</th>
<th>Yes</th>
<th>No</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>to hunt/trap animals and/or fish</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>to visit with friends and family</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>to gather for social events</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>(i.e. marriages, births and funerals)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>to participate in recreational activities</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>(i.e. bingos and hockey games)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>to see friends, family or the elderly in hospitals or care centres</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Others:</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>

**Important conditions (current vulnerability) – flooding:**
1. Is flooding an issue in this community?
   a. How often does flooding occur? Are they similar or different each time?

**Management strategies (current adaptive capacity):**
1. How do you keep your safety for traveling on winter roads?
   a. What constrains your ability to keep your safety on roads?
2. How do you manage the short winter road season?
   a. Do you use barge or air instead?
   b. What constrains your ability to manage such short winter road season?
   c. What can be done to make things easier?
3. How do you manage flooding risks?
   a. What constrains your ability to manage such risks?

**Future challenges (future adaptive capacity):**
1. What future challenges do you see facing your community?
2. Do you see current winter road seasons and conditions getting worse?
   a. If so, what can be done to better deal with those changes?
3. If the winter road seasons become shorter than now, how would this affect your community?
   a. Would it be a problem?
   b. How would your community respond to it?
Appendix 1-B: Consent form

CONSENT FORM

Title of the Study: Implications of Climate Change on Winter Roads and Adaptation Strategies for Remote First Nations Communities in the Western Hudson and James Bay Regions of Northern Ontario

Investigator: Yukari Hori
Ph.D. Candidate
Department of Physical and Environmental Sciences
University of Toronto Scarborough
Tel: 416-287-7210
y.hori@mail.utoronto.ca

Supervisor: William A. Gough
Professor
Department of Physical and Environmental Sciences
University of Toronto Scarborough
Tel: 416-208-4873
gough@utsc.utoronto.ca

Co-Supervisor: Leonard J.S. Tsuji
Professor
Health Sciences
University of Toronto
Tel: 416-208-5087
leonard.tsuji@utoronto.ca

Invitation to Participate: This letter is an invitation to consider participating in a study I am conducting as part of my doctoral degree in the Department of Physical and Environmental Sciences at the University of Toronto under the supervision of Professor William Gough. I would like to provide you with more information about this project and what your involvement would entail if you decide to take part.

Before agreeing to participate in this study, it is important that you read and understand the following explanation of the proposed study procedures. The following information describes the purpose, procedures, benefits, risks, and precautions associated with this study. It also describes your right to refuse to participate or withdraw from the study at any time. In order to decide whether you wish to participate in this research study, you should understand enough about its risks and benefits to be able to make an informed decision. This is known as the informed consent process. Please ask the research team to explain any words you don’t understand before signing this consent form. Make sure all your questions have been answered to your satisfaction before signing this document.

Purpose of the Study: You have been asked to participate in this study because you may have important knowledge on how climate change has affected winter roads and your lifestyle. This study is designed to investigate the effects of climate change on the winter roads in the western
Hudson and James Bay regions of northern Ontario, and also to address adaptation strategies to future change for First Nations communities in the region.

**Procedure:** You will be asked to participate in an interview.

**Benefits:** This study will provide a broader understanding of regional climate change impacts on local and seasonal transportation (e.g. winter roads and trails), and also will allow the remote-northern First Nations communities to develop adaptation strategies and coping measures.

**Risks:** There are no known or anticipated risks in the procedures involved in this study. If you feel the need to stop participating, you are more than welcome to at any time. The collection of data will focus on past experiences and knowledge.

**Confidentiality:** All information obtained during the study will be held in strict confidence. No information identifying you will be used in any publication or presentations without your approval.

**Participation:** Participation in this study is voluntary. It will involve an interview of approximately 1–2 hours in length to take place in a mutually agreed upon location. With your permission, the interview will be audio recorded to facilitate collection of information, and later transcribed for analysis. In appreciation of your time commitment, you will receive a remuneration.

**Handling of the Data:** The research study team, which consists of Yukari Hori, William Gough, and Leonard Tsuji, will be the only persons to have access to the data. The data will be stored in a locked cabinet at the ClimateLab, University of Toronto Scarborough which only the team has access to. The data will be destroyed two years after completion of the study by shredding all material and disposing them.

**Information about the Study Results:** After the completion of the study, you can obtain a copy of the summary report by contacting Leonard Tsuji or me through telephone or email mentioned herein.

**Questions:** If you have any questions or require more information about the study itself, please contact me, Yukari Hori at 416-287-7210. You may also call the study advisors, William Gough at 416-208-4873; or Leonard Tsuji at 416-208-5087. William Gough is a professor from the University of Toronto and is the primary advisor for this research project. Leonard Tsuji is also a professor from the University of Toronto and is the co-advisor for this project.

If you have any questions with regards to the ethical conduct of this study, you may contact the Office of Research Ethics, University of Toronto at 416-946-3273 or ethics.review@utoronto.ca.
CONSENT

I have had the opportunity to discuss this study and my questions have been answered to my satisfaction. I consent to take part in the study with the understanding I may withdraw at any time without negative consequences. I have received a signed copy of this consent form. I voluntarily consent to participate in this study.

Direct quotes may be included in the research report or research presentation. Please check the box indicating whether you wish to be identified or anonymous.

☐ Yes, please include my identification
☐ No, I wish to remain anonymous
☐ I do not want directly quoted in the research paper

Participant’s Name (Please Print) ________________________ Signature ________________________ Date ________________________

I confirm that I have explained the nature and purpose of the study to the participant named above. I have answered all questions.

Name of Person Obtaining Consent ________________________ Signature ________________________ Date ________________________

IF THIS CONSENT HAS BEEN VERBALLY TRANSLATED:

I confirm that I have verbally translated this consent form for the study subject noted above, and in my opinion the study subject has understood what I have explained to them.

Name of Translator ________________________ Signature ________________________ Date ________________________

Language of Translation ________________________ Relationship to Subject (if applicable)
Appendix 1-C: Telephone script

P = Potential Participant;    I = Interviewer

I - May I please speak to [name of potential participant]?

P - Hello, [name of potential participant] speaking. How may I help you?

I - My name is Yukari Hori and I am a graduate student in the Department of Physical and Environmental Sciences at the University of Toronto. I am currently conducting research under the supervision of Dr. William Gough and Dr. Leonard Tsuji on the implications of climate change on winter roads and adaptation strategies for remote-northern First Nations communities in Canada. As part of my research, I am conducting interviews with First Nations members to discover their perspectives on how climate change has impacted their lifestyle regarding the changes of winter road conditions.

As you were identified as a knowledgeable person by Chief, Council/other community members, I would like to speak with you about your perspectives on the impacts of climate change. Is this a convenient time to give you further information about the interviews?

P - No, could you call back later (agree on a more convenient time to call person back).

OR

P - Yes, could you provide me with some more information regarding the interviews you will be conducting?

I - Background Information:

- I will be undertaking interviews starting in winter 2015.
- The interview would last about one-and-a-half hours, and would be arranged for a time convenient to your schedule.
- Involvement in this interview is entirely voluntary and there are no known or anticipated risks to participation in this study.
- The questions are focused on your past experiences and your traditional knowledge on the environment. For example, “How is the weather today compared to long time ago?” or “How are winter roads important to you?”
- You may decline to answer any of the interview questions you do not wish to answer and may terminate the interview at any time.
- With your permission, the interview will be audio recorded to facilitate collection of information, and later transcribed for analysis. In appreciation of your time commitment, you will receive remuneration.
- All information you provide will be considered confidential.
- The data collected will be kept in a secure location.
• If you have any questions regarding this study, or would like additional information to assist you in reaching a decision about participation, please feel free to contact Dr. William Gough at 416-208-4873.

• I would like to assure you that this study has been reviewed and received ethics clearance through the University of Toronto Office of Research Ethics. However, the final decision about participation is yours. Should you have any comments or concerns resulting from your participation in this study, please contact the University of Toronto Office of Research Ethics at ethics.review@utoronto.ca or call 416-946-3273.

• After all of the data have been analyzed, you will receive an executive summary of the research results.

With your permission, I would like to email/mail/fax you an information letter which has all of these details along with contact names and numbers on it to help assist you in making a decision about your participation in this study.

P - No thank you.

OR

P - Sure (get contact information from potential participant i.e., mailing address/fax number).

I - Thank you very much for your time. May I call you in 2 or 3 days to see if you are interested in being interviewed? Once again, if you have any questions or concerns, please do not hesitate to contact me at the number 416-287-7210.

P - Good-bye.

I - Good-bye.
Appendix 1-D: Email script

Subject Line: Invitation to participate in winter road research

Dear_____________________,

My name is Yukari Hori and I am a Ph.D. candidate in the Department of Physical and Environmental Sciences at the University of Toronto Scarborough Campus. I am currently conducting research under the supervision of Dr. William Gough and Dr. Leonard Tsuji on the implications of climate change on winter roads and adaptation strategies for remote-northern First Nations communities in Canada. As part of my research, I am conducting interviews with First Nations members to discover their perspectives on how climate change has impacted their lifestyle regarding the changes of winter road conditions.

The reason that I am contacting you is that you are identified as a knowledgeable person by Chief, Council/other community members. I would like to speak with you about your perspectives on the impacts of climate change.

Participation in this study is voluntary. It will involve an interview of approximately 1.5 hours in length to take place in a mutually agreed upon location. It is expected that there will be no risks to you in taking part in the interview. You can stop at any time. With your permission, the interview will be audio recorded to facilitate collection of information, and later transcribed for analysis. In appreciation of your time commitment, you will receive remuneration. I would like to assure you that the study has been reviewed and received ethics clearance through the University of Toronto Office of Research Ethics. However, the final decision about participation is yours.

If you would like more information on this study or would like to receive a letter of information about this study, please contact me at the contact information given below.

Sincerely,

Yukari Hori
Ph.D. Candidate
Department of Physical and Environmental Sciences
University of Toronto Scarborough
Tel: 416-287-7210
y.hori@mail.utoronto.ca