Manitoba Hydro
Needs For and Alternatives To (NFAT)
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An Overview of Climate Change Impacts and what it means to Manitoba

A sample of the literature related to climate change observations and projections in the Province of Manitoba

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Executive Summary

The Intergovernmental Panel on Climate Change has determined that the warming of the climate system is unequivocal and it is extremely likely due to the observed increase in anthropogenic greenhouse gas concentrations. Changes in temperature and subsequent changes in precipitation and other environmental components have been observed throughout Manitoba and are projected to continue to change into the future.

Impact studies have been conducted globally, nationally and regionally to examine both the observed and projected impacts of climate change. These studies show that climate change impacts are occurring and are projected to continue into the future. There is considerable uncertainity inherent in these future climate impact studies which rely on global climate models and these studies don't necessarily capture the full range of variability that may be found into the future. These studies are instead intended to provide scenarios or pictures of what the future may look like based on a variety of assumptions on how the climate system will respond to a range of greenhouse gas scenarios. When studying future climate change impacts it is important to recognize the uncertainties that surround the climate models used in the study. Key findings from these studies that relate directly to Manitoba include:

- Mean air temperature in Manitoba has increased by approximately 1°C to 2°C over the period of 1950-2007 and is projected to increase by another 2° to 4°C by the middle of the 21st century. These changes in air temperature can have an impact on precipitation and other environmental components.
- Historical changes in precipitation and other environmental components have been studied throughout Manitoba and are projected to change into the future. These changes include decreased ice cover periods and decreased spring snow cover extents. While several locations show substantial changes in precipitation and streamflow, results vary due to large spatial and temporal variability in the historic record. Future projections include increases in mean precipitation, water supply, water temperature, and decreased mean spring snow cover extents, and ice cover periods.
- The health and well-being of Manitoba's freshwater ecosystems are being impacted by historic changes in streamflow, water temperature, and water chemistry. These changes have affected the population size, range and diversity of fish communities. Generally speaking, these changes have included a loss of habitat for coldwater fish species, and a northward range expansion of warm water species. Future climate projections indicate a continuance of these observed historic trends in warming temperatures and changes to the regional water regime in Manitoba.
- Permafrost thaw rates are increasing in northern Manitoba and are projected to continue to accelerate. This is decreasing the utility of winter roads and affecting the communities that depend on them for transportation of material and people as well as causing differential settlement issues that may cause damage to building foundations in northern communities of Manitoba.
- Climate change is contributing to woodland caribou declines in the boreal forest, through changes in predator-prey dynamics, spread of parasites, permafrost losses, and changes in forest fire regime.
- Polar bears in northern Manitoba are being affected by increasing ice-free periods on Hudson Bay, causing nutritional stress and population reductions due to lack of seal access.
- Migratory birds in Manitoba are changing their spring arrival times; some species are arriving earlier, and this is correlated with rising temperatures.

- The agricultural industry in Manitoba is continuously adapting to the changing climate and the overall impact to it will be greatly dependent on the implementation and effectiveness of adaptation strategies that take advantage of the longer growing seasons, the opportunity for higher productivity and mitigation measures to deal with new pests and diseases.
- Heat stress, increased air pollutants from forest fires and exposure to disease-carrying insects such as mosquitoes carrying the West Nile virus are occurring within Manitoba and are projected to increase into the future.
- First Nation people have historically had to adapt to a changing climate, including changes to their traditional foods, medicine and access to hunting and gathering areas. Adaptation has included harvesting different species of animals and plants. In more recent times, there has been some reported indication of impacts on northern communities in Manitoba due to a changing climate.

Adapting to both the positive and negative impacts of climate change may pose challenges to everyone across the globe, including Manitobans. It is expected that there are many more impacts than those summarized above and many that have yet to have been documented.

The objective of this report is to present a sample of the literature related to observed and projected impacts of climate change to the physical environment, aquatic environment, terrestrial environment, infrastructure, agriculture, and socio-economic environment with a focus on the Province of Manitoba.

An Overview of Climate Change Impacts and what it means to Manitoba

A sample of the literature related to climate change observations and projections in the Province of Manitoba

Introduction

The Intergovernmental Panel on Climate Change (IPCC) has determined that warming of the climate system is unequivocal and it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century (van Oldenborgh et al., 2013). Warming has been observed globally and regionally, where Manitoba's mean annual air temperature has warmed approximately 1°C to 2°C over the period of 1950-2007 (Zhang, 2011, Sauchyn & Kulshreshtha, 2008). Changes in temperature and subsequent changes in precipitation and other environmental components have been observed throughout Manitoba and are projected to change into the future. Median projections for Manitoba in the mid 21st century (Sauchyn & Kulshreshtha, 2008) indicate an increase in temperature of approximately 2° to 4°C and precipitation ranging from; increases of less than 10% in the summer and fall, and up to a 30% increase in winter. Projections of increased temperature and precipitation are consistent with other studies such as Dibike et al. (2012), Environment Canada (2011) and results published in IPCC reports (van Oldenborgh et al., 2013, Christensen et al., 2007)

Impact studies have been conducted globally, nationally and regionally to examine both the observed and projected impacts of climate change (van Oldenborgh et al., 2013, Sauchyn & Kulshreshtha, 2008, Henderson & Sauchyn, 2008, Meehl et al., 2007, Lemmen & Warren 2004, Government of Manitoba (date unknown)). These studies show that climate change is occurring and that the impacts are already being felt in many areas. Furthermore, they show that impacts are projected to continue into the future.

Future climate impacts are typically dervied from the output of complex global climate models. Since climate uncertainty is a characteristic of the complex climate system, there is a large source of unceratinity inherent in these models and they don't necessarily capture the full range of variability that may be found in the future. These studies are intended to provide scenarios or pictures of what the future may look like based on a variety of assumptions on how the climate system will respond to a range of greenhouse gas scenarios. These global climate models have a coarse resolution and therefore tend to reproduce larger scale phenomenon such as temperature fluctuations, better than smaller-scale phenomenon, such as extreme precipitation events. When studying future climate change impacts it is important to recognize the uncertainties that surrounds the climate models used in the study. Despite the large uncertainties and continuous evolution of climate modeling science, it is unrealistic for decision makers to wait for ultimate perfection in the global climate models and it is therefore useful to consider the information available at hand along with the associated uncertainties.

The objective of this report is to present a sample of the literature related to observed and projected impacts of climate change to the physical environment, aquatic environment and terrestrial environments, infrastructure, agriculture, and socio-economics environment with a focus on the Province of Manitoba.

Climate Change Impacts on the Physical Environment in Manitoba

Observational evidence shows that many natural systems are being affected by regional climate changes, particularly temperature increases and precipitation changes. In Manitoba, changes have been observed and are projected to continue in four main areas: water supply, water quality, ice and the arctic environment.

Climate Change Impacts on Water Supply

Water supply is typically characterized by measurements of streamflow, which represent an aggregated measure of precipitation, evapotranspiration and water withdrawals occurring in a watershed. Trend analyses of historical streamflow in Manitoba's rivers are conflicting with results ranging from increases (Ehsanzadeh et al., 2011, Déry et al., 2011, St. George, 2007, Westmacott & Burn, 1997) to decreases (St. Jacques et al., 2011, Zhang et al., 2011, Déry & Wood, 2005, Westmacott & Burn, 1997). Many studies emphasize the sensitivity of streamflow trend analyses to time period, river regulation, missing data, non-linear shifts and autocorrelation which complicate interpretation of the significance of results. Westmacott & Burn (1997) and Déry et al. (2011) also report shifts in timing of water availability, primarily driven by earlier spring snow melt as a result of warmer temperatures. An example of water supply related adaptation in Manitoba is presented in Sauchyn & Kulshreshtha (2008) which identifies the re-engineering of the Red River Floodway as a project that enhanced resilience and adaptive capacity. Several studies (Romero-Lankao et al., 2014, Weiland, 2012, Poitras et al., 2011, Meehl et al., 2007, Nohara et al., 2006, Milly et al., 2005) generally project that mean annual runoff for Manitoba basins will increase into the future.

Climate Change Impacts on Water Quality

Water quality measures reviewed for this summary include; temperature, nutrient loading, and sediment loading. Water quality may be impacted by climate change as increased agricultural erosion and forest fires in dry years could increase sediment loads, and nutrient loads, also increasing waterborne pathogens (Sauchyn & Kulshreshtha, 2008, Venema et al., 2010). In northern regions, degradation of permafrost can expose frozen soil and lead to increased erosion (Allard et al., 2011). Increased water temperature and sediment concentrations can also impact the ability of thermal power stations and municipal water supply stations to operate (Sauchyn & Kulshreshtha, 2008). Water quality in Lake Winnipeg is particularly sensitive to temperature and hydrologic cycle changes (McCullough et al., 2012, Shrestha et al., 2012, Environment Canada and Manitoba Water Stewardship, 2011). Environment Canada and Manitoba Water Stewardship (2011) conducted modeling studies to look at how climate change could impact water temperatures and ice coverage on Lake Winnipeg as these variables are important for assessing potential changes on the ecology and biology of the lake. Model results project mean mid-summer surface water temperatures to rise by 1.9 to 2.5°C in both basins of the lake through the first half of this century, although these projections differ depending on the greenhouse gas forcing scenario. On the other hand, the whole water column is unlikely to be heated to these projected surface temperatures.

Stakeholders are becoming more aware of the observed and projected impacts of climate change to their regions of interest. As a result of these potential impacts of climate change to Lake Winnipeg, the Lake Winnipeg Foundation has developed and adopted the following position statement which guide their decision-making in regards to climate change:

> Global climate warming, from human-driven increases in atmospheric CO_2 with associated changes in rainfall, runoff, evaporation, ice duration, and temperatures in the Lake Winnipeg watershed, is impacting the Lake Winnipeg ecosystem. Extreme hydrological events, such as flooding and drought, are becoming more common and are detrimental to the lake's ecology and biodiversity.

> Increasing water temperatures are contributing to proliferation of toxic blue green algae and to invertebrate species changes which ultimately influence the Lake Winnipeg fish community. Lake Winnipeg Foundation supports policies and practices that reduce greenhouse gas emissions (February 1, 2012). (Lake Winnipeg Foundation, 2012)

Past studies have shown linkages between changes in water quality and the occurrence of extreme hydrological events (McCullough et al. 2012). While Lake Winnipeg studies to date have shown some statistically significant changes in extreme events for select contributing sub-basins these studies are sensitive to many factors including the specific location and timeframe of the analysis (Novotny & Stefan, 2007; Ehsanzadeh et al., 2011; Sadri & Burn, 2014). It is challenging to make definitive conclusions regarding the entire Lake Winnipeg watershed due to the complexity of the system and limitations in data availability.

Climate Change Impacts on Snowpack & Ice

Changes in air temperature and precipitation can also impact ice formation, ice breakup, snow cover extent and snow accumulation in Manitoba. Warmer temperatures can result in a reduced ice cover season which impacts travel, transportation, ice fishing and recreation (Sauchyn & Kulshreshtha, 2008). Several studies have shown strong relationships between air temperature and the timing of ice breakup and report changes in the timing of ice coverage for areas in Manitoba and other northern regions (Minister of the Environment, 2008, Prowse et al., 2007, Latifovic, 2007, de Rham et al., 2007, Gagnon & Gough, 2005b). Modeling studies by Environment Canada and Manitoba Water Stewardship (2011) on Lake Winnipeg show that by the middle of the 21st century, breakup could occur on average four to six days earlier in the south basin and about a week earlier in the north basin. It is likely that by the middle of the 21st century the ice-free season will have been increased by two weeks. Under the strongest warming scenario (A2; Nakicenovic et al., 2000) the ice-free season could be nearly a month longer. Ice thickness may also be affected by climate change due to temperature changes and potentially greater insulation from the atmosphere due to increased precipitation (snow) falling on ice in the winter. If the ice is better insulated, and temperatures are higher, ice thickness at the onset of melt seems more likely to decrease rather than increase (Environment Canada and Manitoba Water Stewardship, 2011). Déry & Brown (2007) report significant declines in observed snow cover extent during spring in North America which is highly dependent on latitude and elevation. These declines in observed snow cover are corroborated in Romero-Lankao et al. (2014) which also project a continued decline in snow accumulation into the future as more precipitation will fall as rain rather than snow.

Climate Change Impacts on Arctic and Sub-Arctic Environments

Results from a recent study (Hochheim & Barber, 2014) in Hudson Bay, indicate that seasonal air temperatures play a dominant role in sea ice extent, and since the mid 1990's the air temperatures have increased while the sea ice extents have decreased. Hochheaim and Barber indicate that for every 1°C increase in surface air temperature, sea ice extent decreases by 14% (% of basin area) and delays freeze up by 0.7 to 0.9 weeks on average. The open water season has on average increased by 3.1 (±0.6) weeks in Hudson Bay since 1980. Saucier & Dionne (1998) corroborate these results and show that a climate warming of 2°C could lead to a 20% reduction in annual ice volume. Gagnon & Gough (2005b) discuss the impacts of reduced Hudson Bay ice cover on regional climate. Changes in sea surface temperatures and ice extents can impact other processes such as carbon transport, albedo and ecosystem health. Gagnon & Gough (2005a) used two global climate models and project the disappearance of much of the sea-ice cover by the end of the century, whereas the remaining models project a Hudson Bay with continuous ice cover for a shortened period of the year by the end of the century. Declining ice extents are also linked to food stressing of polar bears which could increase with increased temperatures (Stirling & Parkinson, 2006). Gagnon & Gough (2005a) also suggest that retreating permafrost could amplify climatic warming by reducing soil moisture, therefore causing a drier land surface. Furthermore, Kinnard et al. (2011) concluded that the decline of the extent of Arctic sea ice is unprecedented for the past 1,450 years. This decline seems to be associated with the advection of warmer Atlantic Ocean water to the Arctic.

Climate Change Impacts on Aquatic Environments in Manitoba

Components of the aquatic environments have many vital functions such as recycling nutrients, purifying water, and providing habitat for large and diverse biological communities. The fish communities contained in these environments have both societal and economic value through recreation, commercial, dietary and cultural purposes within the province of Manitoba. Climate change poses a potential threat to the health and well-being of Manitoba's fisheries by altering the flow of water, water chemistry, and thermal regime of the water bodies they inhabit.

Increasing trends in air temperature have been observed in Manitoba and surrounding regions, especially since the 1970s (Sauchyn & Kulshreshtha, 2008). These increasing temperatures have been accompanied with observed changes to the water regime, including the timing and magnitude of streamflow (Sauchyn & Kulshreshtha, 2008), earlier lake ice break-up dates (Prowse et al., 2007), and warmer surface water temperatures (King et al., 1999, Snucins & Gunn, 2000). Though historic observational data is limited primarily to small lakes in the Precambrian shield of northwestern Ontario, these studies have demonstrated linkages of climatic trends to observed changes in the water balance, heat content, thermal regime, and water chemistry of the lakes and streams under observation (Schindler et al., 1996, Snucins & Gunn, 2000, King et al., 1999, Keller, 2007). Studies have also attributed observed increasing trends in mercury concentration in arctic freshwater fish to the effects of climate change through increased water temperatures and primary productivity (Carrie et al., 2010).

Future climate projections from global climate models indicate a continuance of these observed historic trends in warming temperatures and changes to the regional water regime in Manitoba (Sauchyn & Kulshreshtha, 2008).The magnitude of these changes will have direct influence on the biologic productivity of these lakes and the nature of fish communities inhabiting these aquatic ecosystems. Though the specific impacts of climate change to Manitoba's fish communities are still under ongoing study, the potential areas and sensitivities of aquatic ecosystems to climate change have been documented by several authors based on observation in neighboring regions (Keller, 2007) as well as experimental and modeling studies (Fang & Stefan, 2009). Climate change impacts to fish ecology will be variable and depending upon the physical properties of the water body itself, the structure of the inhabiting biological community, the magnitude of climate change impacts, and the rate at which these changes occur (Snucins & Gunn, 2000, Magnusson et al., 1997).

Reduction in Coldwater Fish Habitat

Several studies indicate the potential for coldwater and cool water species to experience a reduction in population or potentially to be extirpated in portions of Manitoba as environmental conditions begin to exceed their physiological tolerances and/or ecological optima, resulting in a northward shift of these fish populations (Chu et al., 2005, Page & Levesque, 2011). Within Manitoba, several coldwater species occupy limited climatic ranges and/or restricted habitat requirements that are vulnerable to the impacts of climate change. Species with low population numbers that reside in restricted and specialized environments will be particularly at risk, even in the absence of invasive competitors (Sharma et al, 2009, Schindler & Gunn, 2004).

Lake trout (*Salvelinus namaycush*), are one of the most studied coldwater species with respect to potential climate change impacts. Researchers have identified southern populations as particularly vulnerable to climate warming due to changing thermal and water chemistry regimes of lakes and the associated loss of summer habitat and productive capacity (Schindler & Gunn, 2004, Magnuson et al. 1997, Schindler et al., 1996) Even at sublethal temperature increases, warming from climate change may cause several fold increases in the energy requirements of young-of-the-year lake trout, thereby reducing the population size that a lake can support (McDonald et al., 1996). Magnuson et al. (1997) projected that climate change may result in a stronger thermal stratification and that the resulting shallower thermocline depths may increase the deep, cold-water habitat for fish. Alternatively, thermal stratification may start earlier, potentially resulting in reduced reproduction because of suboptimal feeding conditions (Jansen & Hesslein, 2004).

Northern regions of Manitoba are also home to stream-inhabiting coldwater species such as brook trout (*Salvelinus fontinalis*). Meisner (1990) concluded that increases in water temperatures in streams at low elevations and latitudes may result in a retraction of suitable coldwater habitat to headwater reaches and groundwater seepage sites. At high latitudes, permafrost may decrease in some areas and produce year-round groundwater flow, potentially providing additional stream habitat for brook trout (Meisner, 1990). Some studies indicate that the range of temperature increases projected by global climate models could potentially impact the geographic distribution of brook trout in the future (Chu et al., 2005)

Studies have recognized similar impacts to other important coldwater and cool water fish species in Manitoba. In assessing potential climate change impacts to Lake Winnipeg fisheries, summarizing the work of Franzin et al., Page & Levesque (2011) concluded that a 2ºC increase in mid-summer monthly mean temperature by the middle of the 21st century could limit the success of as many as 12 fish species common to Lake Winnipeg, and that a further 2ºC warming could affect another 15 fish species by the end of the century. Some of the potential ecological consequences of progressively warmer climate change scenarios for yellow perch (*Perca flavescens*) and, by extension, other cool water species have been discussed by Jansen & Hesslein (2004). The authors concluded that these effects will shift from beneficial to detrimental over time, with air temperature increases up to 4°C improving conditions for perch, but overall detrimental effects at higher temperature increases.

Northward Expansion of Warm and Coolwater Species and Increase in Productivity

Accompanied with the compression or loss of optimal habitat for coldwater species, the northward expansion of warm and cool water southern species has the potential to occur as a result of climate change (Meisner et al., 1987). Northward-flowing rivers in Manitoba provide pathways for colonization of cool and warm water species that, due to climatic limitations, are presently restricted to southern or temperate portions of the Province.

As a result of climate change, the range of smallmouth bass (*Micropterus dolomieu*) could be extended by hundreds to thousands of kilometres northward, owing to the expansion of optimal thermal habitat for this species under climate-change scenarios (Sharma et al., 2009). Based on modeling studies, Chu et al (2005) conclude that by 2020, smallmouth bass may gradually expand throughout southern Manitoba and Saskatchewan and that by 2050, there is high probability that they may expand throughout much of northwestern Ontario and eastern Manitoba. Though smallmouth bass, a warm water fish species, inhabits different habitats than coldwater species, their range expansion may affect coldwater populations as they share similar food resources. Coldwater populations in smaller lakes tend to be most vulnerable to the effects of smallmouth bass invasion, whereas those in larger lakes tend to be more buffered from invasion impacts due to a more diverse food web (Sharma et al., 2009).

In addition to smallmouth bass, the distribution of other warm water species is also projected to expand northward beyond their current range. In their study of climate change impacts to the fish of the Great Lakes watershed, Meisner et al. (1987) concluded that increased temperatures would enable northern range expansion for cyprinids (minnows), esocids (northern pike), centrarchids (sunfish/bass), and ictalurids (catfish). Page & Levesque (2011) concluded that overall productivity of warm water species, as well as cool-water species present in Lake Winnipeg could be expected to increase under any climate-warming scenario due to increased lake productivity, increased sizes from more growth during the longer open-water season leading to better first-winter survival through the shorter winters predicted. Shorter ice covered periods could also reduce the occurrence of anoxic conditions in lakes, reducing the occurrence of winterkill events and resulting in an increase in overall winter survival (Fang & Stefan, 1999).

Lake Sturgeon

Very little is known about the potential impacts of climate change to Manitoba's lake sturgeon (*Acipenser fulvescens*) population. However, lake sturgeon are found over a broad range of temperature zones, and it is not expected that an increase in water temperature would necessarily result in a direct reduction in Manitoba lake sturgeon populations (Schneider-Vieira, Friederike, pers. comm.).

Climate Change Impacts on Terrestrial Environments in Manitoba

Terrestrial environments and the organisms that inhabit them are an important resource to Manitoba. Terrestrial organism (either plants or animal species) in Manitoba can be affected by changes to the air temperature, resource availability, habitat, and predators. Climate change has the potential to change these aspects and is projected to affect individual organisms, populations, species distributions and ecosystem composition directly through changes to the climate such as increasing temperatures and indirectly through impacts to the environment such as increased forest fire frequency. In Manitoba, changes to permafrost due to warming temperatures, as well as impacts on forest ecology, including forest fires have been effected by climate change and will continue to into the future (Weber & Stocks, 1998, Peng & Apps, 1999, Camill, 2005, de Groot et al., 2013). Furthermore, terrestrial wildlife such as woodland caribou, moose, wolves, polar bears, and migratory birds have also been impacted by changes to the climate some positively and some negatively.

Climate Change Impacts on Permafrost

A study by Camill (2005) investigated the state of permafrost in northern Manitoba. Using direct measurements and compression tree ring analysis at various sites, historical permafrost thaw rates were determined. It was found that permafrost thaw rates are 200-300% higher in the period of 1995-2002 relative to that of 1941-1991. Data such as air temperature, mean winter snow depth, and duration of continuous snowpack were gathered from meteorological stations to supplement the analysis. It was found that overall mean temperature increased by 1.08–1.75°C for stations in this study from 1970-2000. Mean snowpack depth showed statistically significant decreases for Thompson and Norway House (more southern in the study area), with little change in other areas. Churchill (most northern station) was the only site to experience statistically significant changes in continuous snowpack duration, with a gradual duration increase. The station data were then used as a basis of statistical regression on thaw rates. Regression thaw rates were extrapolated into the future, to provide projections on possible future climate induced changes. It was found that with continuation of historic temperature increases into the future, thaw rates of permafrost will continue to accelerate. The greatest accelerations in thaw will occur in the southern discontinuous permafrost zones where the greatest temperature increases are expected.

Climate Change Impacts on Boreal Forest

As the Canadian boreal forest is important economically for timber harvests, a number of studies have been conducted to examine the potential impact of climate change to the boreal forest. Peng & Apps (1999) used a plant-soil ecosystem model to simulate the nitrogen and carbon cycles of a boreal region in Manitoba and Saskatchewan. Its three components are a temperature and hydrological variable simulator, vegetation processes simulator, and soil organic matter simulator. Forest fire effects are also included in the model. Net primary productivity (NPP) is calculated by the model, and is the rate at which plants fix carbon by photosynthesis, minus the plant's removal of carbon through cellular respiration. The researchers used this model under several case studies: historical climate conditions only, climate change alone, carbon dioxide fertilization alone, climate change and carbon dioxide fertilization together. The climate change projections used in this study are now outdated; however, the study does show that modeled NPP is sensitive to climate change scenario and forest fire regime.

Forest fires in the boreal region of Canada are projected to increase in severity with climate change (de Groot et al., 2013). de Groot et al. (2013) used fire and weather data from 2001-2007 as the "current" fire regime and modeled future possible fire regimes with climate change projections. The model domain included Manitoba in its western Canadian boreal range. Fuel consumption, head fire intensity, type of fire, and carbon emissions rate were all calculated in this study. Types of fire include crown and surface fires. Modeled future fuel consumption showed increases in all scenarios and locations with climate change, with the greatest consumption occurring later in the season. Head fire intensity showed increases in most cases, with the largest increase with the most severe emission scenario. With increased fires under climate change, resultant carbon emissions should further increase.

Historical increases in forest fires for the boreal forest are also documented in Weber & Stocks, (1998). It was found that average annual fire occurrences increased from 6000 in 1930-1960 to 10000 in the 1980s. While higher occurrences can be partially ascribed to improved detection capability, rising temperatures can contribute to increased susceptibility to lightning and human-caused fires (Weber & Stocks, 1998). Bond-Lamberty et al. (2009) went one step further and examined that significant historical changes in fire regimes impacted overall evapotranspiration rates.

Climate Change Impacts on Caribou

The boreal ecotype of woodland caribou is currently listed as threatened in Manitoba and is considered an umbrella species for a healthy boreal forest ecosystem (Manitoba Conservation, 2005, Environment Canada, 2012). Based on a risk analysis, Racey (2005) indicated various effects of climate change, including changes in fire regime, insect infestations and increased predation pressure as potentially impacting boreal woodland caribou populations in northwestern Ontario. In the federal recovery strategy for boreal woodland caribou, climate change is associated as having a medium level of concern and resulting in "changes in habitat (that) favour deer and other prey species, which expand into boreal caribou range, increasing predator populations and predation of boreal caribou, and facilitating the spread of disease (Environment Canada, 2012)." Accordingly, Rempel (2011) finds that due to increased heat stress in northern Ontario with climate change, moose populations can potentially decrease in their southern limits, while moving northwards into areas used by boreal woodland caribou. As wolves tend to follow moose populations, wolf population increases in northern Ontario are projected and will be a detriment to woodland caribou populations (Rempel, 2011). Substantive moose declines in Minnesota have already been linked to factors associated with the effects of climate change, including heat stress, which may result in a northward shift in moose distribution (Lenarz et al., 2009, 2010). Special moose management initiatives have been implemented in Manitoba to address declining moose populations (MCWS, 2013). It is unclear what might be causing these declines but potential factors include increased hunting, predation and disease transmission, and the complex relationship to climate change, for which ongoing research is being conducted. Similarly, the northwards expansion of deer may also result in increased mortality of boreal woodland caribou through increased predator populations and also due to the spread of meningeal brain worm (*Parelaphostrongylus tenuis*) (Vors & Boyce, 2009). While brainworm is not dangerous to deer it is lethal to caribou.

Yannic et al. (2013), investigate the likelihood of persistence for caribou populations based on sampled levels of genetic diversity. Caribou populations at southern latitudes, including sampled herds from southern Manitoba, are associated with being at an increased risk of extirpation based on a "business-as-usual scenario of the Intergovernmental Panel on Climate Change" modeling the effects of climate change until 2080. In addition to climate change, habitat loss, increased human presence, and overharvest contribute to the decline of woodland caribou (Festa-Bianchet et al., 2011). Predation by wolves is also recognized as a key factor in caribou decline (Festa-Bianchet et al., 2011). On a global scale, Vors & Boyce (2009) examine the decline of caribou, in which Manitoba inhabits some of the most southernmost extents of the study area. Climate change has been cited as one factor affecting this decline.

Impacts of climate change on populations of migratory caribou are of concern. These caribou populations exist in a variety of habitat types including arctic and tundra environments and migrate into Manitoba during winter. Based on the limited availability of forage resources, the timing of the onset of plant growth can play a large role in regulating caribou populations, particularly as it relates to the timing of calving where herds show fidelity to a particular calving area (Sharma et al., 2009). The potential for increased insect harassment, exposure to parasites and vulnerability to predation for migratory caribou based on the effects of climate change have also been noted by Sharma et al. (2009) in northern Quebec and Labrador. Permafrost degradation has been shown to result in the degradation of caribou habitat and is expected to occur at an increased rate based on the increased occurrence of warm weather conditions (Price et al., 2013).

Climate Change Impacts on Birds

The biggest threat for many bird species during their long migrations are loss of habitat in both their summering and wintering grounds; however, pollution, pesticides, hunting, collisions with human structures and climate change also have substantive effects (North American Bird Conservation Initiative Canada, 2012). In general, Price & Glick (2002) and BirdLife International (2004) suggested that changes in climate patterns may result in earlier breeding and egg-laying dates, changes in behaviour associated with environmental cues where migrants may return to breeding grounds too early, range expansions, changing habitats (e.g., drought conditions and the drying of wetland habitat), and disruption of ecological communities resulting in new predators, competitors, and prey to which a species has not adapted. Some bird species or groups may be more disproportionately affected than others as a result of climate change. For example, birds that feed exclusively on flying insects (aerial insectivores) are showing population declines. A contributing factor to these declines is decreases in flying insects from contaminants such as pesticides. In addition, climate change can potentially be impacting shifts in seasonal timing of insect emergence, resulting in mismatched seasonal cycles of aerial insectivores and their prey. With no alternative food source, impacts on these birds can be severe (North American Bird Conservation Initiative Canada, 2012).

Although climate-related bird research in Manitoba is limited, an example of a long-term study was conducted at Delta Marsh, Manitoba to examine any changes in spring migratory bird arrival date (Murphy-Klassen et al., 2005). In this study, data from the Delta Waterfowl Research Station from 1939-2001 was analyzed in conjunction with temperature trends at Winnipeg. Short and long distance migrants were considered. Of 96 migratory bird species examined, 27 showed statistically significant trends in first arrival date with time. Two species, Greater and Lesser Yellowlegs, arrived later as time progressed. The other 25 arrived earlier, with Hooded Mergansers arriving 32 days earlier by the end of the study period. In addition, each species' arrival dates were regressed with monthly average temperatures, to determine influence of temperature on arrival date. Of the 96 species, 44 had arrival dates significantly related to temperature. One species, the Marbled Godwit, arrived later with increasing temperatures, while the other 43 arrived earlier. Canada Geese and Mallards were species who arrived earlier with increasing temperature. It is noted by the authors that many other environmental factors can influence the migrations of birds, which result in high inter-year variability in arrival dates. While not all species show the same trends, that fact that trends in arrival dates can occur, over time and correlated with climatic changes is important to note. In another study by Mazerolle et al. (2011), mean temperatures were correlated to the timing of migratory Yellow Warbler clutch initiation and spring arrival dates at Delta Marsh. In this study climate change inferences were not made, however it is noted that further study is warranted due to their sensitivity to climate variables.

Climate Change Impacts on Polar Bears

The polar bear has been studied and perceived as an index of Arctic ecosystem health in the face of global environmental issues such as a climate change. Polar bears in the Western Hudson Bay (WH) subpopulation in Manitoba are of special ecological significance. Having been the subject of intensive, long-term research and monitoring, knowledge of this subpopulation has contributed substantially to the management and conservation of the species across its range, as well as the general scientific literature surrounding large carnivores. Given its location near the southern extent of the species' range, it has been predicted and observed to be one of the first subpopulations affected by the impact of climate change (Derocher et al., 2004, Stirling & Parkinson, 2006, Regehr et al., 2007).

Eight of 19 global subpopulations are currently considered to be declining in numbers of bears and/or reduced from historic abundance levels (IUCN, 2006, Stirling & Derocher, 2012). The WH subpopulation accounts for approximately 6% of the polar bears in Canada. Regehr et al. (2007) found that the total number of individuals in the WH subpopulation declined from an estimated 1,194 (95% C.I. = 1020 – 1368) in 1987 to 935 bears (95% C.I. = 794 – 1076) in 2005. In part, based on the impacts of climate change and declining subpopulation trends, the polar bear in Manitoba was listed as Threatened in 2008 (*The Endangered Species Act*). In Canada, the polar bear is designated as being of Special Concern (*Species at Risk Act*).

Decline of the WH polar bear subpopulation has been attributed primarily to the effects of climate change mediated by a decline in the number of seals (as evidenced by reduced pregnancy rates and pup survival) (Ferguson et al., 2005, Stirling, 2005) and/or by deteriorating sea ice conditions that have reduced polar bears' access to seals (Stirling & Derocher, 1993, Stirling et al., 1999, Derocher et al., 2004, Stirling & Parkinson, 2006, Regehr et al., 2007). The polar bear is a specialized marine mammal that feeds primarily on seals during ice-on periods to build up fat reserves, to be depleted during summer (ice-off) conditions (Gormezano & Rockwell, 2013a). Although polar bears will occasionally exercise terrestrial food options in summer ice-off periods, they are overall in a negative energy balance during that time. At a broad scale, across the Arctic, there is a positive correlation between the size of ringed seal populations and the polar bear subpopulations they support; essentially, more seals means more bears (Stirling & Oritsland, 1995). This relationship is also evident at a local scale. In some regions, fluctuations in ringed seal survival, reproduction and numbers have been correlated with similar changes in polar bear survival and reproduction (Stirling, 2002).

The duration of the ice-free period has been increasing with climate change, causing nutritional stress in polar bears (Gormezano & Rockwell, 2013a). While variable among years, the average sea ice breakup time in Hudson Bay was three weeks earlier in 2004 than in 1984. A study by Regehr et al. (2007) found a causal relationship between a progressively earlier start of the ice-free period (sea ice breakup) associated with increasing air temperatures and polar bear survival rates. Measures included statistically significant declines of bear condition of all age and sex classes

(Stirling et al., 1999, Regehr et al., 2007, Stirling & Derocher, 2012), a decline in the mean weights of suspected pregnant female bears before maternity denning (Stirling & Parkinson, 2006), and a decline in survival of juvenile, subadult, and senescent-adult polar bears (Regehr et al., 2007). A decline in body size of female polar bears in western Hudson Bay has been demonstrated (Atkinson et al., 1996), and the reproductive rate of females has also declined in other bear populations with increasing duration of the ice-free period, although confidence intervals are wide (Regehr et al., 2010).

With more nutritionally stressed bears in the region in search of food, instances of human-bear interactions at Churchill and elsewhere have also increased (Regehr et al., 2007, Stirling & Derocher, 2012). Polar bears depend on the strength and stability of maternity dens to protect their young from cold weather. These dens are susceptible to collapse in the case of unseasonal warm weather or rain (Stirling & Derocher, 2012). Other effects of climate change may include increased energy costs for movements while foraging and lower stored energy during the longer ice-free period (Sahanatien & Derocher, 2012 in Stirling & Derocher, 2012). Due to the longer ice-free period, Gormezano & Rockwell (2013a) found that polar bears in Manitoba were changing their food intake habits, namely expanding their diet to include more terrestrial options such as snow geese, caribou, eggs, and various plants. The authors noted that while polar bear populations are declining, they have a history of adaptive behavior. For polar bears that adapt to terrestrial food sources such as plants, Gormezano & Rockwell (2013b) found that there can be benefits such as vitamin/mineral intake and toxin dilution. Therefore, provided polar bears can maintain caloric intake from terrestrial sources with climate change, there can be benefits to those that adapt. Conversely, in a review of climate adaptations by other researchers, Stirling & Derocher (2012) suggest that such foraging behaviours are inadequate for long-term sustainability of present polar bear populations. This is in part due to their short digestive tract being inefficient at plant digestion. Therefore, while terrestrial sources of food are useful for polar bears in providing opportunistic nutrition, enough seals and ice to hunt on are necessary for long term viability of sustained populations (Stirling & Derocher, 2012).

Climate Change Impacts on Agriculture in Manitoba

Agriculture is a vital part of Manitoba's economy and food source and its vulnerability to climate change is dependent on the magnitude of changes, how sensitive it is to the changes and its ability to adapt. There are both advantages and disadvantages that may be experienced by agriculture in Manitoba as a result of climate change. How Manitoba's agriculture sectors adapt to these changes will depend greatly on the implementation and effectiveness of adaptation strategies.

The agricultural region of the Prairies has a wide variety of climate zones that impose challenges on production; from moisture limitation and heat stress to excess moisture and cold stress. Producers have adapted to these restrictions through the selection of specific breeds of crops, livestock and management practices that are suited to their climate. This relationship has driven the industry to breed crops that are tolerant to moisture limiting conditions that thrive in semi-arid regions of the Prairies (SPARC, 2014) as well as crops such as winter wheat that are planted in the fall in order to that take advantage of spring moisture and early harvest (University of Saskatchewan, 2014). In areas of excess moisture, crop producers have installed drainage tiles underground in order to remove excess moisture (Rahman & Lin, 2013) which would either prevent seeding or damage existing crops. Livestock producers, for example, choose cattle that have been bred to withstand the harsh Prairie winters while hog and poultry producers house their livestock in climate controlled barns.

Agriculture is inherently sensitive to weather and climate and as a result, agricultural production, more so than any other form of production, could be impacted the most by climate change (Sauchyn & Kulshreshtha, 2008). Depending on future scientific advancements and adaptation strategies, climate change may provide opportunities or challenges for agriculture. For instance, warmer temperatures for crop and feed production will lead to a longer growing season which will result in more crop options in areas where temperature was previously a limiting factor (Amiro et al., 2014, CWS, 2014, Sauchyn & Kulshreshtha, 2008), multiple crops per year (Sauchyn & Kulshreshtha, 2008), improved crop quality (Sauchyn & Kulshreshtha, 2008) and shifts to earlier spring and later fall growth resulting in increased yields (Climate Change Connection, 2013a, Sauchyn & Kulshreshtha, 2008). However it may also lead to accelerated maturation rates and lower yields (Sauchyn & Kulshreshtha, 2008), heat stress (CWS, 2014), increased reproduction, spread and damage due to pests and disease (Amiro et al., 2014, CWS, 2014, MAFRD, 2014, Climate Change Connection, 2013a, Sauchyn & Kulshreshtha, 2008), reduced efficacy of pesticides (Amiro et al., 2014, Climate Change Connection, 2013a, Sauchyn & Kulshreshtha, 2008) and increased winterkill due to reduced snow cover (Climate Change Connection, 2013a). Warmer winter temperatures could potentially increase winter production for overwintering livestock (Amiro et al., 2014, Climate Change Connection, 2013b) while warmer summers may lead to increased heat stress resulting in decreased production and disease susceptibility (Climate Change Connection, 2013b). Seasonal temperatures changes may also result in changes in electricity demand from climate controlled livestock facilities (MAFRD, 2014, Climate Change Connection, 2013b, Sauchyn & Kulshreshtha, 2008).

Changes in the amount, seasonality and intensity of precipitation events, will affect agricultural production. While Manitoba is considered to be the least moisture deficient province (Sauchyn & Kulshreshtha, 2008) (of the Prairie Provinces), changes in the timing of precipitation and potential for agricultural droughts may present challenges for this industry. Decreased growing season soil moisture will result in decreased crop production (Climate Change Connection, 2013a, Sauchyn & Kulshreshtha, 2008) and increased costs for adaptation measures (Sauchyn & Kulshreshtha, 2008) such as irrigation and water storage systems. The potential increased occurrence of agricultural droughts and floods may cause more soil erosion (Climate Change Connection, 2013a) and crop damage, leading to reduced crop productivity and consequently increased insurance premiums (as result of increased insurance claims) (Amiro et al., 2014). Dry spells during critical crop growth phases would also result in a loss of crop productivity (Climate Change Connection, 2013a). The stimulatory effect of increased atmospheric CO_2 levels may increase crop productivity of C3 plants (wheat, canola, soybeans and some forages) while C4 plants (corn, millet, and big bluestem) are less responsive (Porter, 2014, Sauchyn & Kulshreshtha, 2008). The greatest response was found in tuber crops (potatoes) (Porter, 2014). However, increased CO_2 may also decrease crop quality (Sauchyn & Kulshreshtha, 2008), increase the competitiveness of some weeds and reduce the efficacy of some pesticides (Amiro et al., 2014, Porter, 2014, Climate Change Connection, 2013a).

The net impact of climate change on the agricultural industry will greatly depend on the implementation and effectiveness of adaptation strategies to potential negative effects (Sauchyn & Kulshreshtha, 2008). However, adaptation is not a new concept for the agricultural industry. Both the crop and livestock industry have a long history of adapting to climate stresses through technology and breeding programs (Amiro, 2014, Romero-Lankao et al., 2014). In general, with the projections of moderate temperature and precipitation increases within Manitoba, agriculture with some strategic planning and adaptation may benefit from the effects of climate change (Amiro, 2014, Romero-Lankao et al., 2014).

Climate Change Impacts to Infrastructure in Manitoba

Certain infrastructure projects in Canada, and in particular in northern areas of Manitoba are vulnerable to climate change (e.g., IISD, 2013, Prowse et al., 2009, Lemmen et al., 2004) as they will over time be increasingly exposed to conditions they may not have originally been designed to withstand. In Manitoba, climate change is projected to increase temperatures and precipitation (Romero-Lankao et al., 2014) which can potentially impact the design, construction, maintenance and safety of public infrastructure.

Changes to climate are expected to cause a decrease in the permafrost coverage in the northern portion of the Province (Sauchyn & Kulshreshtha, 2008). This will lead to a shorter winter road season (21 days shorter by the 2080s) and more difficulty transporting supplies to northern communities (Sauchyn & Kulshreshtha, 2008). Previous winters have already had shortened winter road seasons due to warm temperatures (Sauchyn & Kulshreshtha, 2008, Stern, 2006, Kuryk, 2003). There is a potential that into the future, the existing winter road network in certain parts of the Province may become inaccessible and permanent all-weather roads will need to be built which are relatively much more expensive (Prowse et al., 2009, University of Manitoba Transportation Institute, 2003, Kuryk, 2003). For example to convert winter roads into all weather roads on the east side of Lake Winnipeg could cost as much as $3 billion (East Side Road Authority, 2013).

Climate warming may decrease the amount of maintenance needed for roads in the southern portion of the Province due to cracking from the cold as well as potentially decreased freeze-thaw cycles; however, this may also lead to increased rutting and pavement flushing from heat during the summer which will increase maintenance costs (IISD, 2013, Sauchyn & Kulshreshtha, 2008). The change in temperature may also lead to more freeze-thaw cycles in the northern portion of the Province which may cause damage and cracking in roadways (IISD, 2013). An earlier spring melt may lead to Spring Road Restrictions being enforced earlier in the year (Lemmen et al., 2004). Spring Road Restrictions are put into effect each spring with timing and duration dependent on current moisture conditions.

Reductions in winter extreme events may lead to less road closures and create savings for the transportation and freight industry (IISD, 2013). Extreme heat events in the summer can cause damage to roadways and decrease the fuel-efficiency of jet engine planes and can even cause air travel to become impossible due to the lower density of the air not being able to supply lift to the plane's wings (Smoyer-Tomic et al., 2003).

Coastal infrastructure is expected to be impacted by rising sea levels (Sauchyn & Kulshreshtha, 2008). The increase in ice-free period (up to 30 days longer by 2080 (Prowse et al., 2009)) in Hudson Bay has the potential to increase ship traffic at the Churchill port but may also increase shoreline erosion on Hudson Bay (Sauchyn & Kulshreshtha, 2008).

Infrastructure in Manitoba has already experienced several impacts from climate change. One example of this is increased spending on transporting supplies to northern communities during warmer winters (University of Manitoba Transport Institute, 2003). In 1997-98 during an El Nino year, at least $14 million was spent to airlift supplies to communities that had previously depended on winter roads. In addition, the warmer winter caused hardships for individuals attempting to access services in major centers such as Thompson and Winnipeg. The phenomenon has not been sustained for a long enough period to determine if it is a statistically significant trend at this point; however, anecdotal evidence points to 1997-98 as being an extreme case while the winters of 2001-02 and 2002-03 each had shortened winter road seasons as well (University of Manitoba Transport Institute, 2003). All cases had associated financial impacts for Manitoba taxpayers. Current regulations state that all major new federal infrastructure projects that are built in northern Canada must include resiliency to the impacts of climate change in their design (Canadian Environmental Assessment Agency, 2012).

Manitoba currently has several adaptation measures in place to promote readiness for climate change and the impacts that it may have on infrastructure (IISD, 2013). Manitoba's current Northern Development Strategy (Government of Manitoba, 2001) is a long-term plan adopted by the Government of Manitoba to develop the natural and human resources of northern Manitoba. This strategy does not mention climate change; however, a new document which is in preparation is expected to address many of the issues related to climate change in Manitoba's north (IISD, 2013). Manitoba also has an inter-departmental working group focused on climate change; and a document called Tomorrow Now-Manitoba's Green Plan is the province's environmental strategy that commits to a provincial climate change risk assessment and adaptation strategy and action plan, parts of which have already been put in place (IISD, 2013, Manitoba Government, 2012). In addition, Engineers Canada has initiated the Public Infrastructure Engineering Vulnerability Committee that facilitates initiatives that provide clear guidance to the engineering and geoscience community of Canada on designing, building and maintaining public infrastructure safely and sustainably while addressing the risks of climate change (Engineers Canada, 2007).

Climate Change Impacts on the Socio-Economic Environment in Manitoba

The impacts of climate change may have implications for the economic and social well-being of Manitobans. Heat stress, exposure to disease-carrying insects and changes to traditional ways of life and culture are some of the already observed and projected impacts for Manitoba.

Climate Change Impacts on Communities

For northern communities, and in particular First Nations' communities in Manitoba, climate change may have implications for their traditional way of life and culture due to their heavy reliance on the environment and their location (Centre for Indigenous Environmental Resources, 2006). One perspective is that First Nation communities are already observing and experiencing direct impacts of climate change through changes to the types and quantities of traditional foods and medicine, loss of transportations systems such as winter roads (i.e., reduced duration of use and/or less predictable use), unsuitable snow and ground conditions which impede travel to hunting grounds, changes to accessibility and timing for harvesting fish and changes to migratory patterns of animals which are used as a food source (Centre for Indigenous Environmental Resources, 2006, Sauchyn & Kulshreshtha, 2008, Yukari, 2010). In a study conducted by Chan et al., (2012) when Manitoba First Nations participants were asked whether they had witnessed any noticeable climate change impacts in their traditional territory over the last ten years, 54% said they had. Perceived climate change impacts included availability and difficulty in obtaining food from traditional sources, and the cycles/patterns of local animals. In Ford et al. (2008) community case studies were conducted, one at Churchill, examining the impacts of climate change on hazards associated with ice use. Interviews with local community members found that perceptions of ice and weather conditions over time are changing, and are consistent with instrumental (gauged) records. Noticeable changes at Churchill included later freeze-up, earlier ice breakup, increasing unpredictable weather conditions, and occasional rainfall in winter months (Ford et. al, 2008). First Nations' communities like the one documented in Turner & Clifton (2009) have adapted well to changes in the climate. It was found that over the past 10,000 years, these communities have traditionally adjusted their diets with resource fluctuations, such as utilizing alternative species of fish, animals, or plants. While this study was not conducted in Manitoba, it does show that community adaptation to climatic changes are not unprecedented (Turner & Clifton, 2009).

Climate Change Impacts on Tourism

Climate change can impact the hydrological cycle which may affect water levels and quality which ultimately may impact opportunities for water-based recreation such as fishing, swimming, boating, and canoeing (Sauchyn & Kulshreshtha, 2008). Also, less snow cover and a shorter season may impact winter recreation such as cross-country skiing, and snowmobiling (Sauchyn & Kulshreshtha, 2008). Furthermore, changes to terrestrial and aquatic species may impact recreational fishing and hunting in both positive and negative ways. Many communities benefit economically from outdoor tourism, and can be affected by changes in climate (IISD, 1997). An example would be towns that benefit from local downhill ski resorts, and increasing expenses from snow-making with shorter winter seasons. Also noted in IISD, (1997) is the potential increase pressure on wilderness areas, as rising temperatures make their recreational use more appealing.

Stewart et al. (2005) highlights the impacts of tourism on Arctic and Antarctic regions. For destinations like Churchill receiving 4000-6000 tourists a year, understanding socio-cultural impacts is cited as an important concern with tourism development. The implications of climate change on tourism are mentioned as an emerging area of research in polar regions (Stewart et al., 2005).

Climate Change Impacts on Human Health

Manitobans may experience increasing negative health impacts from air pollution and particulate matter, heat-related illnesses, and vector-borne diseases (Bélanger et al., 2008).

Studies show that climate change may result in more frequent forest fires from warmer and dryer conditions or from increased lightning storms. These fires will impact people by substantially degrading air quality both locally and away from the location of the fire. The ash and smoke from the fire can cause eye irritation as well as respiratory irritation leading to increased asthma attacks or bronchitis (Bélanger et al., 2008). As discussed earlier in this report, forest fires in the boreal region of Manitoba are projected to increase in severity with climate change (de Groot et al., 2013).

One health risk that is a growing concern because of climate change is extreme heat events. Extreme heat events are defined by hot weather conditions that result in an unacceptable level of health effects, including increased morbidity and mortality (Health Canada, 2011). Studies are showing that climate change can expect to increase extreme heat events (hot days and warm nights) that can negatively impact health (Health Canada, 2011).

Climate variables such as temperature and precipitation can influence the survival and reproduction rate of pathogen carrying organisms that cause disease. West Nile virus is a mosquito-borne illness brought to Canada in 2001 by migratory birds (Séguin & Peters, 2008, Pepperell et al., 2003). Since first introduced to Canada, the prairie provinces have reported the highest human incidence of West Nile virus infection in Canada (Chen et al., 2013). Studies show there is a link between milder winters followed by prolonged drier summers and heat waves that favor the spread of West Nile virus. A study conducted by Chen at al. (2013) constructed models and biological thresholds to predict the spatial and temporal distribution of the West Nile virus infection rate in the prairie provinces under a range of potential future climate and habitat conditions. This study showed that by 2050 under the median future climate projections, the infection rate could rise by 17.91 times compared to current climate conditions and that the seasonal range of spread could extend from June to August to include May and September. Their conclusions project a future health risk from West Nile Virus within the Canadian prairie provinces.

Summary

Adapting to both the positive and negative impacts of climate change may pose challenges to everyone across the globe, including Manitobans. There is considerable unceratinity inherent in future climate change impact studies which rely on global climate models and these studies may not necessarily capture the full range of future variability. When studying future climate change impacts it is important to recognize the unceratinities that surrounds the climate models used in the study. It is also important to undestand that as we increase our understanding of the climate system, these climate models and their projections will evolve. These climate models should be used as tools to provide us with pictures of what the future may look like based on a set of assumptions including how future greenhouse gas emissions will evolve. Much of the discussion in this document has focused on trends or projected trends documented by studies with relevance to Manitoba; however, this summary has not considered where these studies conflict or how the aggregated layers of unceratinity influence the interrelatoinships between the specific ecosystem components mentioned throughout. The six impact areas (physical, aquatic, terrestrial, agriculture, infrastructure and socio-economic) described in this report outline some of the already observed and potental impacts within Manitoba. Key findings from this report include:

- Mean air temperature in Manitoba has increased by approximately 1°C to 2°C over the period of 1950-2007 and are projected to increase by another 2° to 4°C by the middle of the 21st century. These changes in air temperature can have an impact on precipitation and other environmental components.
- Historical changes in precipitation and other environmental components have been studied throughout Manitoba and are projected to change into the future. These changes include decreased ice cover periods and decreased spring snow cover extents. While several locations show substantial changes in precipitation and streamflow, results vary due to large spatial and temporal variability in the historic record. Future projections include increases in mean: precipitation, water supply, water temperature, water sediment load, water nutrient load, and decreased mean: spring snow cover extents, and ice cover periods.
- The health and well-being of Manitoba's freshwater ecosystems are being impacted by historic changes in streamflow, water temperature, and water chemistry. These changes have affected the population size, range and diversity of fish communities. Generally speaking these changes have included a loss of habitat for coldwater fish species, and a northward range expansion of warm water species. Future climate projections indicate a continuance of these observed historic trends in warming temperatures and changes to the regional water regime in Manitoba.
- Permafrost thaw rates are increasing in northern Manitoba and are projected to continue to accelerate. This is decreasing the utility of winter roads and affecting the communities that depend on them for transportation of material and people as well as causing differential settlement issues that may cause damage to building foundations in northern communities of Manitoba.
- Climate change is contributing to woodland caribou declines in the boreal forest, through changes in predator-prey dynamics, spread of parasites, permafrost losses, and changes in forest fire regime.
- Polar bears in northern Manitoba are being affected by increasing ice-free periods on Hudson Bay, causing nutritional stress and population reductions due to lack of seal access.
- Migratory birds in Manitoba are changing their spring arrival times; many species are arriving earlier, and this is correlated with rising temperatures.

- The agricultural industry in Manitoba is continuously adapting to the changing climate and the overall impact will be greatly dependent on the implementation and effectiveness of adaptation strategies that take advantage of the longer growing seasons, the opportunity for higher productivity and mitigation measures to deal with new pests and diseases.
- Heat stress, increased air pollutants from forest fires and exposure to disease-carrying insects such as mosquitoes carrying the West Nile virus are occurring within Manitoba and are projected increase into the future.
- First Nation people have historically had to adapt to a changing climate, including changes to their traditional foods, medicine and access to hunting and gathering areas. Adaptation has included harvesting different species of animals and plants. In more recent times, there has been some reported indication of impacts on northern communities in Manitoba due to a changing climate.

It is expected that there are more impacts than the sample described in this report and more that have not yet been documented. This reports main objective was to present a sample of the literature related to observed and projected impacts of climate change with a focus on the Province of Manitoba.

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