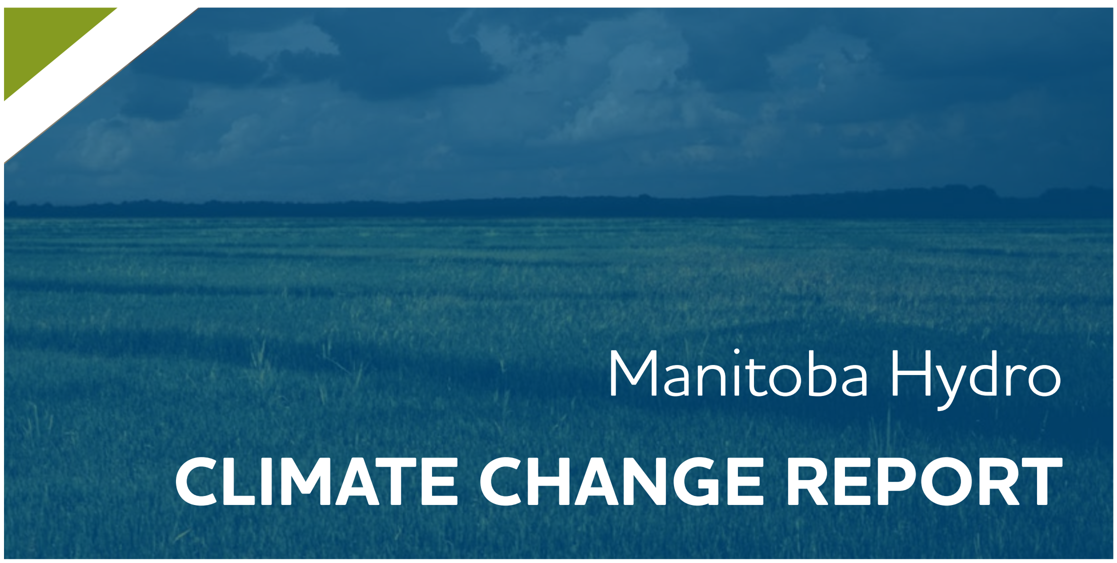

Manitoba Hydro
CLIMATE CHANGE REPORT

Providing unique insight into the strategies, research, planning, advocacy, and greenhouse gas reduction actions that have made Manitoba Hydro an industry leader in responding to climate change.

Fiscal Year:
2014-2015

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EXECUTIVE SUMMARY

The core physical processes that regulate the Earth's climate continue to be altered. Science has provided strong evidence that humanity's collective activities are resulting in climate change. The multidimensional characteristics of climate change require a variety of sustained actions that address both local and global challenges. As a utility and a member of the provincial and global community, Manitoba Hydro will be challenged by climate change on many fronts, but will strive to maintain vision and focus in the corporation's response.

This document details Manitoba Hydro's current and historical efforts, actions, and initiatives related to climate change. For over two decades Manitoba Hydro has taken a leadership role in not only understanding the science of climate change and projecting future impacts, but also measuring and reducing corporate emissions and advocating for effective policies to achieve national and international greenhouse gas (GHG) reductions.

Manitoba Hydro has established the following five climate change strategies to shape the organization's response to climate change:

- Understand the Changing Climate
- GHG Measurement and Reporting
- Contribute to GHG Emission Reductions
- Support GHG Policy and Market Development
- Adapt and Plan

Understand the Changing Climate

Due to the importance of the physical environment to Manitoba Hydro's core business, the corporation has invested resources and deploys the best available technology to ensure a robust understanding of the range of potential implications due to climate change. Manitoba Hydro is currently undertaking a number of initiatives to increase internal knowledge of the potential impacts, with a particular focus on energy demand, extreme events, and water supply within the Nelson-Churchill Watershed.

For the 2050 time frame the Global Climate Models (GCMs) ensemble is generally projecting temperature to increase by approximately 2.4 C and precipitation is projected to increase by 6.1% for the Nelson-Churchill Watershed. The greatest increases in temperature are projected for the winter months (2.7-3.4 C) with precipitation increases between 8.1-13.9%. The summer months are projecting small to no increases in precipitation (1.4 -2.5%) with temperature increases between 2.2 and 2.6 C. While the shoulder seasons (Spring and Autumn) are projecting temperature increases between 2.0-2.6 C with precipitation increases between 10.0-11.7% (Spring) and 6.6-8.3% (Autumn).

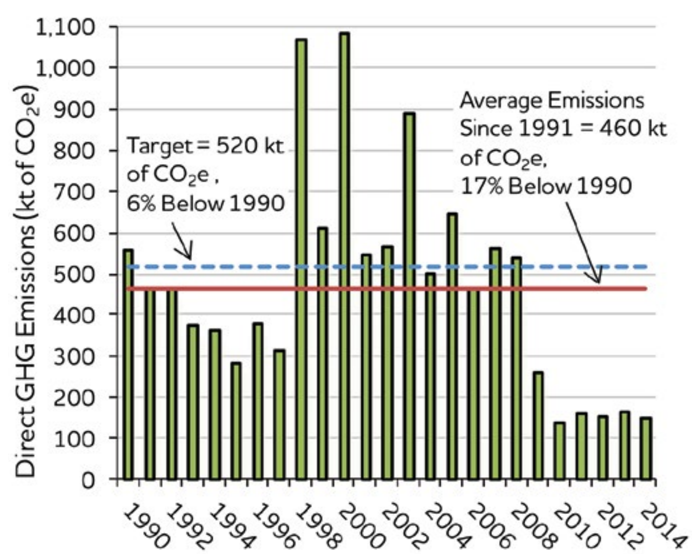
As a result of the increase in precipitation, annual runoff is also projected to increase between 7.3% and 23.3% throughout the watershed. Efforts are underway to calibrate hydrological models for each of the river basins in the Nelson-Churchill Watershed to examine more details about seasonal shifts of streamflow distribution. While it is expected to take several years to analyze the entire Nelson-Churchill Watershed, the preliminary results show increasing annual average streamflows and seasonal shifts in the timing of runoff.

Monitoring of climatic conditions and environmental conditions throughout the Nelson-Churchill Watershed is occurring, and will be ongoing, to provide modeling feedback and to help guide decisions and adaptation efforts over time.

GHG Measurement and Reporting

Accurate GHG measurement and reporting are integral in ensuring that Manitoba Hydro understands their emission liabilities, identifies opportunities for further reductions, and demonstrates the results of actions taken. Investigating the GHG impacts of future projects helps Manitoba Hydro make sustainable resource choices and distinguish the organization's low GHG emitting electricity from other sources.

FIGURE 1: MANITOBA HYDRO DIRECT GHG EMISSIONS



Manitoba Hydro began measuring and reporting their corporate GHG emissions in 1995 and has set aggressive voluntary emission reduction targets. Manitoba Hydro's GHG emissions are small: they represent less than 1% of the emissions within a province that represents less than 3% of national emissions. Despite Manitoba Hydro's low emissions starting point, the corporation has achieved substantial further reductions. Manitoba Hydro has achieved an average long-term emissions reduction of 17% since 1990, as shown in Figure 1.

Manitoba Hydro also estimates the GHG implications of its major projects using life cycle assessment. All forms of electrical generation, including renewable sources, have GHG implications when a facility's design, construction, operation, and decommissioning are all considered. Accounting for all aspects of the project life cycle allows for comparison of the levelized life cycle GHG implications of various electricity resources. When taking life cycle GHG emissions, including reservoir emissions, into consideration, Manitoba Hydro's new generating stations result in very low emissions per unit of energy, comparable to wind farms and 99% less than the most efficient natural gas generation resources (Figure 2).

Contribute to GHG Emission Reductions

Manitoba Hydro has very low electrical generation GHG emissions relative to other utilities and regions. Building on this advantageous starting position, Manitoba Hydro has continued to reduce reliance on fossil fuel generation and to pursue renewable electricity development, along with the delivery of energy efficiency programs.

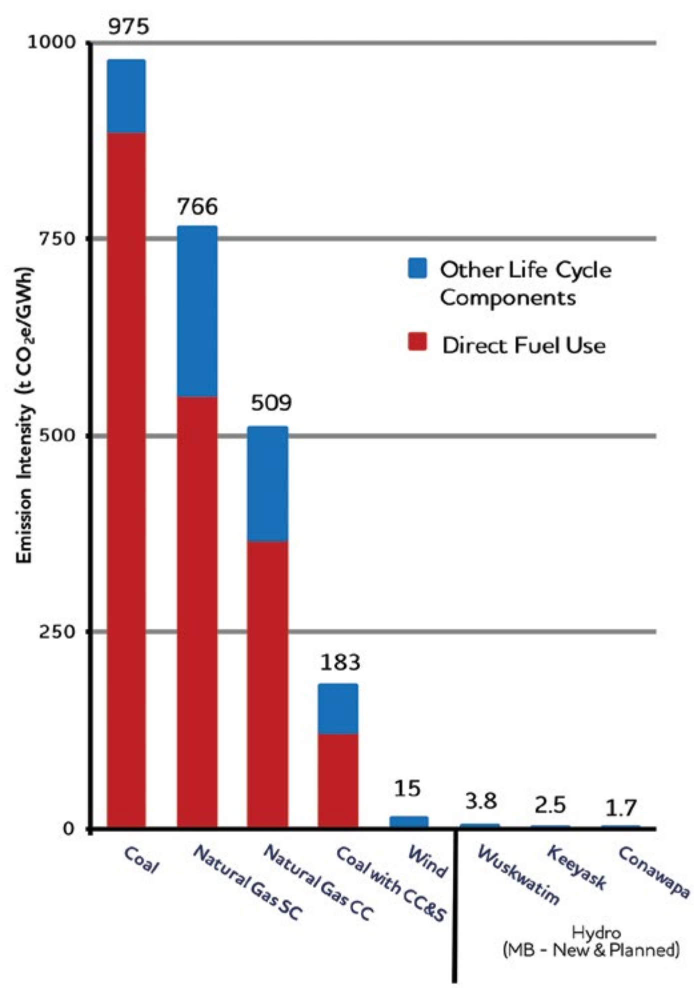
In the early 1990s, Manitoba Hydro operated coal-generating units located in Brandon and Selkirk. Four of five units at the Brandon Generating Station (G.S.) were shut down by 1996, eventually being replaced by two new natural units in 2002. At the Selkirk G.S., both units were converted from coal to natural gas. Since December 31, 2009, Unit 5 at Brandon G.S., Manitoba Hydro's only remaining coal unit, has been regulated to only operate to support emergency operations.

In 1991, Manitoba Hydro established Power Smart*, the customer oriented brand for all of Manitoba Hydro's demand side management programs, initiatives, and activities. Energy conservation initiatives are designed to reduce domestic customer energy requirements through energy-efficient measures that use less energy to obtain comparable or superior services. Manitoba Hydro's Power Smart program has resulted in a total annual energy savings of 2,512 GWh of electricity and 93 million cubic meters of natural gas to date.

These energy savings reduce GHG emissions globally by approximately 1,871 kilotonnes (kt) of carbon dioxide equivalent (CO_2e) per year. This is comparable to removing approximately 394,000 vehicles from the road annually.

Manitoba Hydro also considers efficiency opportunities within its operations. By enhancing the generation output of existing generating facilities and transmission systems, Manitoba Hydro is able to maximize the production and availability of renewable electricity to displace fossil-fuel fired electric generation both within Manitoba and in the export region. In addition to activities done to date, such as Kelsey Rerunnering Project and the refurbishment of some of the oldest generation equipment in the system, a number of Supply Side Enhancement initiatives are currently underway.

FIGURE 2: COMPARISON OF LIFE CYCLE GHG EMISSIONS [PEMBINA INSTITUTE, 2003; PEMBINA INSTITUTE, 2010; PEMBINA INSTITUTE, 2013]



*Manitoba Hydro is a licensee of the Trademark and Official Mark.

Hydropower has allowed Manitoba Hydro to operate one of the cleanest generation systems in the world. With the 2012 completion of the Wuskwatim G.S., Manitoba Hydro now has approximately 5,200 MW of hydroelectric generation, with the majority of this capacity located in northern Manitoba. The Keeyask (695 MW) Generation Project will add to that capacity in 2019/20. Following the completion of the Keeyask G.S., there is an opportunity to add even more renewable capacity with the Conawapa (1,485 MW) Generation Project. Wuskwatim, Keeyask, and Conawapa Generation Projects are all models of sustainable hydropower development, including minimal flooding (approximately 50 km^2 cumulatively), incorporation of low environmental impact design features, and collaboration with local First Nation communities.

To further renewable power development in the province, Manitoba Hydro has also contracted over 250 MW of wind capacity in service at the St. Leon and St. Joseph wind farms under the terms of long-term Power Purchase Agreements.

Hydropower, wind, and Power Smart efficiency improvements all contribute to increased exports. Since 2005, annual electricity exports by Manitoba Hydro have averaged approximately 10,000 GWh per year. Electricity exports to neighbouring states and provinces have kept Manitoba electricity rates amongst the lowest in the world and contributed to significant GHG reductions outside of the province. Manitoba Hydro's actions demonstrate that energy needs can be met in a sustainable and affordable fashion while proactively addressing climate change.

Support GHG Policy and Market Development

Ultimately, GHG policies that deliver broad emission reductions will be required to achieve global climate change objectives. Manitoba Hydro has participated in and supported provincial, regional, national, and international GHG policy dialogues for nearly twenty years. Manitoba Hydro supports GHG policies that deliver a meaningful carbon price for emissions, such as a carbon tax or cap-and-trade program, as they are the most flexible and economically efficient ways to reduce emissions. By increasing the variable costs of fossil fuel energy sources these policies improve the economics for non-emitting resources. By striving to enable practical policies that are environmentally effective and economically efficient, Manitoba Hydro has developed the expertise needed to navigate a carbon constrained future.

Over the past 20 years, various national cap-and-trade frameworks were proposed and designed in Canada but were never implemented. Similarly in the United States (U.S.), several cap-and-trade bills were proposed by both Democrat and Republican members of Congress; however none of these were passed into law. Instead, governments in both countries are using their regulatory authority to pursue GHG reductions. The U.S. Environmental Protection Agency is moving forward with regulating GHG emissions from major stationary sources, including power plants, with regulations potentially being finalized in the summer of 2015. These, and other regulations that manage air and water pollutants, could put significant constraints on electricity sector emissions should they withstand a variety of legal and legislative challenges.

The Government of Canada aligned its GHG reduction targets with those of the U.S. and is also pursuing a sector-by-sector regulatory approach. In September 2012, Canada published its "Reduction of Carbon Dioxide Emissions from Coal-Fired Generation of Electricity Regulations". These regulations effectively phase out conventional coal-fired electricity generation over the long-term. Continuing this approach, the government may move to regulate emissions from natural gas-fired power plants in the electricity sector.

In addition to federal legislation and regulation, state and provincially led GHG cap-and-trade initiatives have also been pursued. The Western Climate Initiative (WCI) partner jurisdictions developed a cap-and-trade initiative to reduce regional GHG emissions to 15% below 2005 levels by 2020. Under the initiative, both California and Quebec established cap-and-trade regulations and have linked their respective markets. In April 2015, Ontario signaled its intent to join the WCI as well. The Regional Greenhouse Gas Initiative (RGGI), which took effect in January 2009, called for a 10% reduction in GHG emissions from 2005 levels by 2018 for nine participating Northeastern states. Besides regional cap-and-trade initiatives, some provinces have implemented alternative carbon pricing mechanisms. British Columbia has a revenue-neutral carbon tax, applied to all fossil fuels.

Manitoba Hydro actively collaborates with a number of different stakeholders from both inside and outside of the electricity sector on these various regional, national, and international initiatives. This includes direct engagement with the Canadian and U.S. federal governments, provincial and state governments, along with variety of energy policy stakeholders at the regional, national and international levels.

In North America, voluntary GHG emission reduction programs have emerged as opportunities for proactive companies to transition towards a carbon constrained economy. Manitoba Hydro has also nurtured the development of carbon markets through its participation in programs such as the Chicago Climate Exchange. This helps the corporation to better understand carbon markets through hands-on experience and demonstrates the effectiveness of these types of programs.

Adapt and Plan

Climate change has the potential to influence Manitoba Hydro's resource plans and future operations. Several key inputs to the integrated resource planning process may be sensitive to a changing climate or the human response that may arise in response to climate change. These resource planning considerations include the projections of changes to runoff, the load forecast, and the market price for electricity. Manitoba Hydro is investigating how best to factor climate change impacts into long-term planning and operation of its system. The intent is to explore the sensitivity of these inputs to climate change and determine the robustness of Manitoba Hydro's development plans. Similarly, where there appears to be implications for Manitoba Hydro's operations, adaptation strategies will be considered.

Projections that Manitoba Hydro makes today are based on a much more comprehensive understanding than those made several years ago as they undergo more comprehensive modeling. While Manitoba Hydro is at the forefront of hydrologic and hydroclimatic studies, there is still a significant amount of work to be done. Over the next several years, the modeling work that is currently underway will enhance Manitoba Hydro's understanding and planning projections even further. Through ongoing research and analyses, Manitoba Hydro will continue to advance the state of knowledge about the range of potential climate change impacts at the system-wide scale and improve Manitoba Hydro's understanding of how these impacts could affect existing and proposed facilities.

Operating practices, unlike fixed assets, may change and adapt over time. Therefore current activities are not focused on anticipating future changes in operations but rather are focused on developing the modeling tools that enable Manitoba Hydro to better meet the needs of today and enhance their understanding and ability to adapt to changes. This includes improving short term hydrologic modeling for forecasting upcoming water conditions and possible extreme events.

Temperature changes can also impact weather affected electrical energy and natural gas demand. Manitoba Hydro has studied these potential impacts through sensitivity analyses as well as GCM studies. In a recent study, the GCM ensemble average projected a 2.5 C increase in annual average temperature for the 2050s, with greater winter temperature increases relative to summer. The seasonal differences have a counteracting effect on total annual electrical energy demand. Relative to Manitoba's 2014/15 load, the 2050s projected weather effect results in a 1.1% decrease in total annual electrical energy demand, a 3.7% decrease in winter peak demand, a 9.4% increase in summer peak demand, and a 6.9% decrease in natural gas demand.

One of the most important adaptation issues relates to responding to emerging climate change or GHG policies. GHG policies, typically presented either through a cap-and-trade program or carbon tax framework, will impact the generating costs and the market price for electricity. GHG price assumptions are embedded in Manitoba Hydro's resource planning activities to account for the impact on electricity export prices as well as increased costs related to utilizing thermal generation in Manitoba. Planning assumptions for coal generation already account for Manitoba's existing tax on emissions from coal. While Manitoba Hydro generally assumes that North American GHG price signals will converge or harmonize in the longer term, there will likely be short-term local or regional discrepancies due to differences in timing and policy details. Projecting the future impact of GHG policies ensures that the appropriate costs and revenues are included in the integrated resource planning process for the evaluation of future resource options and development plans.

Conclusion

Science has provided strong evidence that our collective human activities are resulting in climate change. Reducing GHG emissions and avoiding the risks associated with climate change requires diverse sustained responses across the spectrum of related challenges. For over two decades, Manitoba Hydro has taken a leadership role in not only understanding the science of climate change and projecting future impacts, but also measuring and reducing corporate emissions and advocating for effective policies to achieve national and international GHG reductions. Manitoba Hydro activities have been organized under five climate change strategies that strive to provide a comprehensive approach that ensures all potential risks are analyzed and all opportunities are enabled. The balance of the document will provide more details of Manitoba Hydro's current and historical efforts, actions, and initiatives related to climate change.

"Climate change is one of the defining issues of our time. It is now more certain than ever, based on many lines of evidence, that humans are changing Earth's climate. The atmosphere and oceans have warmed, accompanied by sea-level rise, a strong decline in Arctic sea ice, and other climate-related changes." [The National Academy of Sciences, 2014]

1 INTRODUCTION

The objective of this report is to provide insight into Manitoba Hydro's climate change activities including research, greenhouse gas (GHG) reductions, policy advocacy, and planning and adaptation activities.

The Earth's climate is dynamic and has changed significantly in the past; however, the nature and cause of the current changes being experienced are different. Since the pre-industrial era anthropogenic GHG emissions have increased and scientists believe that these GHG emissions are extremely likely to have been the dominant cause of the observed warming that has occurred since the mid-20th century [IPCC, 2014]. Manitoba Hydro accepts the results of this scientific body and recognizes the evidence that emissions from human activities are resulting in climate change. Coordinated efforts will be required to reduce global emissions and avoid the risk of dangerous climate changes.

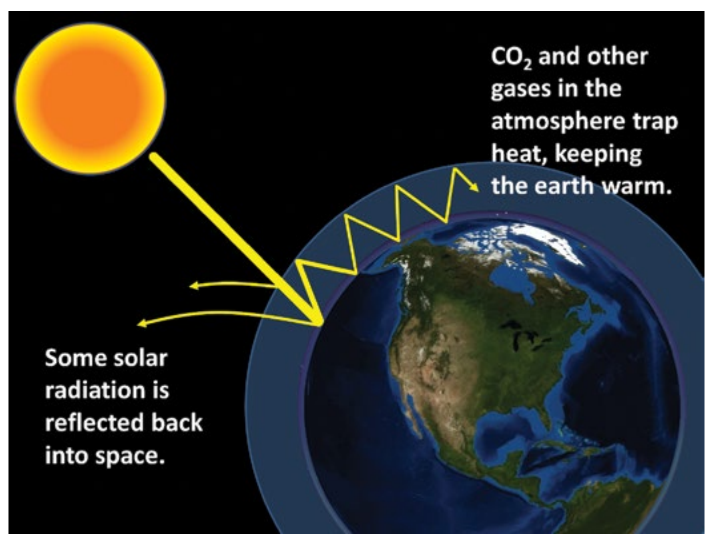
To date, Manitoba Hydro has focused on building a strong foundation of knowledge and tools to undertake climate change impact studies on future water supply, energy demand, and extreme events. Manitoba Hydro employs sophisticated Global Climate Models (GCMs) along with downscaling techniques to develop future climate scenarios and determine impacts. Future water supply assessments utilize advanced hydrological models. These models are being set-up for the river basins of interest to simulate future hydrological conditions including streamflow. A detailed meteorological and hydrological monitoring program has been established and will continue to provide modeling feedback to help guide decisions, identify risks, and inform adaptation efforts over time.

While Manitoba Hydro may be impacted by changes to the climate, the Corporation also has the potential to affect and influence the outcomes. The Corporation can contribute emission-free electricity, assist in shaping policy frameworks, guide development of efficient technologies, and help domestic customers make wise choices regarding their energy use.

1.1 CLIMATE CHANGE SCIENCE

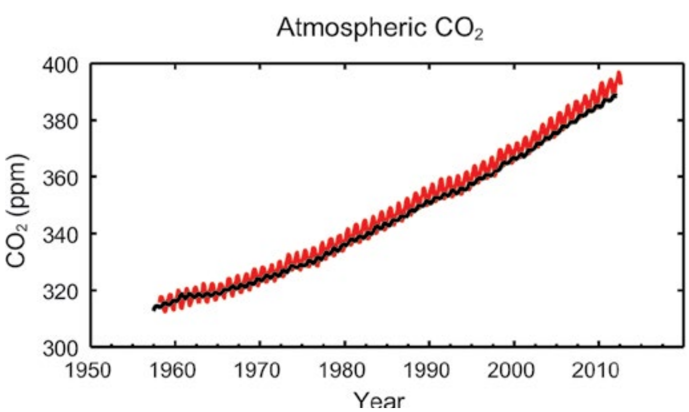
To understand how GHGs act to increase the Earth's temperature, one should consider the Earth's energy balance system, which is essentially driven by solar radiation (Figure 3). Approximately 30% of the sunlight that reaches the top of Earth's atmosphere is reflected back to space. The energy that is not reflected into space is absorbed by the Earth's atmosphere and surface and is converted from visible and other spectra of light into heat. Keeping the energy roughly in balance, the Earth radiates heat back to space as longwave (infrared) radiation. GHGs (e.g. water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone and various chlorine, fluorine, and bromine-containing molecules) absorb the reflected infrared radiation, acting as a partial blanket. By trapping heat, these gasses act like the glass in a greenhouse warming the Earth's surface and hence the process is termed the "greenhouse gas effect". This process is critical in maintaining a habitable planet. In the absence of any GHGs, the planet would be too cold to support many life forms.

FIGURE 3: GREENHOUSE GAS EFFECT



The current concern is that the burning of fossil fuels such as coal, natural gas, and oil is releasing additional heat-trapping gases, intensifying the natural greenhouse effect, thereby changing the Earth's climate. Since the industrial revolution, humans have burned more fossil fuels each decade. Figure 4 shows the recent atmospheric trend in one of the key GHGs that human activities release, CO_2. The CO_2 values are presented in parts per million (ppm). As of 2011, levels have reached 391 ppm [IPCC, 2013]. The red and black line shows seasonal changes in monthly measurements at two locations (Hawaii and the South Pole). Although GHG composition within the atmosphere has changed over the course of the Earth's history, the magnitude and rate of the recent changes appear to be unprecedented.

FIGURE 4: ATMOSPHERIC CO_2 MEASURED AT THE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION'S MAUNA LOA OBSERVATORY ON HAWAII (RED) AND THE SOUTH POLE (BLACK). [IPCC, 2013]



1.2 CLIMATE CHANGE INDICATORS

Climate change indicators are useful in measuring changes to the Earth's physical environment. Surface temperatures that have been measured on land and at sea for more than a century show that Earth's surface temperature (globally averaged) is experiencing a long-term warming trend. Arctic sea ice is another useful climate change indicator. In the Arctic Ocean the area covered by sea ice grows and shrinks over the course of the year. The increased sunlight and higher temperatures of summer typically result in the sea ice shrinking to its minimum extent each September. Sea ice responds to warmer temperatures by retreating further. Minimum sea ice observed each September has decreased by an average of 12% per decade compared to the 1979-2000 average [National Oceanic and |Atmospheric Administration, 2014].

An additional consequence of reduced ice cover is a decrease in the reflected sunlight from the surface. Snow covered surfaces reflect incoming solar radiation and provide a cooling effect, however, when the extent of snow covered areas is reduced, solar radiation is absorbed by the Earth and contributes to additional warming. This is an example of "positive feedback", which reinforces the warming cycle.

Studies have been conducted nationally and regionally to examine other potential indicators of a changing climate [van Oldenborgh et al., 2013; Sauchyn & Kulshreshtha, 2008; Henderson & Sauchyn, 2008; Meehl et al., 2007; Lemmen et. al. 2004; Warren & Lemmen 2014]. Some regional studies show that changes are already being observed in the physical environment and they may be attributed to climate change (Table 1). Due to challenges in attributing impacts to climate change, a longer timeframe of observations is required before more confident statements can be drawn as to whether these detected changes can be directly linked to global climate change.

TABLE 1: CLIMATE CHANGE INDICATORS

Climate Change Indicators	Examples of Published Studies
Climate	Sauchyn & Kulshreshtha, 2008; Ehsanzadeh et al., 2011; Déry et al., 2011; St. Jacques et al. 2011; Zhang et al., 2011; Déry & Wood, 2005; Westmacott & Burn, 1997
Permafrost Thaw Rates	Sauchyn & Kulshreshtha, 2008
Aquatic Animal & Habitats	Sauchyn & Kulshreshtha, 2008; Venema et al., 2010; Environment Canada and Manitoba Water Stewardship, 2011; Chu et al., 2005; Page & Levesque, 2011
Terrestrial Animal & Habitats	Environment Canada, 2012; Price et al., 2013; Racey, 2005; Stirling & Derocher, 1993, Stirling et al., 1999, Derocher et al., 2004, Stirling & Parkinson, 2006, Regehr et al., 2007, Price and Glick, 2002, Chen at al., 2013

1.3 CLIMATE CHANGE STRATEGIES

The science has made it clear that our collective human activities are resulting in climate change. Reducing GHG emissions and avoiding the risks associated with climate change requires a wide variety of actions that address the local and global challenges. Manitoba Hydro strives to understand and manage risks, liabilities, and opportunities related to climate change with a focus on providing leadership on social, environmental, and economic issues. In alignment with Manitoba Hydro's corporate strategic plan and existing corporate goals, Manitoba Hydro has established the following five climate change strategies to shape the organization's response to climate change:

1. Understand the Changing Climate
2. GHG Measurement and Reporting
3. Contribute to GHG Emission Reductions
4. Support GHG Policy and Market Development
5. Adapt and Plan

Understand the Changing Climate

Manitoba Hydro strives to understand the implications of climate change. This includes maintaining a comprehensive understanding of the science of anthropogenic climate change, and the resulting local, regional, and global hydrological impacts. A comprehensive understanding is vital to ensure that Manitoba Hydro can plan for and adapt to a changing physical environment.

GHG Measurement and Reporting

Accurate GHG measurement and reporting are vital towards ensuring that Manitoba Hydro understands emission liabilities, discovers opportunities for further reductions, and demonstrates progress. Since Manitoba Hydro began its voluntary reporting efforts both the Provincial and Federal governments have introduced mandatory reporting requirements for some of Manitoba Hydro's facilities. Investigating the GHG impacts of their future projects helps Manitoba Hydro make informed resource choices and distinguish its low GHG emitting electricity from other sources.

Contribute to GHG Emission Reductions

Manitoba Hydro has very low power generation GHG emissions relative to other electrical utilities. Despite this advantageous starting position, the corporation has set aggressive voluntary emission reduction objectives over the past twenty years. Manitoba Hydro has continued to pursue hydropower, wind generation, and Power Smart* energy efficiency programs while reducing emissions from corporate facilities and contributing to reduced emissions outside Manitoba through electricity exports.

Support GHG Policy and Market Development

Effective GHG policies will be required to achieve necessary emission reductions. Manitoba Hydro has participated in and supported provincial, regional, national, and international GHG policy dialogues for more than fifteen years. Manitoba Hydro has also nurtured the development of carbon and renewable energy markets. Through Manitoba Hydro's expertise in energy technologies and practical experience in environmental markets the corporation strives to enable practical policies that are environmentally effective and economically efficient.

Adapt and Plan

Successfully responding to a changing physical environment requires that Manitoba Hydro's plans are robust under various potential climate scenarios and that its operations are positioned to adapt to changing operating parameters such as flow conditions and electrical loads. Manitoba Hydro must also adapt to the human response to climate change that may include changes in societal preferences for energy sources and policies and their implications on the market price for electricity.

The following chapters provide the details of Manitoba Hydro's significant and coordinated efforts within the framework of these five climate change strategies.

> *"Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased" [IPCC, 2013]*

2 UNDERSTAND THE CHANGING CLIMATE

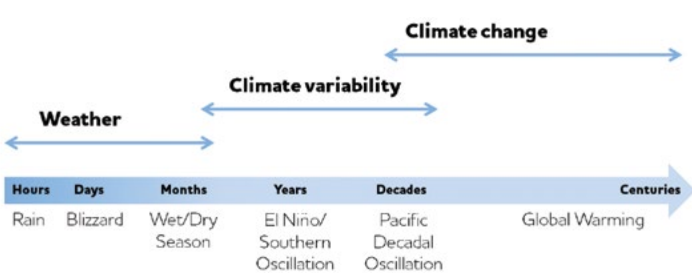
Due to the importance of the physical environment to Manitoba Hydro's core business, the corporation has invested resources and deploys the best available technology to ensure a robust understanding of the potential range of future changes due to climate change. This allows Manitoba Hydro to be in a position to plan and adapt accordingly.

2.1 GLOBAL CLIMATE CHANGE

When studying climate change, it is important to understand the difference between weather and climate (Figure 5). Weather refers to the day-to-day variable state of the atmosphere, and is characterized by temperature, precipitation, wind, clouds, and various other weather elements [IPCC, 2013]. Weather results from rapidly developing and decaying weather systems and is difficult to predict on a daily basis. Climate, on the other hand, refers to the weather statistics in terms of its means, variability, extremes, etc. over a certain time span and area [IPCC, 2013]. Climate varies from place to place depending on the latitude, vegetation cover, distance to large bodies of water, topography, and other significant geographic features.

The United Nations Environment Programme and the World Meteorological Organization have established the Intergovernmental Panel on Climate Change (IPCC) which is the leading body for the assessment of climate change. The IPCC brings together many of the world's leading scientists to conduct comprehensive assessments of the current state of knowledge on climate change and its potential environmental and socio-economic consequences. The IPCC refers to climate change when there is a statistically significant variation to the mean state of the climate (or of its variability) that usually persists for decades or longer and which includes shifts in the frequency and magnitude of sporadic significant weather events as well as the slow continuous rise in global mean surface temperature [IPCC, 2013].

FIGURE 5: WEATHER, CLIMATE VARIABILITY AND CLIMATE CHANGE TIME SCALE



2.2 CLIMATE CHANGE AND MANITOBA HYDRO

Climate change scientists have projected changes in future temperature and precipitation patterns, frequency and intensity of severe weather events, and sea level rise as a result of rising concentrations of anthropogenic GHGs in the atmosphere [IPCC, 2014]. For hydroelectric power companies like Manitoba Hydro these changes have the potential to influence energy production, infrastructure, energy demand, and the physical environment in which they operate (Figure 6).

FIGURE 6: IMPACTS OF CLIMATE CHANGE ON HYDROPOWER

Physical assets are planned, constructed, and operated based on historical climatic and hydrologic conditions, and changes in climate may alter their performance. Transmission and distribution systems may be exposed to a number of vulnerabilities of climate change such as extreme weather events. Manitoba Hydro is striving to assess the risks associated with climate change and determine how to best adapt to future conditions.

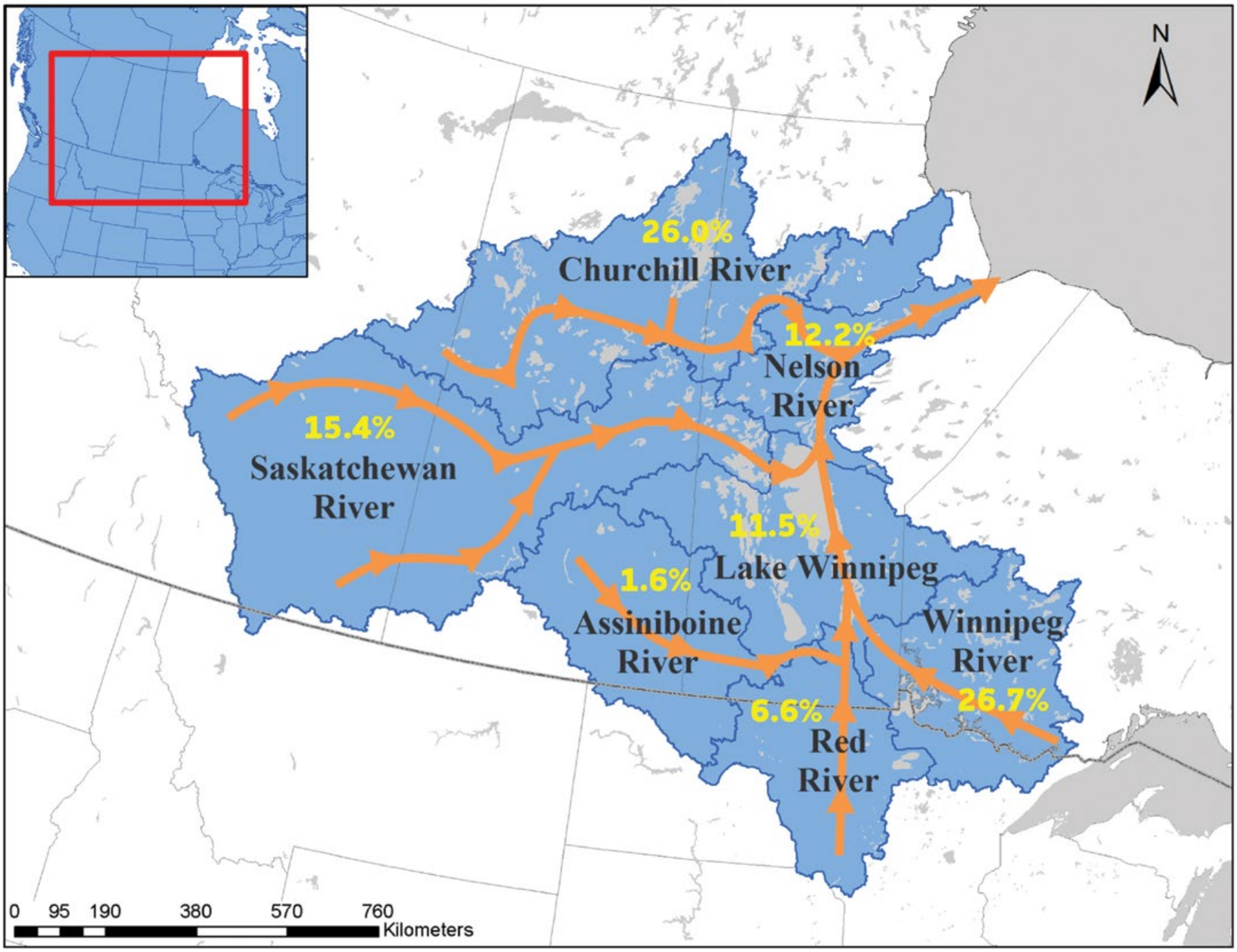
The scope of the climate change studies at Manitoba Hydro includes all of the river basins in the Nelson-Churchill Watershed which supply approximately 95% of Manitoba Hydro's energy in the form of water (Figure 7). This watershed is vast at 1.4 million km^2 and covers a sizable portion of central North America and includes a range of different ecozones and geographic areas (Figure 8). The approximate average per cent of water that is supplied from each of these basins in the Nelson-Churchill Watershed is illustrated in Figure 7.

2.3 MANITOBA HYDRO'S CLIMATE CHANGE STUDIES

A series of comprehensive studies have been initiated to increase Manitoba Hydro's knowledge of the implications of future climate change on future water supply, energy demand and extreme events in the Nelson-Churchill Watershed. The main objective of these studies is to incorporate outcomes into long-term planning and operations and consequently adapt infrastructure and business practices as required (Figure 9).

The approach to these climate change studies is to adapt existing models and to use the outputs from reputable climate change modeling centers. Manitoba Hydro has been working with leading experts (such as those involved in the Ouranos Consortium, refer to Section 2.4) in climatology and hydrology. As new models and tools become available, the ability to project changes in climatic variables at the regional level will evolve.

FIGURE 7: NELSON-CHURCHILL WATERSHED (% CONTRIBUTION OF TOTAL WATER SUPPLY)



*per cent contributions are calculated based on 1981-2010 average inflows available for outflow. For the Churchill River, only a portion of the inflow available for outflow is diverted into the Nelson River.

FIGURE 8: ECOZONES WITHIN THE NELSON-CHURCHILL WATERSHED

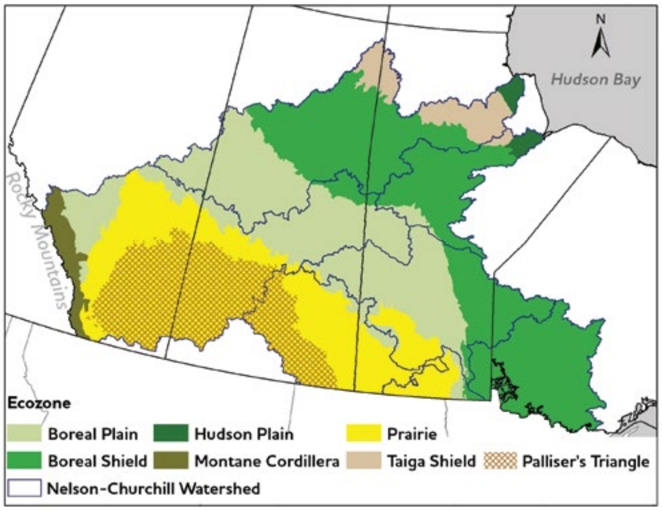
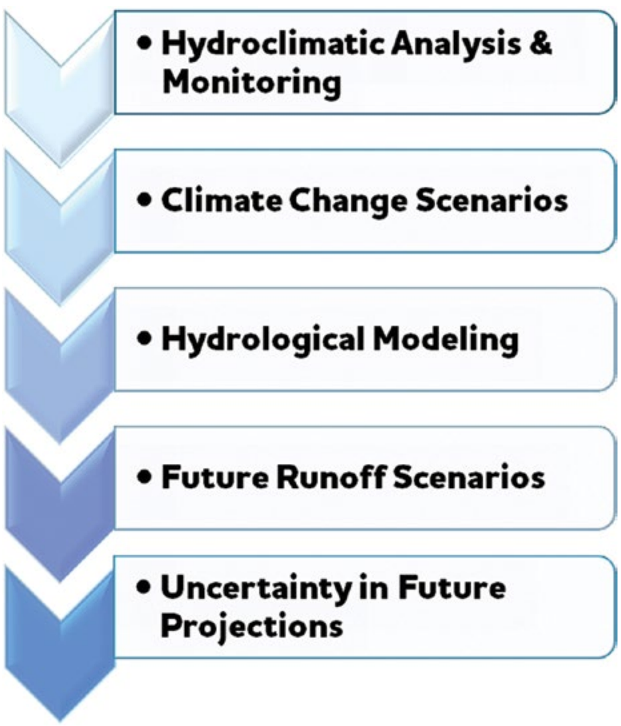


FIGURE 9: CLIMATE CHANGE STUDIES



2.3.1 HYDROCLIMATIC ANALYSIS & MONITORING

The objective of the hydroclimatic analysis & monitoring studies is to collect all relevant historical hydrology and climate data to characterize the hydrological and climatic (hydroclimatic) conditions in the Nelson-Churchill Watershed. This information will provide the foundation for understanding future hydroclimatic variability and change.

Normals (1981-2010)

Climate normals are used to represent the average climatic conditions over a certain time period at a certain location. Currently, Environment Canada publishes 1981-2010 climate normals for a variety of stations.

Generally in the Nelson-Churchill Watershed the annual average temperature ranges, north to south, from -6.5 C to +6.1 C; and total annual precipitation ranges, west to east, from 323 mm to 777 mm with a small region within the Rocky Mountains exceeding 1000 mm. During the winter months temperatures exhibit a distinct south-west to north-east gradient which range from -4 C to -22 C and a large portion of precipitation is stored as snowpack which is released during the spring melt. During these winter months average precipitation ranges from 29 mm to 120 mm and areas within the Rocky Mountains receive up to 270 mm. During the summer months temperatures range from 6 C to 20 C with a south to north gradient and precipitation varies from 120 mm to 300 mm. Spring and Autumn are shoulder seasons where temperatures range between -9 C to 6 C and precipitation ranges between 50 mm to 220 mm. Figure 10 illustrates annual temperature and total precipitation normals across the Prairie Provinces and the western part of Ontario while Figure 11 and Figure 12 illustrate the seasonal normals [Hopkinson et al. 2011; Hutchinson et al. 2009].

Similar to the climate, the annual water supply within the Nelson-Churchill Watershed is also spatially diverse. Table 2 summarizes the average streamflow conditions for the contributing basins of the Nelson-Churchill Watershed for the 1981-2010 period. Average streamflow near the outlets of each basin varies from 48 cubic metres per second (cms) from the Assiniboine River Basin to 947cms from the Winnipeg River Basin.

FIGURE 10: ANNUAL CLIMATE NORMALS FOR AVERAGE TEMPERATURE (LEFT) AND TOTAL PRECIPITATION (RIGHT) FOR THE 1981-2010 PERIOD

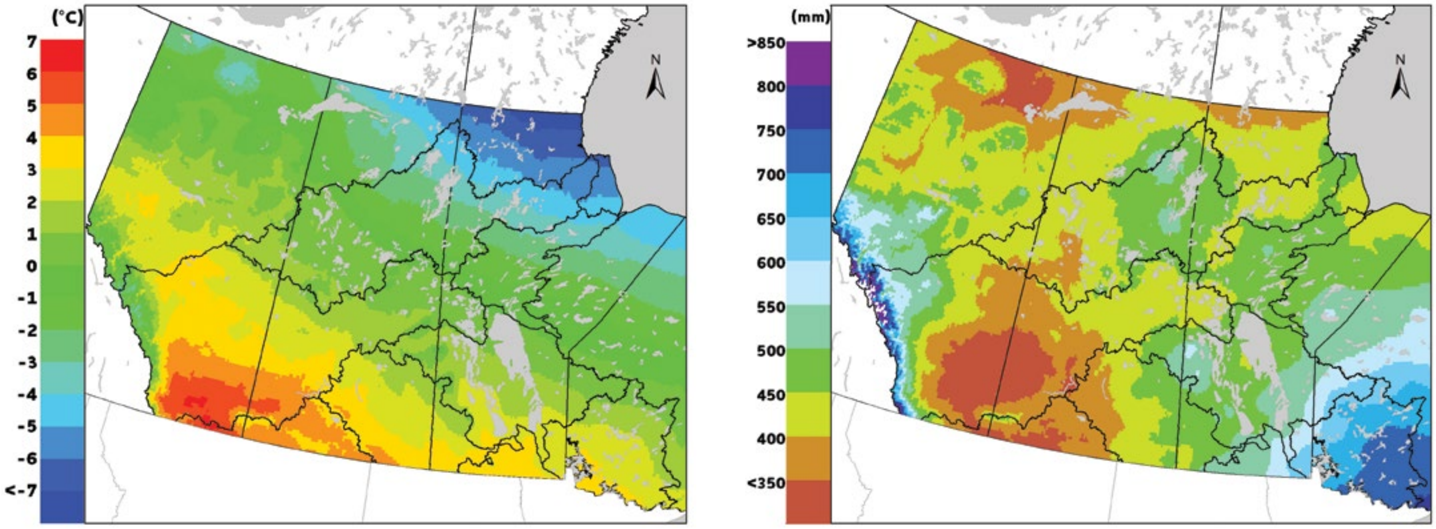


TABLE 2: AVERAGE ANNUAL STREAMFLOW NEAR BASIN OUTLETS FOR THE 1981-2010 PERIOD

Basin	Station Name	Outlet Gauge ID	Average Annual Streamflow (cms)		
			Min	Avg.	Max
Saskatchewan River	Saskatchewan River at The Pas	05KJ001	308	551	960
Assiniboine River[a]	Assiniboine River at Headingley	05MJ001	14	48	103
Red River	Red River at Emerson	05OC001	28	184	405
Winnipeg River[b]	Winnipeg River at Pine Falls G.S.	05PF063	458	947	1415
Lake Winnipeg[c]	East and West Channel	05UB008 05UB009	1139	2181	3566
Churchill River	Churchill River Above Leaf Rapids	06EB004	574	844	1321
Nelson River[c,d]	Nelson River at Kettle G.S.	05UF006	2157	3278	5114

[a] record reflects losses due to the Portage Diversion,
[b] includes flow from the Lake St. Joseph diversion,
[c] record represents the combined flow of all upstream basins
[d] includes Churchill River Diversion

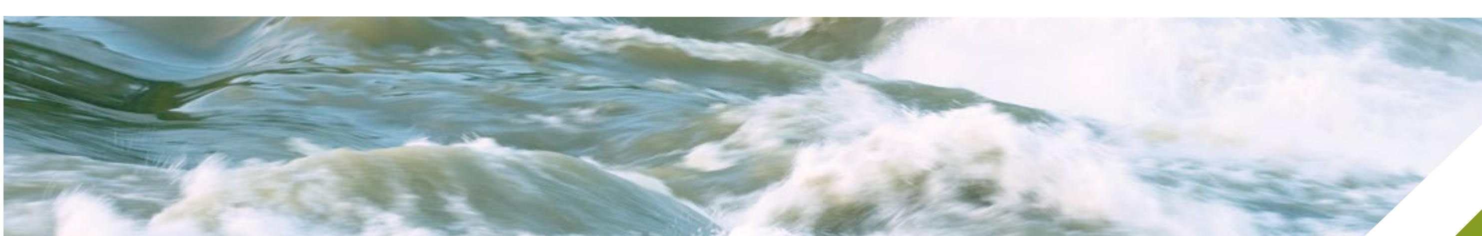


FIGURE 11: SEASONAL TEMPERATURE NORMALS (1981-2010)

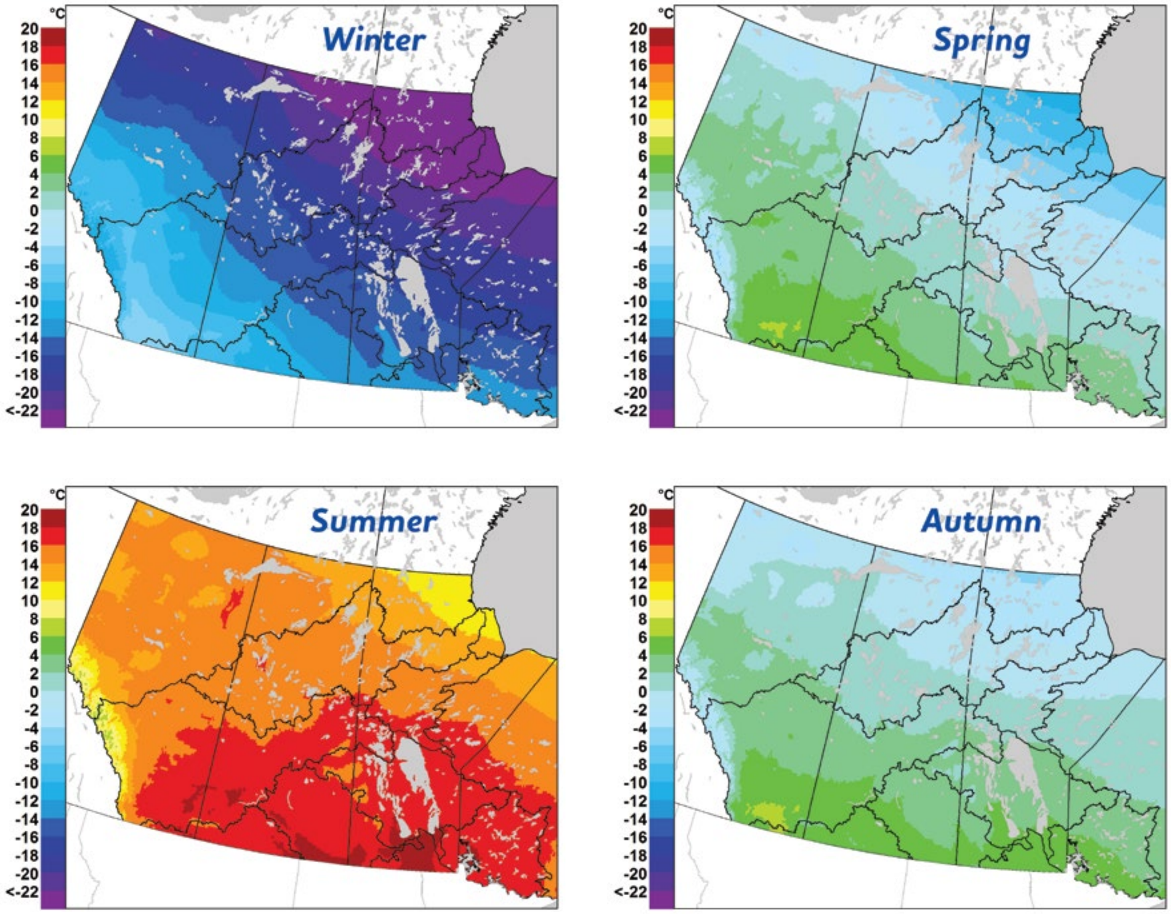
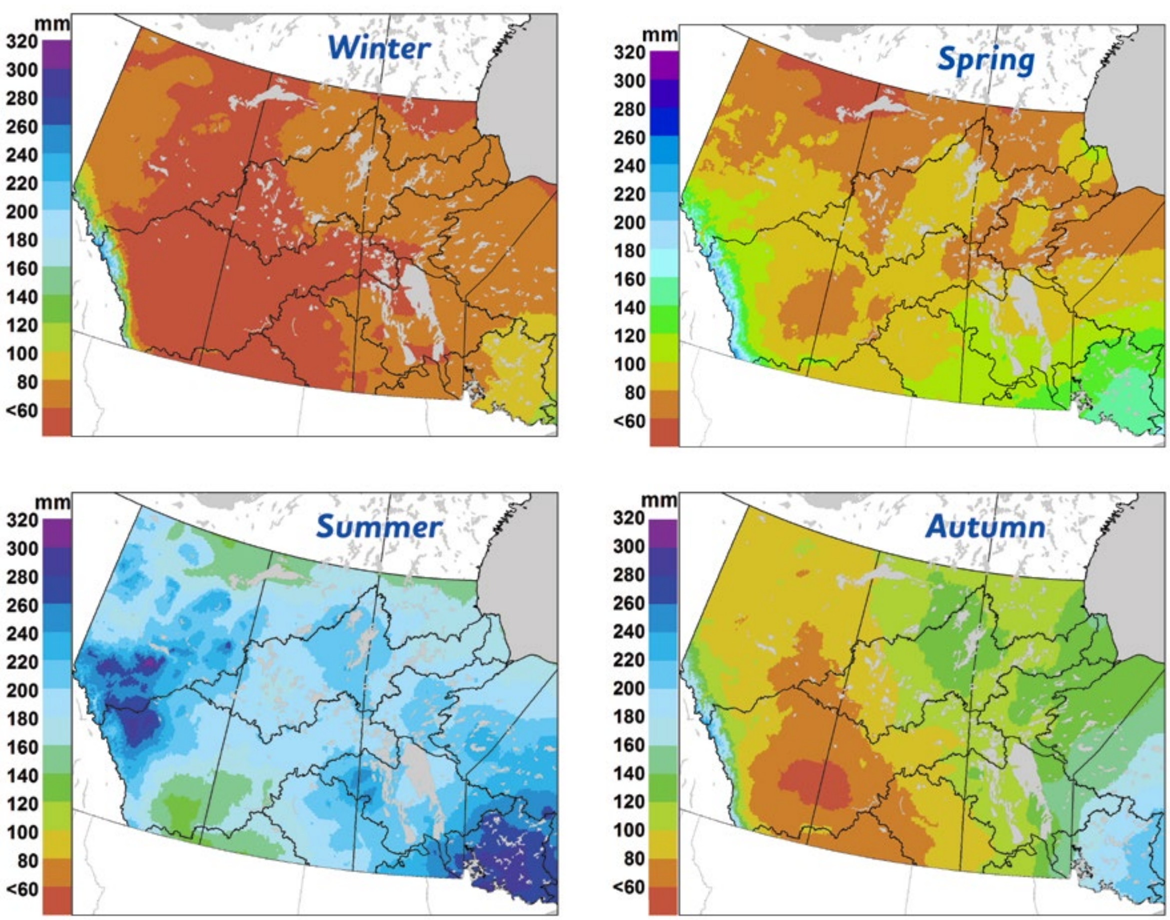


FIGURE 12: SEASONAL PERCIPITATION NORMALS (1981-2010)



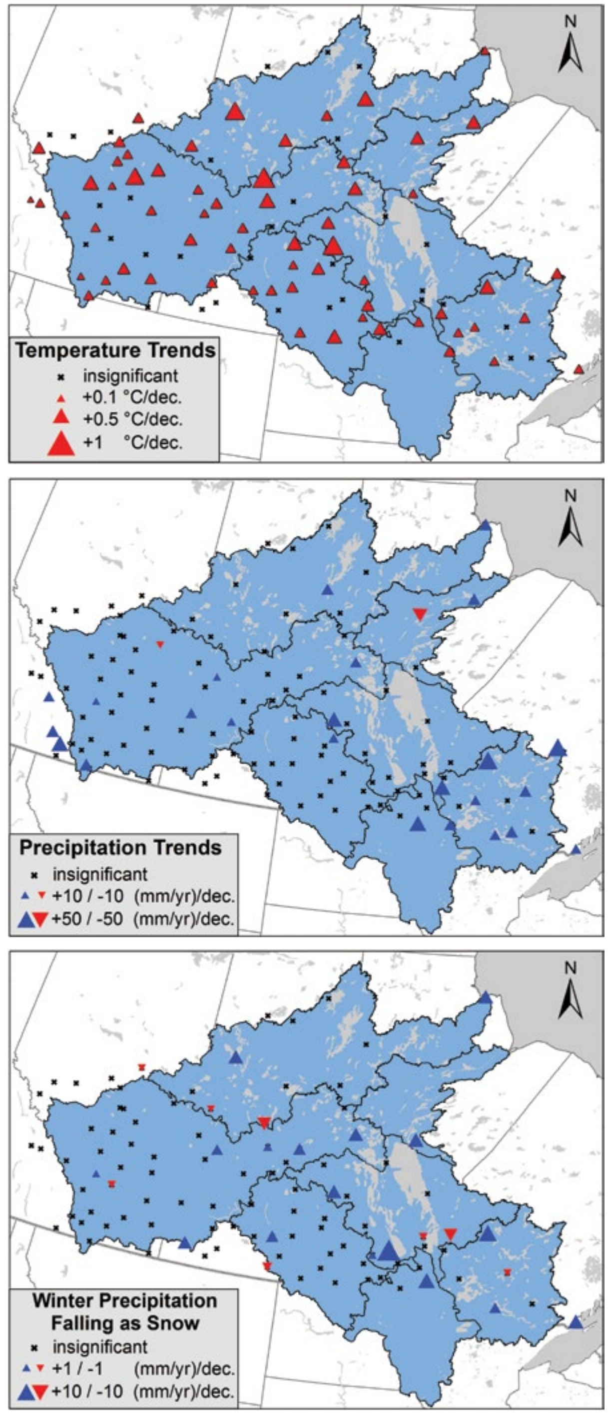
Trends

In general, using the longest period of records available at each station in Environment Canada's Adjusted and Homogenized Canadian Climate Dataset, most locations across the Nelson-Churchill Watershed show statistically significant increasing temperature trends ranging from +0.1 C/decade to +1 C/decade (Figure 13). Statistically significant changes to precipitation were also found in the historic record; however the results are less conclusive (Figure 13). For precipitation many stations indicated insignificant trends, several stations indicated positive significant trends, and two stations indicated decreasing significant trends. Despite the variability in precipitation trend direction and magnitude, there seems to be evidence that precipitation has been increasing across the south-eastern portion of the Nelson-Churchill Watershed between 10 to 40 mm/year/decade. Examining winter precipitation (falling as snow) in more detail indicates evidence of both increasing and decreasing trends in winter precipitation occurring throughout the watershed (Figure 13). Due to the spatial variability in trend direction and magnitude, no definitive conclusion regarding winter precipitation can currently be made.

Streamflow trends are useful in representing the area aggregated climate signal within a watershed. However, trend analysis can be challenging due to large natural variability and regulatory effects. Streamflow trends in the Nelson-Churchill Watershed exhibit spatial variability and are sensitive to the time period examined. Using the longest period of record from the Water Survey of Canada's dataset, statistically significant increasing trends were detected for annual average streamflow in the Winnipeg River, the Red River (upstream of the Assiniboine River confluence), and within the Lake Winnipeg Basin. Decreasing trends, although insignificant, were detected for the Churchill River, Saskatchewan River and in the Nelson River Basin.

Trends in extreme meteorological events vary spatially throughout Manitoba. Regional and global trends are described in the IPCC's Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change (SREX) [SREX, 2012]. Generally there is higher confidence in temperature related trends including increases in warm days and warm nights, and decreases in cold days and cold nights. There is spatially varying trends in precipitation related indices including likely increases in heavy precipitation in some areas; and there is low confidence in wind speed related trends. More complex trends such as multi-year hydrological droughts, with fewer historic events, are more difficult to draw conclusions on.

FIGURE 13: HISTORIC TRENDS FOR ANNUAL TEMPERATURE (TOP) ANNUAL PRECIPITATION (MIDDLE) AND WINTER PRECIPITATION (BOTTOM) FOR ENTIRE PERIOD OF RECORD (UP TO 2010)



It is important to acknowledge that trend analysis results can be sensitive to the record length, missing data and the use of different record periods, all of which can contribute to the variability. Trend analysis results, such as those presented in Figure 13 are intended to develop an understanding on the direction and significance of historic climate change and are not to be used to project the precise change into the future.

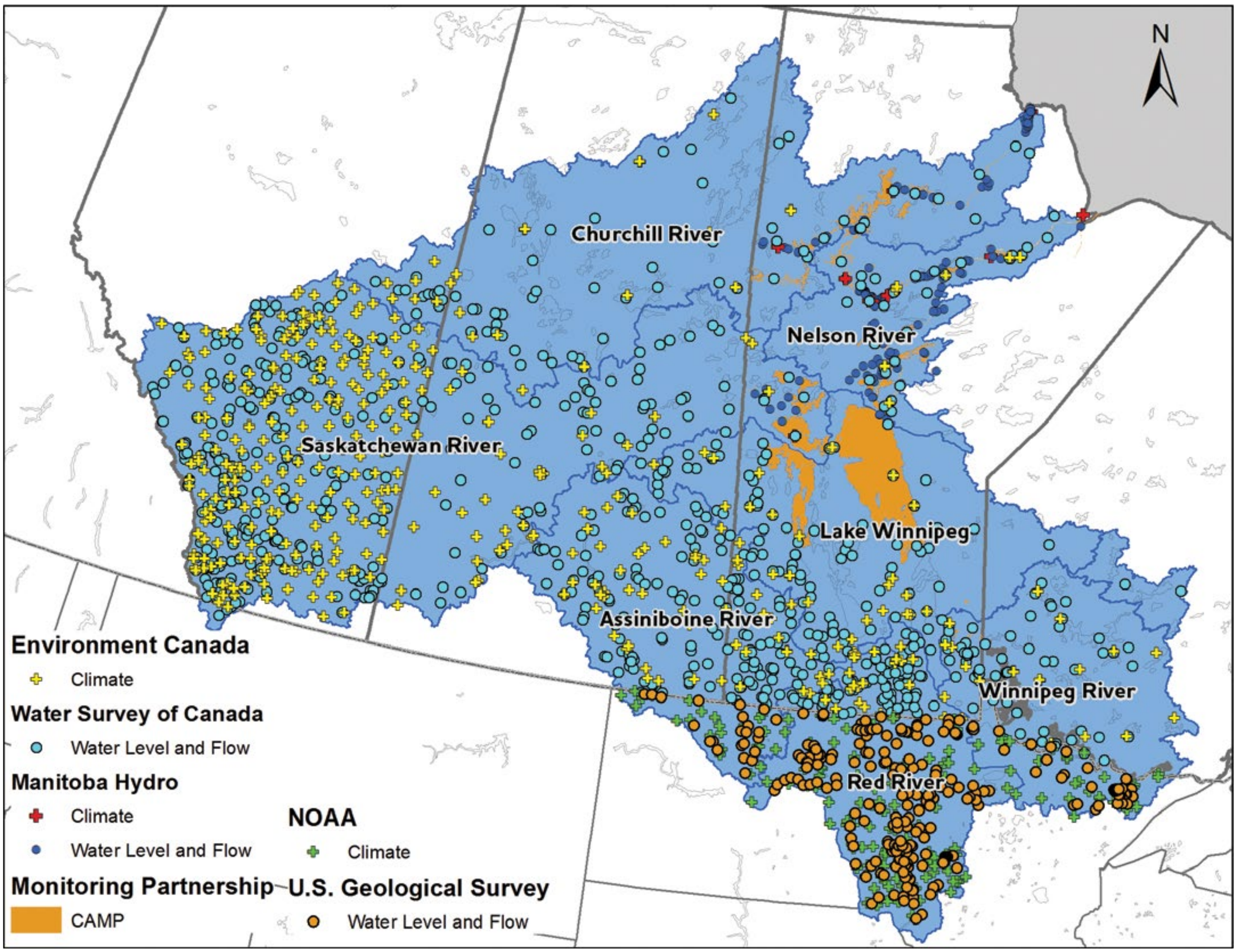
Paleoclimate

Paleoclimate data is recognized as a potential source for extending observed records further back in time. Sources of paleoclimate data include tree rings and lake sediments which can be correlated to climate variables and used as proxy records. Manitoba Hydro is interested in exploring the use of these datasets in its hydro-climatic studies, but direct applications are currently limited due to the uncertainty of generated streamflow from these proxy records, especially in watersheds as large and diverse as the Nelson-Churchill Watershed. Manitoba Hydro continues to follow the advances of paleoclimatic reconstruction techniques and endeavors to explore potential applications of paleoclimatic records to better inform its decision-making.

Monitoring

Manitoba Hydro will continue to monitor changes in the regional climate and hydrology using climate and hydrometric information, which includes measurements of temperature, precipitation, wind speed, and streamflow provided by Manitoba Hydro's Hydrometrics Program, Meteorological Services of Canada, and Water Survey of Canada (Figure 14). Under Manitoba Hydro/Manitoba's Coordinated Aquatic Monitoring Program (CAMP) additional environmental parameters are monitored including water quality (more than 50 parameters are analyzed including temperature, dissolved oxygen, pH, etc.), phytoplankton (algae), fish community, benthic invertebrates, and sediment quality. CAMP establishes the current quality of the aquatic ecosystem across Manitoba Hydro's hydraulic system and helps to assess changes over time. Figure 14 shows the regions sampled under CAMP as well as the meteorological and hydrometric monitoring networks.

FIGURE 14: ENVIRONMENTAL MONITORING LOCATIONS



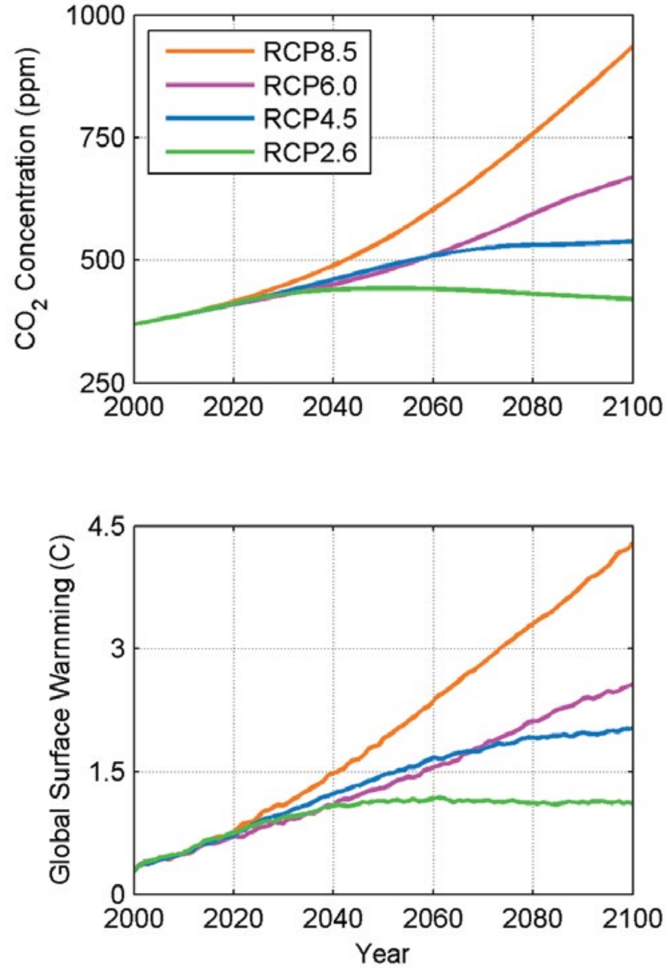
2.3.2 CLIMATE CHANGE SCENARIOS

In addition to leading research, compiling information, and providing climate change study guidance, the IPCC also brings together international modeling agencies that have developed GCMs to conduct assessments. The IPCC's Fifth Assessment Report (AR5) was released in 2013 and is the most recent report available. AR5 was based on results from the most recent suite of GCMs from the Coupled Model Intercomparison Project Phase 5 (CMIP5). Many of the CMIP5 GCMs offer improvements over the previous generation (CMIP3), including finer spatial resolutions and the inclusion of carbon cycling.

GCMs are numerical models used to translate future atmospheric forcing (i.e. GHG concentrations) scenarios into physically consistent effects on the climate. GCMs compute energy and mass balances, based on physical equations and are the most advanced tools for projecting future climate. GCMs are forced by Representative Concentration Pathways (RCPs) which are used to prescribe the levels of various forcing agents (e.g. GHGs and aerosols) in the atmosphere. RCPs include a number of assumptions about societal evolution and represent different demographic, social, economic, regulatory, technological, and environmental developments. Four RCPs are currently considered by the CMIP5 GCMs and they represent a range of futures from the optimistic (RCP2.6) to a business as usual case (RCP8.5). Global CO_2 emissions are presently tracking closest to RCP8.5 but given the large time horizon, it is not possible to accurately predict which RCP will be the closest to reality in the year 2100. Figure 15 illustrates the RCP modeled trajectories of global surface warming to 2100.

GCMs tend to agree on the future warming of the earth however their projection of precipitation and other climatic parameters at the regional or local scale is less consistent and has a greater degree of uncertainty. GCMs use relatively coarse resolutions, ranging from approximately 40 km to 400 km horizontally, and include 18 to 95 vertical levels. The coarser resolutions can make it challenging to interpret projected changes in precipitation and temperature at finer scales (Figure 16 illustrates the coarse grid spacing of the Canadian Center for Climate Modeling Analysis Canadian Earth System Model (CanESM2) at approximately 250 km resolution). Therefore, agencies have developed Regional Climate Models (RCMs) which simulate the climate for a limited area such as North America at a finer resolution than the GCMs.

FIGURE 15: TRAJECTORIES OF CO2 CONCENTRATION AND MODELED GLOBAL SURFACE WARMING FROM VARIOUS REPRESENTATIVE CONCENTRATION PATHWAYS (RCPs)



Just like the GCMs, these models are physically based but their resolution is typically 50 km or less allowing them to be able to account for important local forcing factors such as better topography representation, especially in mountain regions and other geographic features which GCMs are unable to resolve (Figure 17).

The primary dataset for Manitoba Hydro's climate change studies consists of 147 GCM simulations which represent a large ensemble of opportunity. These simulations contain a common set of monthly data for multiple variables up to the year 2100. This ensemble captures 18 GCMs and all four RCPs from the CMIP5 experiment. For certain studies, RCM data is also used and allows analysis at finer spatial resolution.

TABLE 3: GLOBAL CLIMATE MODELS*

Model	Country	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
BCC-CSM1.1	China	✓	✓	✓	✓
BCC-CSM1.1(m)	China	✓	✓	✓	✓
CanESM2	Canada	✓	✓	-	✓
CMCC-CM	Italy	-	✓	-	✓
BNU-ESM	China	✓	✓	-	✓
CSIRO-Mk3.6.0	Australia	✓	✓	✓	✓
GISS-E2-H	USA	-	✓	-	-
GISS-E2-R	USA	✓	✓	✓	✓
INM-CM4	Russia	-	✓	-	-
IPSL-CM5A-LR	France	✓	✓	✓	✓
IPSL-CM5A-MR	France	✓	✓	✓	✓
IPSL-CM5B-LR	France	-	✓	-	✓
MIROC5	Japan	✓	✓	✓	✓
MIROC-ESM	Japan	✓	✓	✓	✓
MIROC-ESM-CHEM	Japan	✓	✓	✓	✓
MPI-ESM-LR	Germany	✓	✓	-	✓
MPI-ESM-MR	Germany	✓	✓	-	✓
MRI-CGCM3	Japan	✓	✓	-	-

*Manitoba Hydro acknowledges the World Climate Research Programme's Working Group on Coupled Modelling which is responsible for CMIP and the climate modeling groups who produced and made their model outputs available.

FIGURE 16: CANADIAN EARTH SYSTEM MODEL GRID EXAMPLE

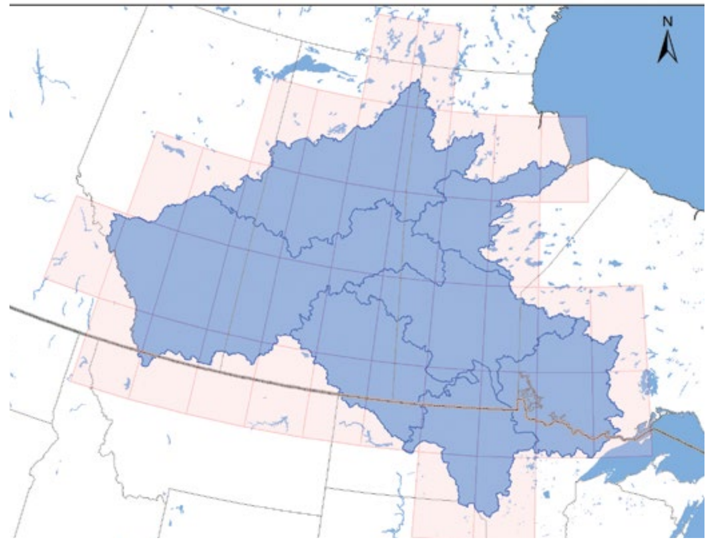
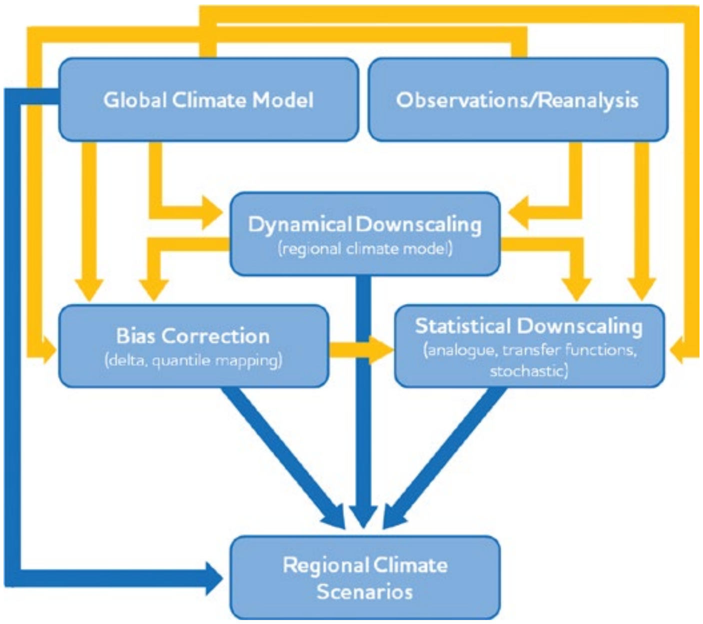


FIGURE 17: CANADIAN REGIONAL CLIMATE MODEL (RCM) GRID EXAMPLE

Most climate models (GCMs and RCMs) have a tendency to under or over estimate baseline climate conditions. When these differences in climate models occur consistently they are called biases. In general, this means the raw climate simulations need to be adjusted before they are used in a regional climate analyses. Various downscaling methods such as quantile mapping, transfer functions, and the delta method are used to develop regional climate scenarios (Figure 18). The Delta method is one of the most common methods as it provides realistic temporal sequencing associated with the historic record and allows future climate change impacts to be evaluated in the context of historical events.

FIGURE 18: DOWNSCALING METHODS



To assist with the development of quality, regional climate change (downscaled) projections Manitoba Hydro has become an affiliated member of the Ouranos Consortium (Refer to Section 2.4). Through its affiliation Manitoba Hydro gains access to their Canadian Regional Climate Model data, and expert guidance for analytical processes used to resolve key features of regional climate.

For the Nelson-Churchill Watershed the GCM ensemble average (147 projections using RCP 2.6, 4.5, 6.0 and 8.5) projected changes (deltas) in temperature and precipitation for the 2050s (2040-2069). Table 4 shows changes in annual mean temperature and annual total precipitation projected over the watershed. Generally annual temperature is projected to increase by approximately 2.4 C and annual precipitation is projected to increase by 6.1% for the Nelson-Churchill Watershed.

Seasonal variability in both temperature and precipitation projections are presented in Table 5 and Table 6. Generally, the greatest increase in temperature is projected for the winter months (2.7-3.4 C) along with an 8.1-13.9% increase in precipitation. Projected temperature increases for the summer months are between 2.2-2.6 C with small to no increases in precipitation (1.4-2.5%). Projections for the shoulder seasons show temperature increases between 2.0-2.6 C and precipitation increases between 10.0-11.7% (spring) and 6.6-8.3% (autumn).

Generally, the GCM ensemble average precipitation projections (Table 6) shows stronger signals for changes in winter, spring and autumn. Additional work is required to interpret the near-zero summer projections, which could reflect GCM disagreement on the direction of change or GCM agreement that average summer precipitation is projected to experience little change.

Projections from two example climate simulations (CanESM2 run1, RCP4.5 and RCP8.5) are illustrated in Figure 19 and Figure 20. These maps compare the differences in projections resulting from different emission forcing scenarios (RCPs). Generally, the RCP8.5 scenario projects a warmer climate with greater precipitation. Spatial patterns generally show up better when using a larger number of averaged simulations or a RCM. Some spatial patterns are evident in these maps such as greater warming for the northern region.

Future projections of extreme events and their associated impacts are of particular importance. However, studies of future extremes are generally surrounded by greater uncertainty than studies of future climate means. Additionally, defining extreme events can be challenging and depends on the specific objectives of the study. Manitoba Hydro's analysis of extreme events is ongoing and combines regional analysis with peer-reviewed and published scientific literature [e.g. Sillmann et al. (2013) and SREX, 2012]. In general, the climate models are projecting more pronounced changes in temperature based extreme indices especially minimum daily temperature for the RCP8.5 scenario. Specifically, the IPCC report indicates warmer and fewer cold days and nights, warmer and more frequent hot days and nights, and increased frequency of warm spells/heat waves [SREX, 2012]. Some studies project increases in extreme precipitation however the results are typically qualified with less confidence than extreme temperature projections. Generally these studies project increased frequency or proportion of total rainfall from heavy precipitation events [SREX, 2012]. Future projections of multi-year hydrological droughts and extreme floods cannot be analyzed through temperature and precipitation change alone as the hydrology of large watersheds is complex. Due to insufficient agreement among future projections of extreme hydrological events, the IPCC assigns a low confidence in their projections [SREX, 2012].

TABLE 4: GCM ANNUAL TEMPERATURE AND PRECIPITATION PROJECTIONS FOR THE 2050s RELATIVE TO 1981-2010

Basin/Watershed	Temperature	Precipitation
Churchill River Basin	↑ 2.5 C	↑ 6.7%
Saskatchewan River Basin	↑ 2.3 C	↑ 5.2%
Assiniboine River Basin	↑ 2.4 C	↑ 5.5%
Red River Basin	↑ 2.5 C	↑ 5.9%
Winnipeg RIver Basin	↑ 2.4 C	↑ 7.1%
Lake Winnipeg Basin	↑ 2.5 C	↑ 6.5%
Nelson River Basin	↑ 2.6 C	↑ 7.0%
Nelson-Churchill Watershed	↑ 2.4 C	↑ 6.1%

TABLE 5: GCM SEASONAL TEMPERATURE PROJECTIONS FOR THE 2050s RELATIVE TO 1981-2010

Basin/Watershed	Winter	Spring	Summer	Autumn
Churchill River Basin	↑ 3.2 C	↑ 2.1 C	↑ 2.2 C	↑ 3.1 C
Saskatchewan River Basin	↑ 2.7 C	↑ 2.0 C	↑ 2.4 C	↑ 2.5 C
Assiniboine River Basin	↑ 2.9 C	↑ 2.1 C	↑ 2.5 C	↑ 2.6 C
Red River Basin	↑ 2.9 C	↑ 2.2 C	↑ 2.6 C	↑ 2.6 C
Winnipeg River Basin	↑ 2.9 C	↑ 2.1 C	↑ 2.5 C	↑ 2.7 C
Lake Winnipeg Basin	↑ 3.1 C	↑ 2.1 C	↑ 2.4 C	↑ 2.8 C
Nelson River Basin	↑ 3.4 C	↑ 2.1 C	↑ 2.3 C	↑ 3.1 C
Nelson-Churchill Watershed	↑ 3.0 C	↑ 2.1 C	↑ 2.4 C	↑ 2.7 C

TABLE 6: GCM SEASONAL PRECIPITATION PROJECTIONS FOR THE 2050s RELATIVE TO 1981-2010

Basin/Watershed	Winter	Spring	Summer	Autumn
Churchill River Basin	↑ 11.4%	↑ 10.1%	↑ 2.5%	↑ 8.3%
Saskatchewan River Basin	↑ 8.8%	↑ 10.2%	↓ -0.9%	↑ 6.8%
Assiniboine River Basin	↑ 7.8%	↑ 11.7%	↓ -0.5%	↑ 6.8%
Red River Basin	↑ 8.1%	↑ 11.7%	↓ -0.1%	↑ 6.6%
Winnipeg River Basin	↑ 11.0%	↑ 11.1%	↑ 2.3%	↑ 7.7%
Lake Winnipeg Basin	↑ 11.0%	↑ 10.9%	↑ 1.4%	↑ 7.2%
Nelson River Basin	↑ 13.9%	↑ 10.0%	↑ 2.6%	↑ 7.2%
Nelson-Churchill Watershed	↑ 10.0%	↑ 10.3%	↑ 0.5%	↑ 7.3%

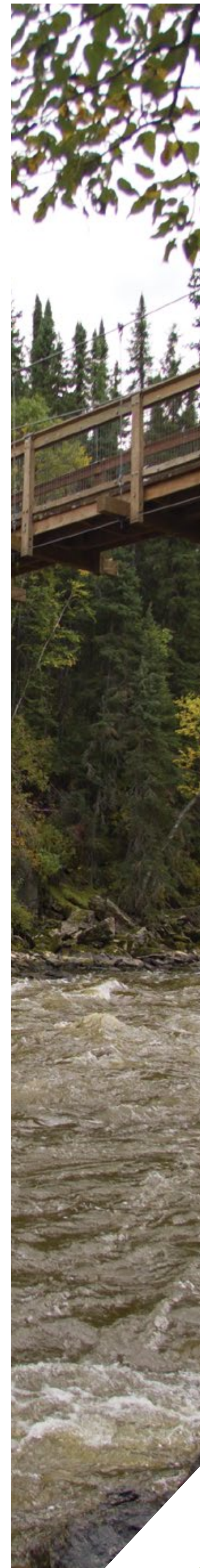


FIGURE 19: ILLUSTRATION OF ANNUAL 2050s TEMPERATURE PROJECTIONS ASSUMING LOWEST (LEFT) AND HIGHEST (RIGHT) EMISSION SCENARIOS RELATIVE TO 1981-2010

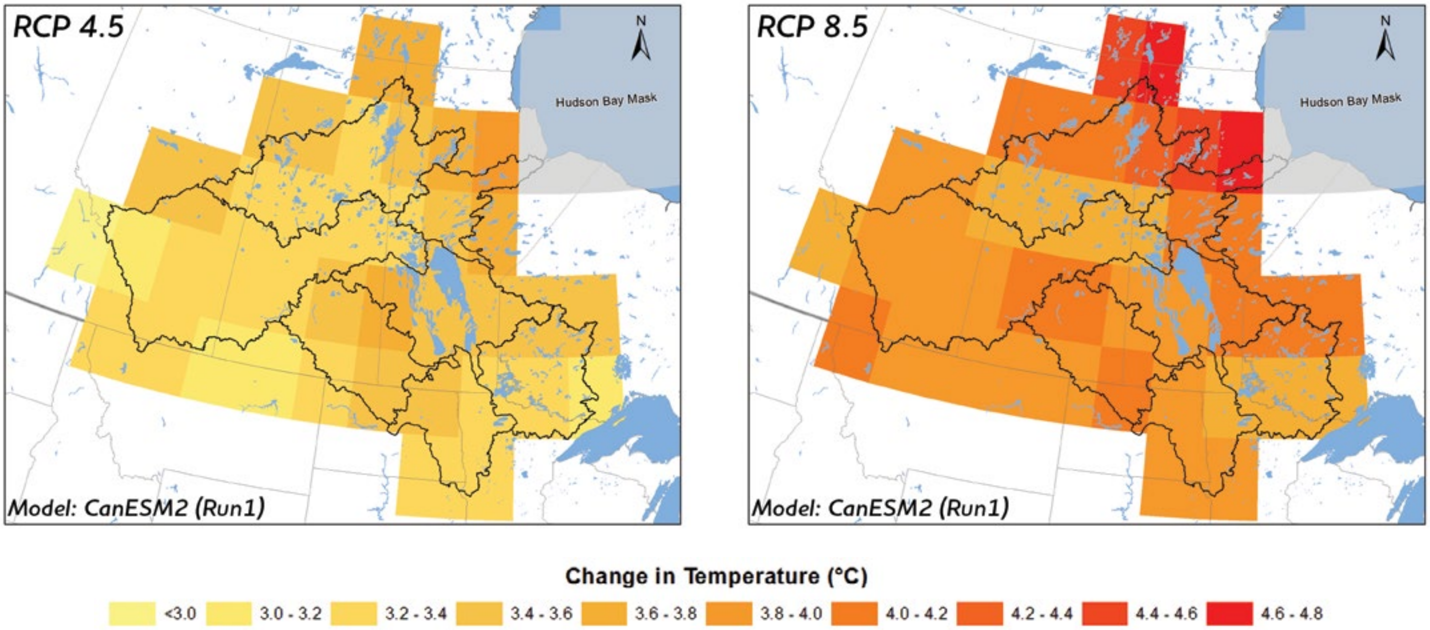
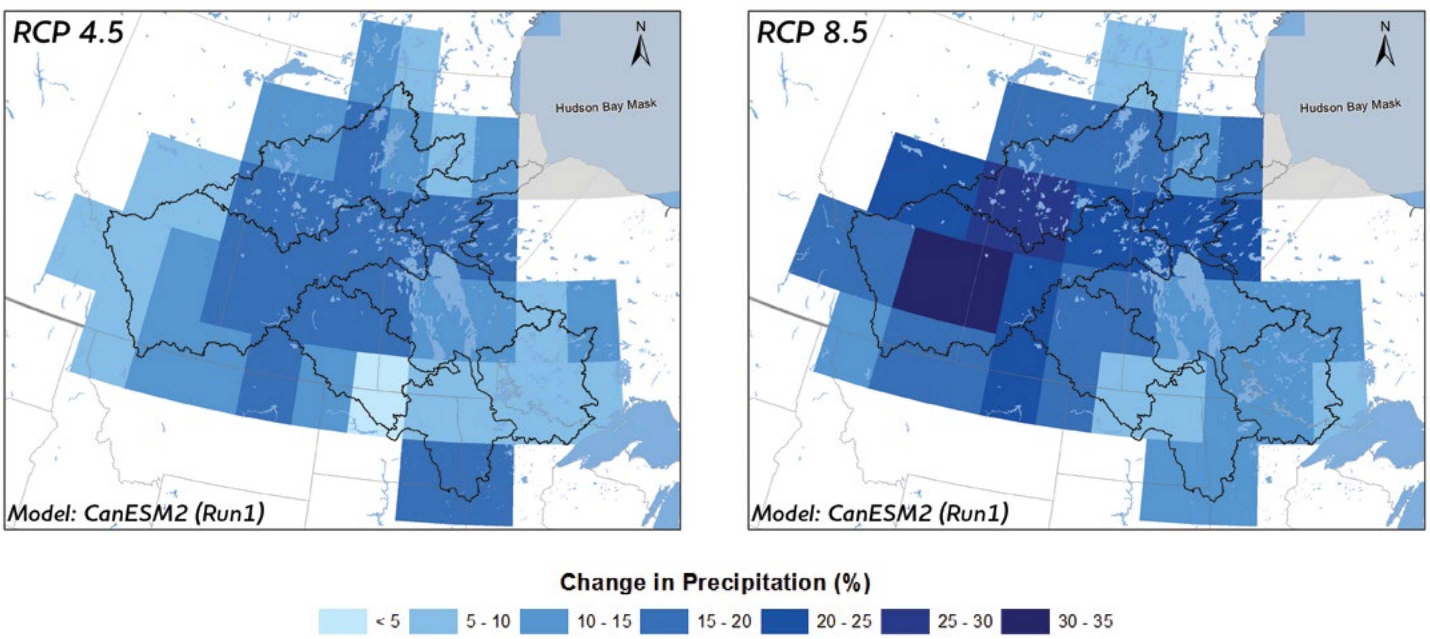


FIGURE 20: ILLUSTRATION OF ANNUAL 2050s PRECIPITATION PROJECTIONS ASSUMING LOWEST (LEFT) AND HIGHEST (RIGHT) EMISSION SCENARIOS RELATIVE TO 1981-2010



2.3.3 HYDROLOGICAL MODELING

Hydrologic models are simplified, conceptual representations of a part of the hydrologic cycle. They are primarily used for hydrologic simulation and for understanding hydrologic processes. These models numerically represent the physical processes observed in the real world and can include representations of surface runoff, subsurface flow, evapotranspiration, and channel flow.

Hydrological models are being developed for each of the river basins within the Nelson-Churchill Watershed (Winnipeg River, Red River, Assiniboine River, Saskatchewan River, Nelson River and Churchill River). Figure 7 shows the massive scale of the watershed and the key river basins being studied. The hydrological model selected for these studies is the WATFLOOD model which is a partially physically-based, distributed model that maintains a high computational efficiency and incorporates specialized processes (irrigation withdrawals in the Saskatchewan and dynamically calculated Lake St. Joseph diversions in the Winnipeg, for example) that are able to handle the complex and highly variable hydrologic influences throughout Manitoba Hydro's River Basins. A schematic of the general hydrologic processes simulated by the WATFLOOD model are shown in Figure 21. WATFLOOD allows for the incorporation of remotely sensed topographical, land cover, and soil information as well as meteorological forcing data to derive physically representative streamflow responses throughout the watershed.

2.3.4 FUTURE RUNOFF SCENARIOS

To assess climate change impacts on surface runoff, GCMs can be employed in several ways. One approach uses direct runoff output from the GCMs. GCM Runoff represents a spatial integrator of weather events over time and annual GCM runoff is used as a basic measure of water availability [Frigon, 2010]. However, the hydrological components of many current GCMs lack details such as river routing and lake routing and operate on coarse spatial resolutions. As such, a second approach combines GCM climate projections with a hydrological model to study finer details such as seasonal shifts in timing of water at finer temporal and spatial resolutions. These shifts in the streamflow hydrographs are then quantified with respect to current conditions.

Direct GCM Runoff:

Future runoff scenarios projected by GCMs for the Nelson-Churchill Watershed are derived by assessing the relative change in annual runoff from the simulated baseline (1981-2010) and the simulated future time period (2050s) for each basin. Changes in runoff (%) are shown in Table 7. Generally, for this time period, runoff is projected to increase across all the basins with the annual average projected change for the entire Nelson-Churchill Watershed at 9.7%.

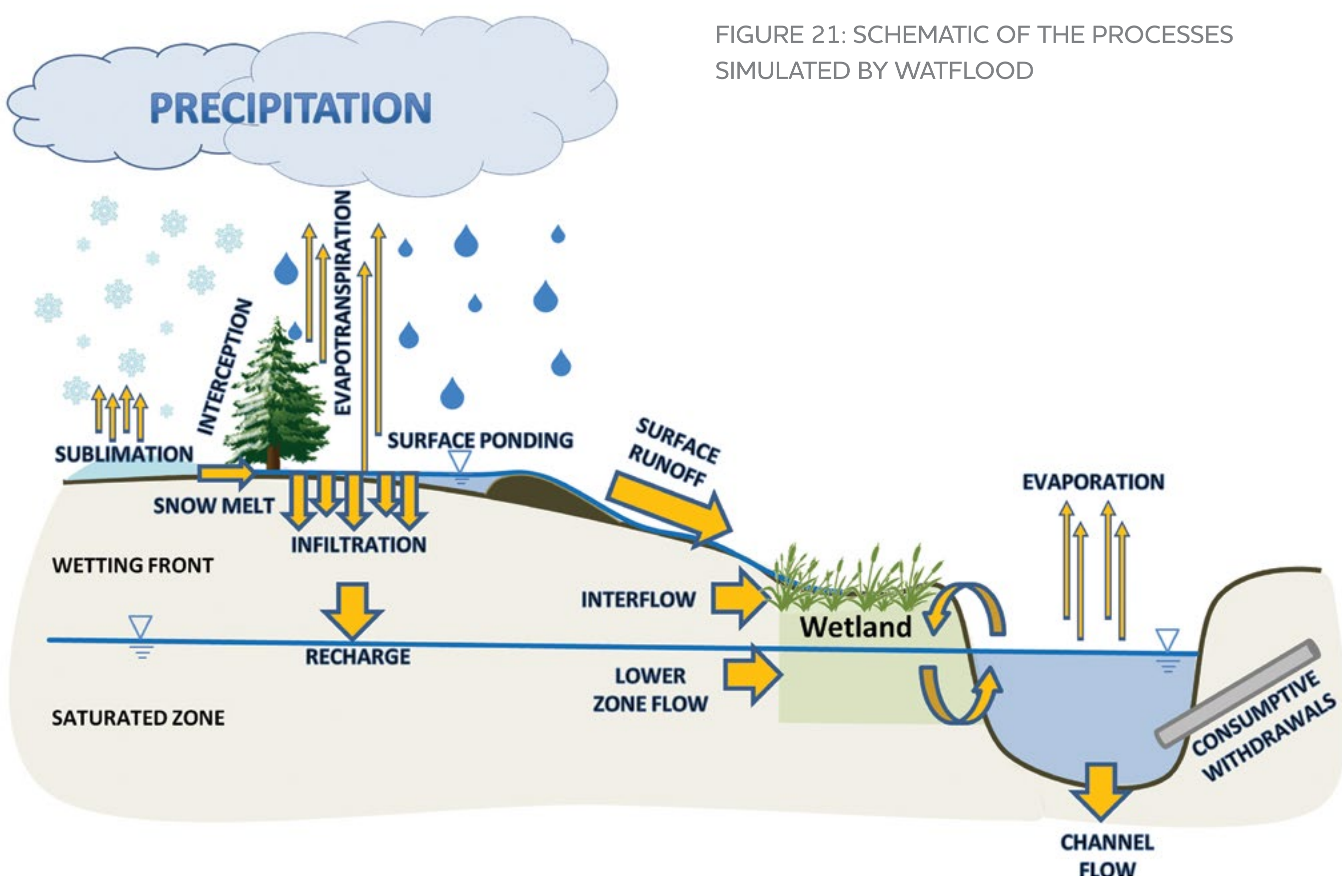


FIGURE 21: SCHEMATIC OF THE PROCESSES SIMULATED BY WATFLOOD

TABLE 7: GCM ENSEMBLE AVERAGE ANNUAL RUNOFF PROJECTIONS FOR THE 2050s RELATIVE TO 1981-2010

Basin/Watershed	Runoff
Churchill River Basin	↑ 7.9%
Saskatchewan River Basin	↑ 9.5%
Assiniboine River Basin	↑ 23.3%
Red River Basin	↑ 19.0%
Winnipeg River Basin	↑ 13.5%
Lake Winnipeg Basin	↑ 11.3%
Nelson River Basin	↑ 7.3%
Nelson-Churchill Watershed	↑ 9.7%

Hydrological Modeling Forced with GCM Projections:

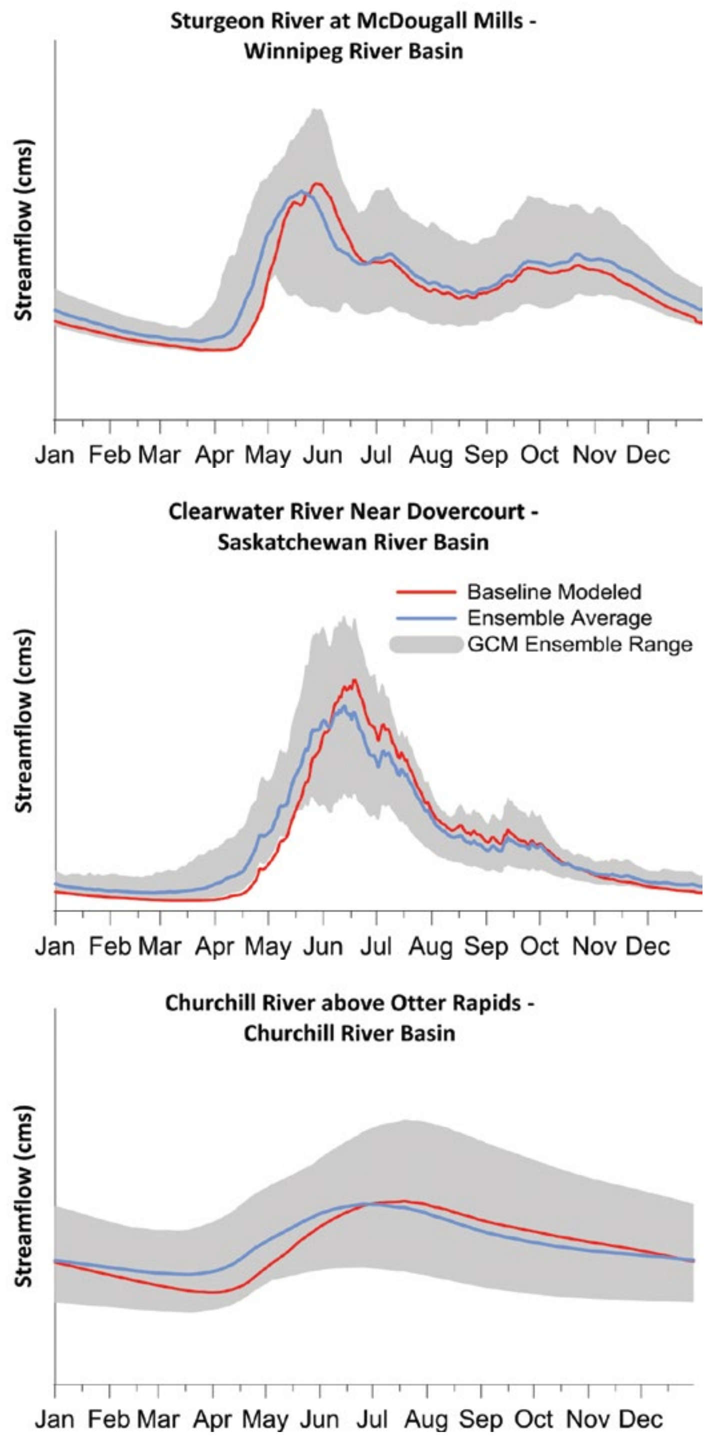
Future climate projections are implemented in a hydrological model (WATFLOOD) to analyze finer details about the future hydrological regime including changes to seasonal flows. Thirty year time-series of baseline climate conditions (1981-2010) are adjusted to represent the future (2040-2069: i.e., the 2050s) using the Delta Change method.

Figure 22 illustrates baseline and future projected hydrographs within the Winnipeg River, Saskatchewan River and Churchill River Basins. These figures illustrate smaller sub-basins which represent more natural, un-regulated, portions of the basins and show a picture of how climate change might impact the natural water regime. In general, the GCM ensemble average shows:

- Increased winter flows;
- Earlier spring freshet;
- Decreases or increases in summer and autumn flows, depending on the location.

Direct GCM runoff projections generally agree with hydrological model simulations that annual average streamflow will increase.

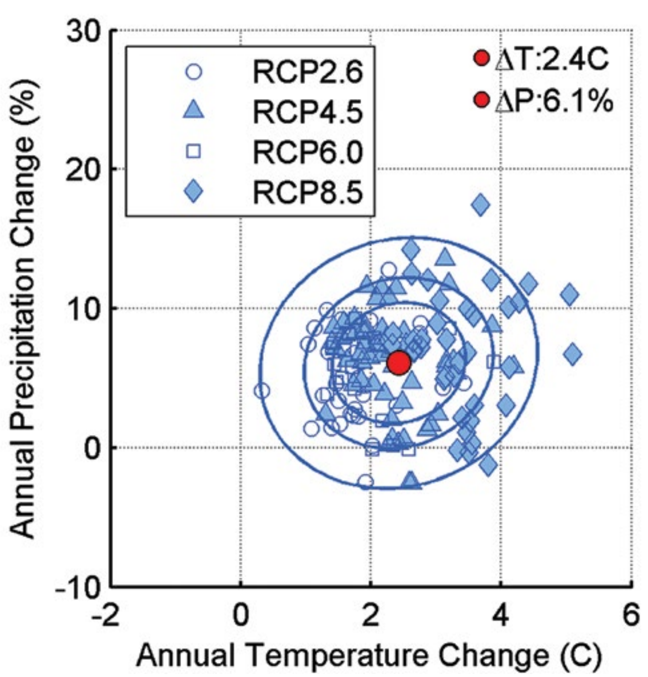
FIGURE 22: FUTURE STREAMFLOW PROJECTIONS FOR THE 2050s USING WATFLOOD



2.3.5 UNCERTAINTY IN FUTURE PROJECTIONS

Many sources of uncertainty exist in the modeling of future climate and must be considered when interpreting results. Sources of uncertainty include choice of emission scenario (RCP), GCM structure, natural climate variability, and downscaling technique [Chen et. al., 2011]. Figure 23 illustrates annual temperature and precipitation projections from 147 GCM simulations for the Nelson-Churchill Watershed in the 2050s, helping to illustrate some of the uncertainties. Distribution ellipses are imposed on the figures to illustrate model agreement. The inner, middle and outer ellipses contain 50%, 75%, and 95% of the simulations respectively. Future scenarios are typically summarized by presenting the ensemble average (red marker on Figure 23). However, it is important to consider the range as there is no way of evaluating which simulation best projects the 'real' future conditions. For example, since it is not possible to estimate all factors that influence future radiative forcing, the four RCPs are currently considered to be equally plausible. The actual future will depend upon many factors, such as efforts made towards reducing GHG emissions, technological advances, and economic development. Note however, that the four RCPs only start to diverge around the 2050s (Figure 15) and over a shorter-term horizon, the climate change signal is generally masked by natural climate variability. As such, Manitoba Hydro's Climate Change studies typically focus on the latter part of the 21st century.

FIGURE 23: PROJECTED CHANGES IN ANNUAL PRECIPITATION AND TEMPERATURE FOR THE 2050s RELATIVE TO 1981-2010 FOR THE NELSON-CHURCHILL WATERSHED



Additional sources of uncertainty exist in developing future streamflow scenarios. These uncertainties relate to hydrological model structure, parameter selection and assumptions about future withdrawals, regulation practices, and land use changes. Accessible information on projected climate impacts could contribute to future water resource management and planning changes, but there is a need to determine how best to interpret the set of scenario-based projections of future water availability so water managers like Manitoba Hydro can make the best decision.

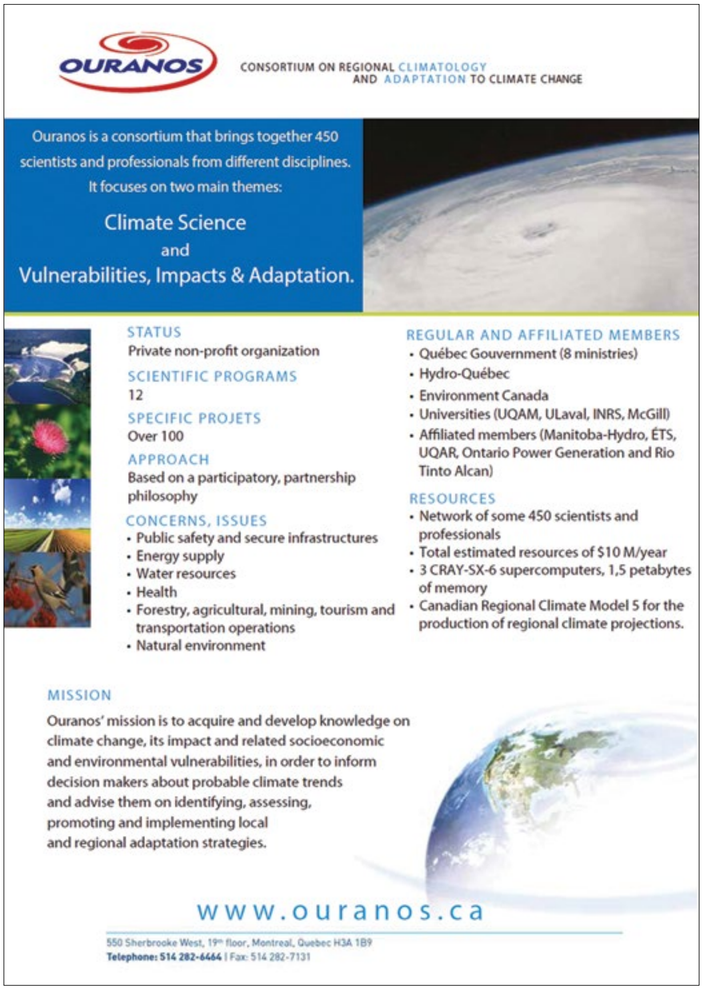
2.4 MEMEBERSHIPS, WORKING GROUPS, AND RESEARCH & DEVELOPMENT

As part of Manitoba Hydro's climate change strategy, Manitoba Hydro has been working with leading scientists in climatology and hydrology through memberships, working groups, and research and development projects to determine how climate change may affect its core business and the environment in which it operates. The following sections list a few of the areas that Manitoba Hydro is currently involved in:

Ouranos Consortium

Manitoba Hydro is an affiliated member of the Ouranos Consortium and actively participates in many of their research projects to stay informed about the latest advances in the climate science field. Ouranos is a research consortium that brings together more than 400 scientists and professionals from many disciplines, working in collaboration on regional climatology or climate change adaptation (Figure 24). Its activities are principally determined by the issues and needs facing its members, as well as by Quebec and Canadian government departments and institutions. Ouranos' mission is to acquire and develop knowledge on climate change, along with its impact and related socioeconomic and environmental vulnerabilities, in order to inform decision makers about probable climate trends and advise them on identifying, assessing, promoting and implementing local and regional adaptation strategies. There are 12 scientific programs (Climate Simulation and Analysis, Climate Scenarios and Services, Agriculture, Commercial Fisheries and Aquaculture, Built Environment, Ecosystems & biodiversity, Energy, Forest Resources, Health, Maritime Environment, Northern Environment, Tourism, Water Management) at Ouranos. Manitoba Hydro has a representative that actively participates on the Energy Program Committee and participates as a member on their Board of Directors.

FIGURE 24: OURANOS CONSORTIUM



Manitoba Inter-Departmental Climate Adaptation Working Group

The Provincial Inter-Departmental Climate Adaptation Working Group (IAWG) is tasked to strategically position the Province of Manitoba to address climate change impacts to achieve climate-resilient and sustainable economic development. To achieve this strategic goal the IAWG serves as the key institutional mechanism that fosters shared understanding of climate change impacts, communicates current and planned adaptation initiatives across government, and provides a forum for effective climate adaptation going forward within government and across Manitoba. Manitoba Hydro has a representative that actively participates in the IAWG.

Natural Resources Canada - Energy Program Working Group

Led by the Climate Change Impacts and Adaptation Division at Natural Resources Canada (NRCan) the Adaptation Platform brings together key groups from government, industry, and professional organizations to collaborate on adaptation priorities. The Platform structure includes a Plenary (the coordinating forum) and a series of Working Groups. Current Working Groups include: Science Assessment, Northern Canada, Measuring Progress on Adaptation, Coastal Management, Mining, Forestry, Energy, and Economics of Adaptation.

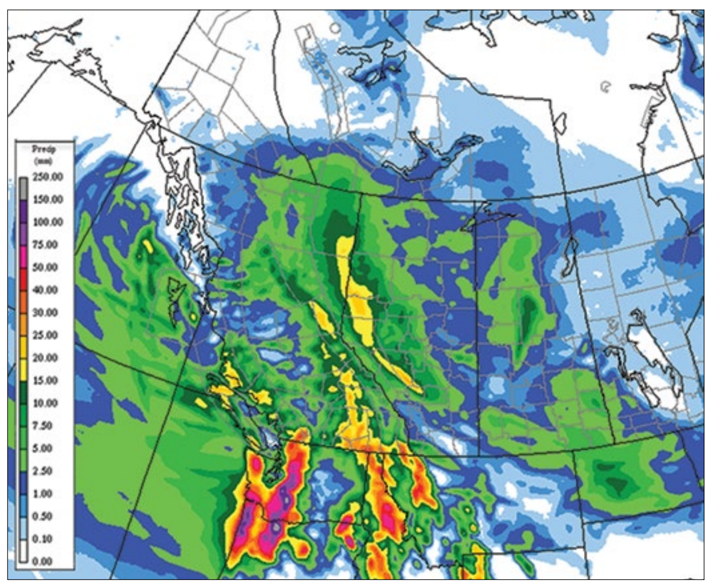
Manitoba Hydro has a representative that actively participates on the Energy Working Group. The purpose of the Energy Working Group is to design and deliver a Program of Work that addresses common issues and needs related to practical adaptation in the energy sector in Canada.

Canadian Precipitation Analysis for Hydrological Modeling at Manitoba Hydro

Collaborators: Environment Canada, University of Manitoba

The Canadian Precipitation Analysis (CaPA) is a computer optimization model that estimates precipitation based on a 15 km square grid representation of North America. CaPA integrates different sources of weather information, including ensemble precipitation and temperature forecasts, ground observations from synoptic stations, additional stations from cooperative networks, Geostationary Operational Environmental Satellite imagery and weather radar. CaPA has been designed to optimize precipitation to produce the most reasonable estimate possible. Further development of the CaPA domain will increase its utility within the Nelson-Churchill Watershed.

FIGURE 25: EXAMPLE OF CaPA MAP PRODUCT



Current research will enhance the CaPA product for the entire Nelson-Churchill Watershed. Once fully developed CaPA will then be combined with existing watershed models to improve the climate change induced future streamflow projections. In addition to facilitating climate change projections, the development of the CaPA has the potential to improve Manitoba Hydro's short-term operating modeling to enhance efficiency and profitability.

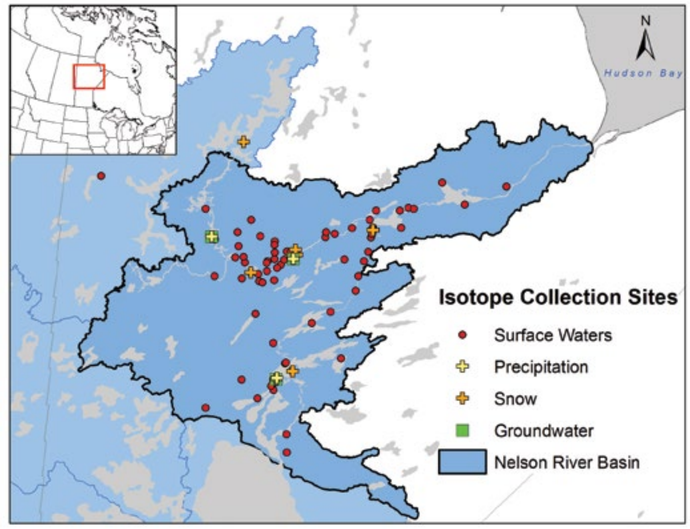
Water Availability Assessment in the Nelson River Basin Using a Coupled Water-Isotope Approach - Phases II and III

Collaborators: University of Manitoba, Water Survey of Canada, Lake Winnipeg Research Consortium

Physically-based watershed modeling offers increased confidence in future flow projections. The modeling simulates an environment's response to changes in hydrological inputs (various climates) and the interconnecting processes generating streamflow. However, the models are only as accurate as their calibrations to the natural environment. It is important that the models are simulating the streamflow for the right reasons and most closely represents reality (i.e., water is apportioned correctly throughout the entire hydrologic cycle). Research to improve hydrological model calibration has resulted in the capability to simultaneously model isotope tracers within the hydrological model framework. These models generate more physically-representative, less uncertain simulations of runoff and streamflow by improving calibration using stable isotopes. The calibration approach is ideal for remote, seasonally variable river basins where streamflow measurement is often sporadic, seasonal, and unreliable for model calibration. Once isotope data has been collected in a river system, this modelling methodology can be applied to produce a more physically-sound model of the river system and its sources of water, reducing uncertainty in flow predictions.

Water isotope sampling has been underway in the Nelson River Basin at Manitoba Hydro since 2010 (Figure 26) and is integrated with current hydrometric field visits by Manitoba Hydro staff. The isotope samples aid in distinguishing water sources and examines the progressive downstream evolution of streamflow on a regional scale. The goal of this research is to continue collecting stable water isotopes in the Nelson River Basin to provide a comprehensive record of isotopic variability associated with different hydrologic conditions. The coupled isotopic-hydrologic record will then be used to improve calibration of the Nelson River Basin model. This will result in more accurate simulations of future streamflows under climate change because there is more certainty that the watershed model is simulating streamflow for the correct reasons, from the right hydrologic components.

FIGURE 26: ISOTOPE COLLECTION SITES FOR THE NELSON RIVER BASIN



Probable Maximum Precipitation and Its Impact on Probable Maximum Flood: Climate Change Proof Dam Safety Assessments

Collaborators: Ouranos, NRCan, Hydro-Quebec, Centre d'expertise hydrique du Québec, Hydro Québec Institut national de la recherché scientifique Eau-Terre-Environnement, Rio Tino Alcan, Ontario Power Generation,

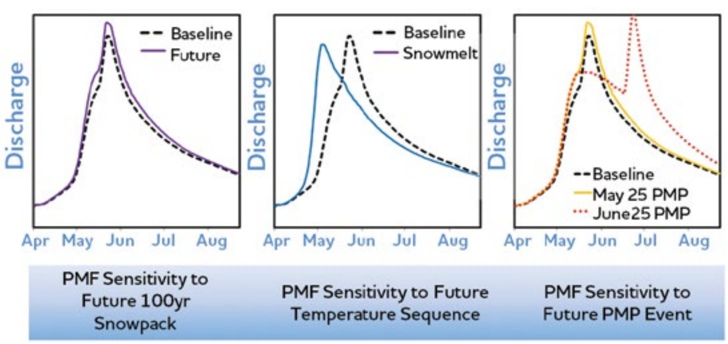
For major dams or for those whose failure may cause loss of life or significant economic losses the Probable Maximum Precipitation (PMP) and the Probable Maximum Flood (PMF) are criteria commonly used in their design and safety analyses. The PMF is typically estimated to be the flood generated by the most severe precipitation event possible at a site at a particular time of year (referred to as the PMP). The PMF can also be a function of snow accumulation, snow melt sequencing, and upstream reservoir releases. Analysis of the observed records and future climate model projections indicate that the occurrence and frequency of extreme precipitation events are increasing. In addition, recent studies indicate that both the PMP and PMF are sensitive to climate change and establishing future projections of these extreme variables poses challenges for both researchers and practitioners. This project seeks to provide Canadian dam managers with estimates of maximized precipitation using numerical climate simulations that account for climate change. These estimates will be used by hydroelectric collaborators to compute PMFs for a diverse set of Canadian watersheds used for energy production.

Evaluation of Probable Maximum Flood (PMF) Scenarios under Climate Change for the lower Nelson River System

Collaborators: University of Manitoba, Ouranos

The goals of this research are to project the sensitivity of PMF scenarios to projected changes to the climate in the Nelson River Basin, and to quantify the level of uncertainty of these estimates related to hydrological model selection, structure, and parameterization. The scope of this work includes estimation of PMP and PMF within the lower Nelson River Basin domain for present day and the 2050 time horizon (2040-2069). The scope also includes consideration of changes to snowpack, PMP timing, melt sequencing, and upstream releases. The work will utilize existing RCMs and GCMs, relying on project outcomes from the "Probable Maximum Precipitation and its impact on Probable Maximum Flood: Climate Change Proof Dam Safety Assessments" project to guide design storm sequences representative of the PMP event and other antecedent hydrometeorological input (Figure 27).

FIGURE 27: CONCEPTUAL PMF SIMULATION



Adaptation Case Studies in the Energy Sector

Collaborators: Ouranos, NRCan, Hydro-Quebec

The primary objective of the project is to document successful climate change adaptation efforts across the energy sector in order to highlight the barriers to adaptation and how they can be overcome. The secondary objective is to understand how climate information is converted into decision-making output in order to provide better support to stakeholders in this area.

A Testbed for an Advanced Decision Making Protocol: From Climate Change Scenarios to Decisions on Hydropower Investment

Collaborators: Ouranos, NRCan , Hydro-Quebec

Increasing scrutiny has been placed on decisions by hydro power utilities for new construction projects or infrastructure upgrades, especially in regards to incorporating climate change impact assessment in the analysis of the project. This project will explore the methodology used to undertake climate change impact assessments and how to best incorporate results into decision making frameworks. This methodology can potentially support decisions regarding new construction projects or upgrade existing infrastructure.

Projected Climate Change Impacts on Energy and Peak Demand in Manitoba

Collaborators: Ouranos, NRCan, Pacific Climate Impacts Consortium, Province of Manitoba

Projected temperature changes can impact energy demand patterns. As temperatures increase, the demand for energy used to heat buildings decreases while the demand for energy used to cool buildings increases. A greater understanding of their projected changes, variability in time and space, and uncertainties can facilitate future resource planning, development of adaptation strategies, and identification of opportunities. This project summarizes current practices and future projections of energy and peak demand for future temperature scenarios in Manitoba, including potential impacts, adaptation strategies, and opportunities.

Global Climate Model Simulated Hydrologic Droughts and Floods in the Nelson-Churchill Watershed

Collaborators: University of Manitoba

GCM simulated hydrology can improve Manitoba Hydro's understanding of the observed hydrologic record and how it compares to natural variability in a stationary climate and future projections under climate change. Collaborative research between Manitoba Hydro and the University of Manitoba is coupling 738 year simulations of daily GCM runoff with a modified version of the WATROUTE routing model for the entire Nelson-Churchill Watershed. Five GCMs, some with multiple members, and two future forcing scenarios provide information about uncertainty. Analysis of bias corrected streamflow output will aid the understanding of how observed multi-year hydrologic droughts and floods compare to a longer record and how they are projected to change into the future.

BaySys - Contributions of Climate Change and Hydro-Electric Regulation to the Variability and Change of Freshwater-Marine Coupling in the Hudson Bay System

Collaborators: University of Manitoba, Ouranos, National Sciences and Engineering Research Council, ArcticNet, Hydro Quebec, University of Quebec at Rimouski, Laval University, Trent University, University of Calgary, University of Northern British Columbia

Manitoba Hydro and the University of Manitoba are collaborating on a research project to assess the relative effects of climate change and hydroelectric regulation of freshwater flows on the physical, biological, and biogeochemical conditions in the Hudson Bay. Results from this project will aid in the assessment of impacts of climate change on water supply, and increase the understanding of the effects of climate change and regulation on northern ecosystems, which are key pillars of the Manitoba Hydro's climate change strategy. Manitoba Hydro's operations are linked to Hudson Bay through the Churchill River Diversion and Lake Winnipeg Regulation projects. The research will benefit Manitoba Hydro by enhancing the quality and capacity of corporate climate science, adding to its knowledge of the Hudson Bay, strengthen its goals of sustainable development, and support corproate climate change and GHG strategies. The research will provide high quality data useful in developing environmental assessment predictions, refining regulatory compliance standards, and helping to define mitigation and adaptive follow up monitoring programs. Collaborating with universities on climate change and watershed modeling is beneficial from both an environmental and energy supply and risk perspective.

FIGURE 28: HUDSON BAY DRAINAGE BASINS

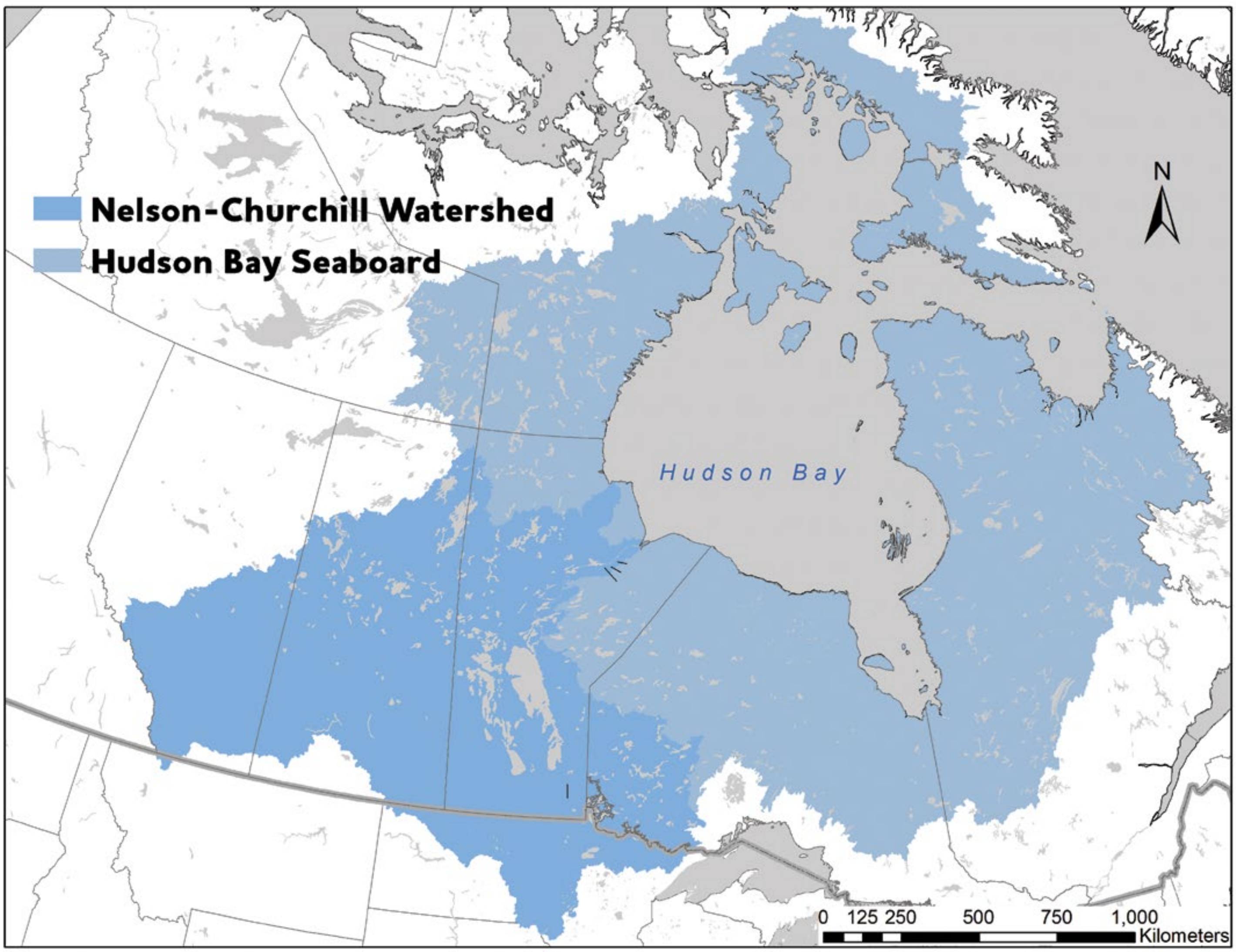
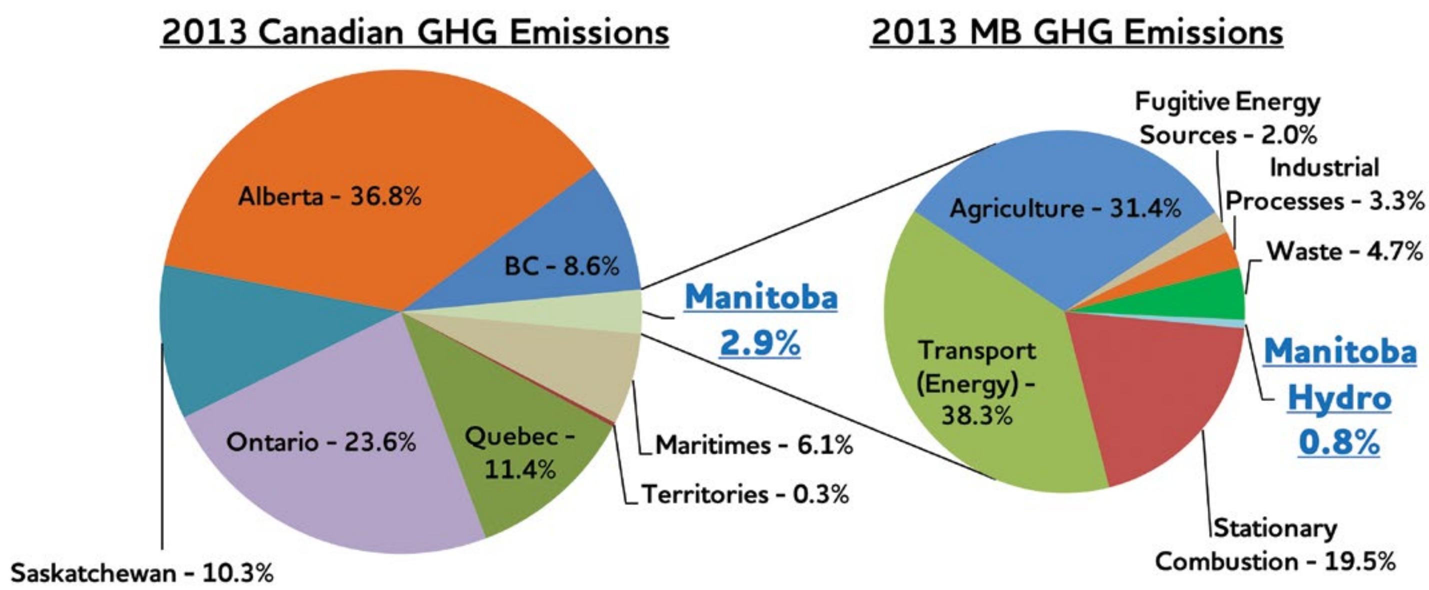


FIGURE 29: 2013 CANADIAN AND MANITOBA GHG EMISSIONS [ENVIRONMENT CANADA, 2015]



3 GHG MEASUREMENT AND REPORTING

Accurate GHG measurement and reporting are integral in ensuring that Manitoba Hydro understands its emission liabilities, identifies opportunities for further reductions, and demonstrates the results of actions taken. Manitoba Hydro began measuring and reporting its corporate GHG emissions in 1995 and has set aggressive voluntary emission reduction targets. Since Manitoba Hydro began its voluntary reporting efforts both the Provincial and Federal governments have introduced mandatory reporting requirements for some of Manitoba Hydro's facilities.

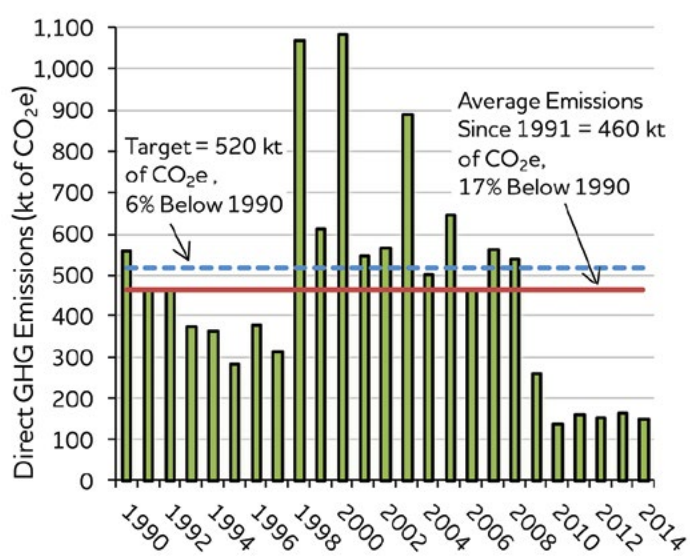
Manitoba Hydro also estimates the GHG implications of its major projects using Life Cycle Assessments (LCAs). All forms of electrical generation, including generation from renewable sources, have GHG implications when a facility's design, construction, land-use impact, operation, and decommissioning are all considered. This chapter presents measurement and reporting of emissions, voluntary commitments, as well as the LCAs associated with major projects.

3.1 VOLUNTARY REPORTING

Manitoba Hydro's emissions are small. Figure 29 demonstrates that they represent less than 1% of provincial emissions within a province that represents less than 3% of national emissions.

Despite Manitoba Hydro's initial low emissions starting point, the corporation has achieved substantial further reductions. While national electricity sector emissions have averaged 15% above 1990 levels since 1991, Manitoba Hydro has achieved an average long-term emissions reduction of 17% over the same time period, as shown in Figure 30 [Environment Canada, 2015].

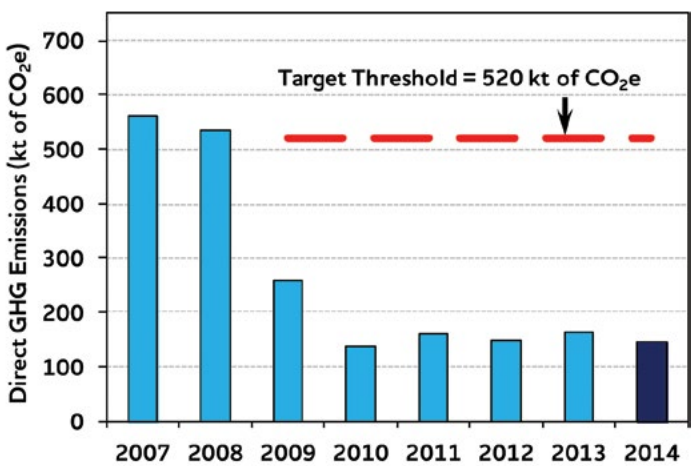
FIGURE 30: MANITOBA HYDRO DIRECT EMISSIONS RELATIVE TO TARGET (1990-2014)



The scope of Manitoba Hydro's voluntary GHG reporting is broad and includes direct emissions from the following sources: fossil fuelled electric generation, natural gas transmission and distribution, fleet vehicles, sulphur hexafluoride (SF_6), and natural gas combusted in buildings. Manitoba Hydro's voluntary commitment maintains an annual GHG emission target threshold of 520 kilotonnes (kt) of carbon dioxide equivalent (CO_2e), representing GHG emissions six per cent below 1990 levels. In the 2014 calendar year, total direct GHG emissions were 147 kt CO_2e, 72% below the target threshold. Figure 31 depicts Manitoba Hydro's recent performance relative to the voluntary commitment.

Electric generation accounted for 54% of all corporate GHG emissions in 2014, with fleet vehicles and natural gas operations at 14% and 19% respectfully. The remaining 13% was a result of emissions from insulating gas for electrical equipment (SF_6), diesel power generation for remote northern communities, and natural gas used in buildings owned by Manitoba Hydro. The GHG emission contributions of each of these sources are shown in Figure 32. Manitoba Hydro's activities result in emissions of CO_2, CH_4, N_2O, and SF_6; these GHGs are expressed in CO_2e as calculated using their appropriate Global Warming Potential (GWP) factors [Environment Canada, 2013].

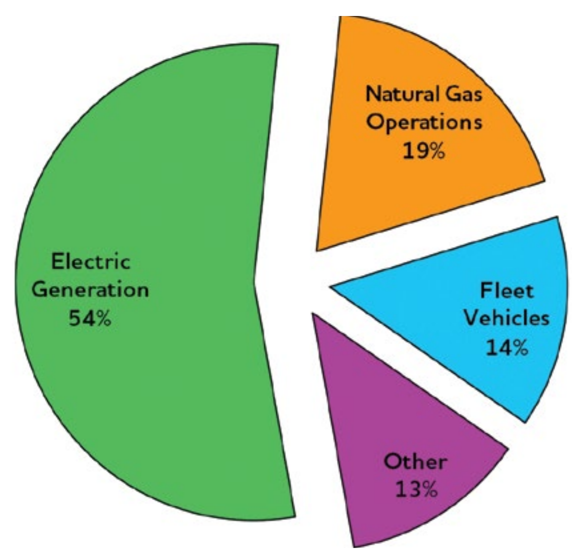
FIGURE 31: MANITOBA HYDRO DIRECT EMISSIONS RELATIVE TO TARGET



3.2 MANDATORY REPORTING REQUIREMENTS

Both the federal and provincial governments have requirements to report certain GHG emissions. In compliance with their respective Environmental Act Licenses, the provincial government requires that Manitoba Hydro report the total direct GHG emissions associated with electric generation from each of the fossil fueled units at the Selkirk and Brandon generating stations. Federally, Environment Canada requires reporting on GHG emissions from Canadian facilities through its Facility Greenhouse Gas Emissions Reporting Program. This reporting program is under the authority of Section 46 of the Canadian Environmental Protection Act, 1999, and has collected GHG information on an annual basis since 2004. Canadian facilities that emit GHGs over a 50,000 tonnes of CO_2e threshold are required to formally report the source, type, and quantity of those emissions, as per provided reporting protocols [Environment Canada, 2013b]. To date, within Manitoba Hydro's portfolio only the GHG emissions associated with Brandon G.S. have met this minimum reporting threshold.

FIGURE 32: MANITOBA HYDRO GHG EMISSIONS BY SOURCE: 2014 ACTUAL EMISSIONS



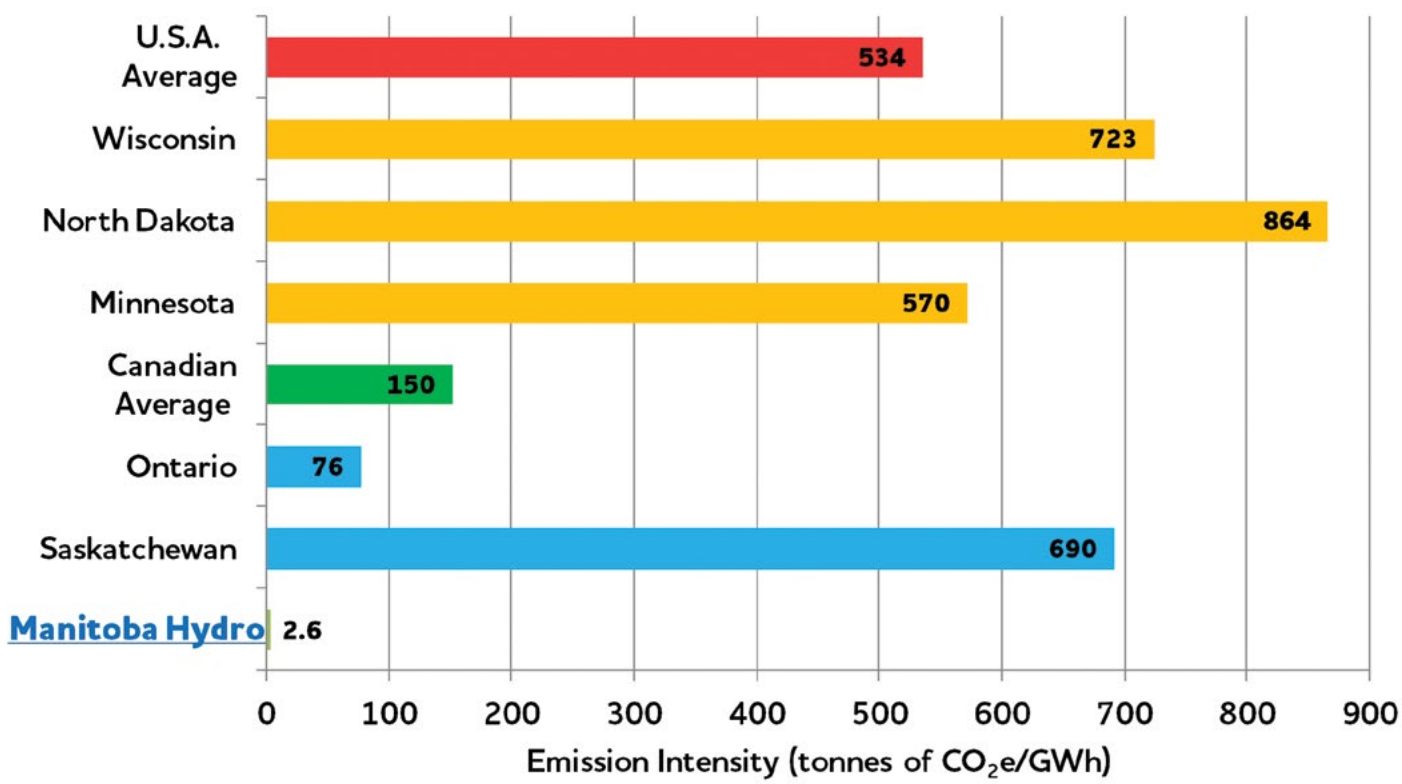
3.3 GLOBAL EMISSION REDUCTIONS

Manitoba Hydro operates an electrical system that facilitates the production and sale of surplus electricity to interconnected neighbouring jurisdictions. As a result, electricity production and use in Manitoba can impact GHG emissions both inside Manitoba (the provincial perspective) and outside of Manitoba as export sales displace electric generation and associated emissions in interconnected regions. The combined implication of the GHG emissions within and outside of the province is referred to as Manitoba Hydro's global GHG perspective. The most significant contribution that Manitoba Hydro makes toward GHG reductions is facilitating the displacement of fossil fuelled generation in neighbouring states and provinces.

Figure 33 compares the generation emission intensity of Manitoba Hydro with interconnected jurisdictions. As is shown in Figure 33, Manitoba Hydro's low emission intensity makes their exports a valuable resource to help reduce global GHG emissions. When considering incremental changes to electricity consumption through energy efficiency, or fuel switching applications, Manitoba Hydro evaluates these decisions based on the global GHG consequences. Manitoba Hydro has assumed a factor of 750 tonnes CO_2e/GWh since 2006, which reflects a conservative estimate of the incremental GHG emission effects of consumption changes within the broader interconnected regional electricity market. Analysis has indicated that the 750 tonnes CO_2e/GWh factor will remain conservative for the next decade, and beyond [The Brattle Group, 2014].

In 2014, electricity exports from Manitoba reduced net global GHG emissions by an estimated 6,600 kt of CO_2e. According to typical passenger vehicle GHG emission estimates from the U.S. Environmental Protection Agency (EPA), this is equivalent to removing nearly 1.4 million vehicles from the road [U.S. EPA, 2014].

FIGURE 33: GHG EMISSION INTENSITY COMPARISON OF ELECTRICITY GENERATION: 2013 (ENVIRONMENT CANADA, 2015; UNITED STATES ENERGY INFORMATION ADMINISTRATION, 2015)



3.4 RESERVOIR MONITORING

Due to the potential uncertainty of hydroelectric reservoir emissions, direct reservoir monitoring is very important. Starting in 1999, Canada's Department of Fisheries and Oceans started sampling GHG concentrations in the forebay water areas of some of Manitoba Hydro's hydroelectric generating facilities. Building on this pioneering work, Manitoba Hydro has taken over and continues to study GHG dynamics in Manitoba hydroelectric reservoirs as well as other Manitoba water bodies. Manitoba Hydro's continuous monitoring program commenced in 2003 and has continued since.

Manitoba Hydro's work has included continuously monitoring aquatic GHG concentrations at five existing generating stations, representing mature reservoirs on three river systems: The Winnipeg, Saskatchewan, and Nelson Rivers. Manitoba Hydro has conducted pre and post construction aquatic GHG monitoring upstream and downstream of the recently completed Wuskwatim G.S., has monitored pre-construction GHG concentrations in the Keeyask region with post-construction monitoring planned, and has monitored baseline GHG concentrations in the vicinity of the proposed Conawapa G.S. site.

Manitoba Hydro's reservoir monitoring efforts continue to indicate that GHG emissions are not a significant issue for the planned hydroelectric facilities in Manitoba, in part due to the minimal amount of flooding and limited impacted forested areas. Future monitoring will help confirm whether assumptions made regarding the impact of flooded peat in the Keeyask area will be correct.

3.5 RESEARCH & DEVELOPMENT SUPPORT

GHG measurement and calculation techniques are constantly evolving. In addition to being up to date on recent industry developments, Manitoba Hydro directly supports and participates in research and development efforts.

The Canadian Energy Partnership for Environmental Innovation (CEPEI)

CEPEI is the environmental technical committee of the Canadian Gas Association (CGA) and Manitoba Hydro has been a long-time active committee member. CEPEI member companies collaborate to develop technical information to meet the increasing demands of regulatory and public reporting. This work has directly influenced GHG calculation methodologies used by Manitoba Hydro.

Through CEPEI supported research an air emissions methodology manual was developed which details the most recent, and best available, methodologies for quantifying GHG and other air emissions from natural gas transmission and distribution operations. This manual provides a standardized but flexible framework to help CGA member companies, including Manitoba Hydro, prepare air emission inventories. Ongoing research leads to the manual being updated regularly, including with the most recent emission factors.

GHGSat

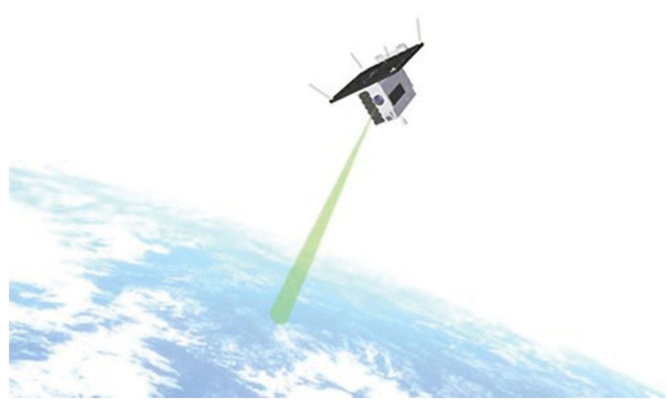
Manitoba Hydro is sponsoring a project with GHGSat to assess GHGSat's innovative satellite-based remote sensing technology to measure GHG emissions from Manitoba Hydro's hydroelectric reservoirs and thermal generating stations.

Instantaneous concentrations of CO_2 and CH_4 will be measured in the atmosphere above the planned Keeyask reservoir and the Brandon G.S. The satellite launch is planned for late 2015 and will provide Manitoba Hydro with measurements approximately every two weeks for one year.

GHGSat data will be compared to Manitoba Hydro's on-the-ground reservoir GHG monitoring results and to the corporation's GHG estimates from the Brandon G.S.

While the GHGSat technology needs to be tested and proven, this type of technology has the potential to augment Manitoba Hydro's reservoir GHG monitoring program and GHG emission estimates from thermal operations, provide improved spatial monitoring coverage for large watershed areas, reduce ground-level GHG monitoring costs, and minimize the health and safety risks associated with conducting field work in aquatic and remote areas.

FIGURE 34: CONCEPTUAL REPRESENTATION OF GHGSAT



3.6 LIFE CYCLE ASSESSMENTS (LCAs)

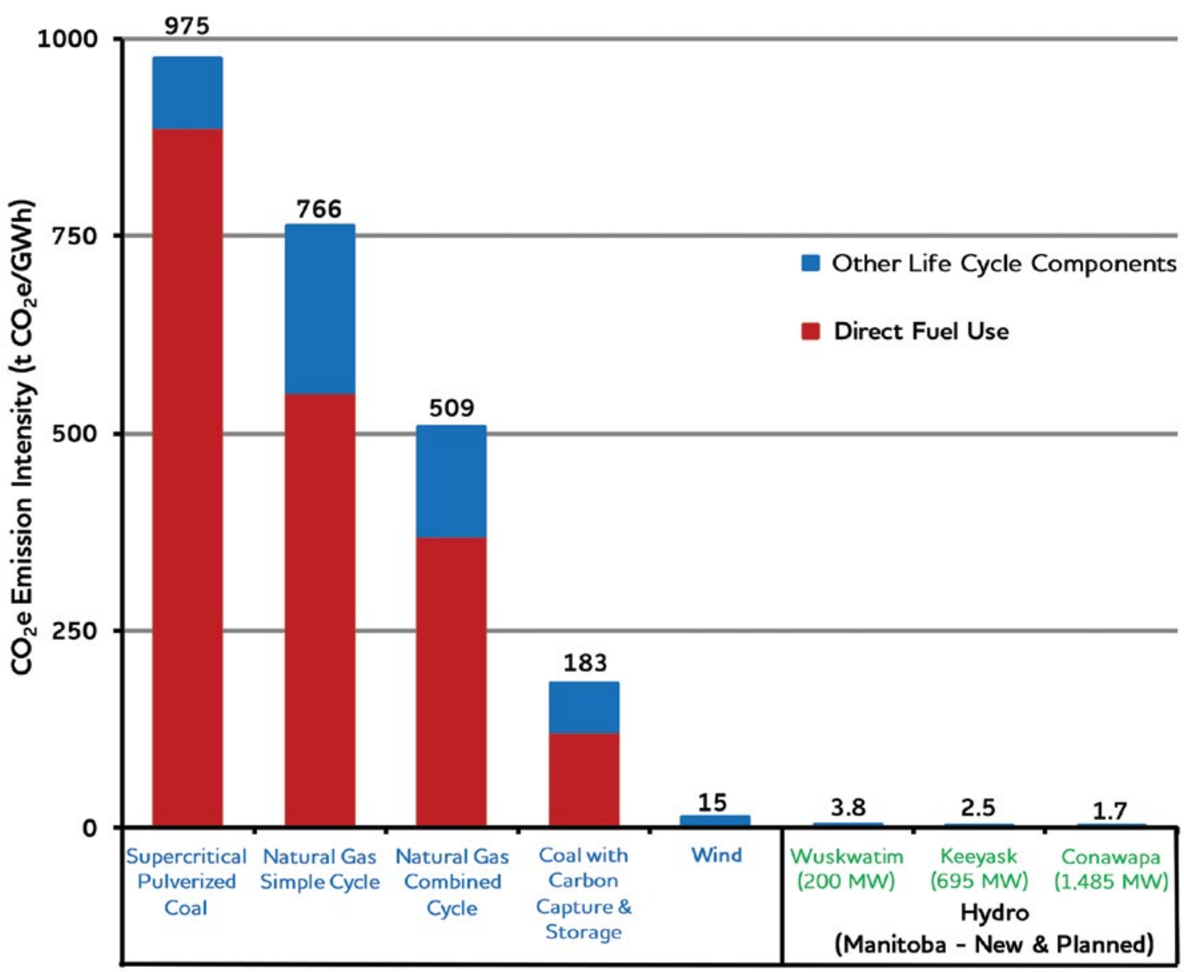
For new major facilities being constructed, a detailed LCA of the GHG implications is undertaken. The LCA process assesses the GHG emission implications throughout a facility's life, not just GHG emissions resulting from direct fuel use. These assessments help screen and evaluate different resource types as part of the power planning process, as well as meeting regulatory requirements such as Environmental Impact Studies. Manitoba Hydro worked with the Pembina Institute to assess the life cycle GHG implications of major projects such as the Wuskwatim, Keeyask, and Conawapa Generation Projects and Bipole III. The Manitoba-Minnesota Transmission Project is currently undergoing a LCA.

These scientific studies follow the International Organization for Standardization 14040 principles and framework (International Organization for Standardization, 2006) utilizing a complete "cradle to grave" analysis of the GHG emissions. A LCA fully considers GHG implications of all aspects of a project:

- Construction components and materials used (including emissions from raw material extraction, production, and transportation);
- Construction activities and equipment operation on site and worker transport (primarily vehicle fuel);
- Land clearing and other land-use change impacts (including reservoir formation);
- Operation throughout the life of the project including emissions associated with maintenance activities and the use of fossil fuels;
- Impacts associated with ultimately decommissioning the project

Use of LCAs ensures all the significant GHG impacts of a project are considered and allows for an equitable comparison between both conventional and renewable electricity generating technologies. For fossil fuel generators, such as coal and natural gas, assessment reveals that life cycle GHGs are dominated by emissions from the fuel needed to generate power (Figure 38). In comparison, for renewable sources such as wind and hydro, the bulk of life cycle GHGs are associated with the construction stage and land-use change.

FIGURE 35: COMPARISON OF LIFE CYCLE GHG EMISSIONS [PEMBINA INSTITUTE, 2003; PEMBINA INSTITUTE, 2010; PEMBINA INSTITUTE, 2013]



The GHG implications of each project are unique depending on the results of analysis of the above parameters. For example, Figure 36 and Figure 37 illustrate the GHG emissions by primary activity for the Keeyask Generation Project (in construction) and Conawapa Generation Project (potential project). In the case of the Keeyask Generation Project, the majority of GHG emissions are associated with land-use change implications and the production of raw building materials needed for construction of the facility. This is not the case for the Conawapa Generation Project because its land-use change and flooding implications are minimal: 87% of Conawapa's emissions are associated with construction.

One component of these assessments is land-use change, including the reservoir formation associated with new hydroelectric facilities. The GHG emissions associated with flooding are often misrepresented. All bodies of water naturally produce and release varying levels of GHGs (Tremblay et al., 2004). If a significant amount of biomass is flooded during reservoir formation, GHG emissions will increase. However, scientific research has shown that emissions are modest in northern ecosystems and return to natural levels within about 10 years. The Pembina Institute's LCAs, summarized in Figure 35, fully include these implications and demonstrate that reservoir GHG emissions are small for Manitoba Hydro's projects. Also, based on the vintage of the majority of Manitoba's hydropower generation, the reservoir implications associated with existing Manitoba Hydro facilities are long over.

To put their emission intensities into perspective, an identically sized combined cycle natural gas facility produces more GHG emissions in its first 100 days of operation than the proposed Conawapa hydropower station would over its entire 100 year expected life. In order for North America to achieve reductions in GHG emissions it is necessary to reduce fossil fuel dependence and develop renewable sources of electricity, such as hydropower.

4 CONTRIBUTE TO GHG EMISSION REDUCTIONS

Responding to climate change requires a diversity of sustained actions throughout the local to global continuum. As shown previously in Figure 33, Manitoba Hydro has very low electric generation GHG intensity relative to other electrical utilities. Despite this advantageous starting position, the corporation has set aggressive voluntary emission reduction objectives over the past seventeen years. Manitoba Hydro has continued to pursue hydro and wind developments, along with Power Smart energy efficiency programs, while also reducing emissions from its facilities within the province. Outside of Manitoba, Manitoba Hydro's electricity exports have contributed to significant GHG emission reductions.

FIGURE 36: KEEYASK GENERATION PROJECT LCA RESULTS – GHG EMISSIONS PER PRIMARY ACTIVITY [PEMBINA INSTITUTE, 2010]

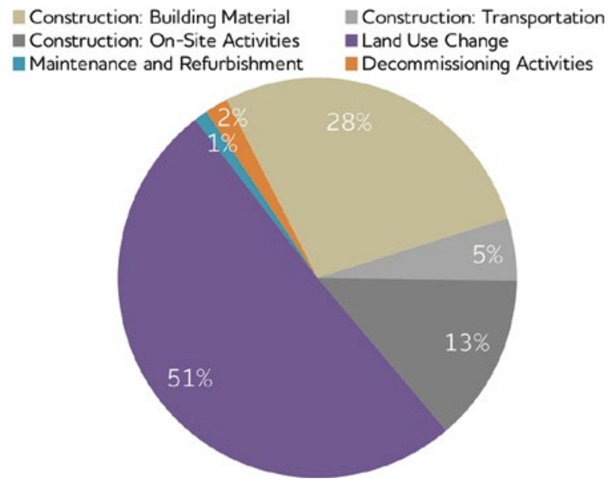


FIGURE 37: CONAWAPA GENERATION PROJECT LCA RESULTS – GHG EMISSIONS PER PRIMARY ACTIVITY [PEMBINA INSTITUTE, 2013]

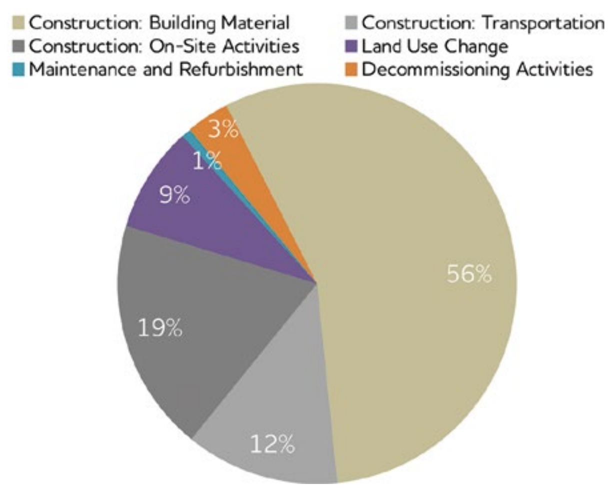
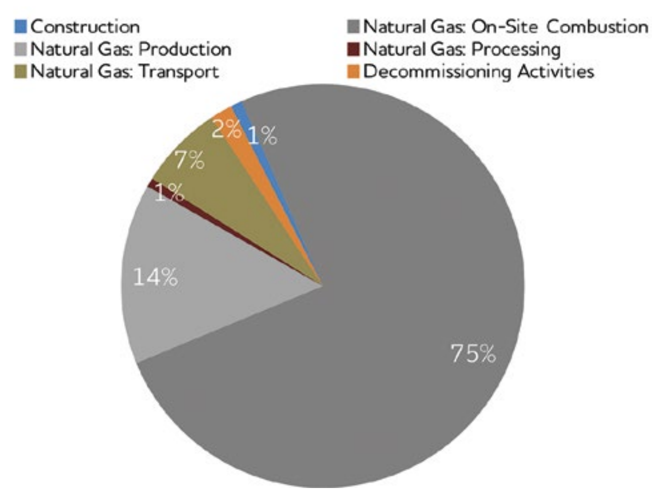


FIGURE 38: NATURAL GAS COMBINED CYCLE PLANT: LITERATURE SURVEY OF LCAs – GHG EMISSIONS PER PRIMARY ACTIVITY [PEMBINA INSTITUTE, 2013]



4.1 REDUCTIONS IN FOSSIL FUELED GENERATION

Manitoba Hydro has been able to reduce its dependence on fossil fueled electrical generation by increasing its reliance on renewable generation and energy conservation. Prior to the mid-1990s, Manitoba Hydro operated seven coal-generating units located at Brandon G.S. and Selkirk G.S. As an outcome of the Environment Act's licensing process, four of the five units at Brandon G.S. were shut down by 1996, eventually being replaced by two new natural gas units in 2002. At the Selkirk G.S., both units were converted from coal to natural gas. The latter action received an Honorable Mention in the 2002 Canadian Council of Ministers of the Environment Pollution Prevention Awards – Greenhouse Gas Reduction Category.

Since December 31, 2009, the Province of Manitoba's Climate Change and Emissions Reductions Act (CCERA) has restricted the use of coal to generate power, except to support emergency operations [Province of Manitoba, 2008]. In the case of Manitoba Hydro's one remaining coal unit, Brandon G.S. Unit 5, this means that power generation is minimally used to maintain the facility in a state of readiness. From 2005 through 2009 the average annual emissions for Brandon G.S. Unit 5 were approximately 400,000 tonnes of CO_2e per year (with fluctuating periods of high/low operation intensity). Under the new Act, annual GHG emissions from Unit 5 have been less than 80,000 tonnes annually. While Manitoba Hydro has significantly reduced its typical and average GHG emissions, under circumstances such as severe drought or major equipment outages, Manitoba Hydro's annual GHG emissions from Brandon G.S. Unit 5 could approach 1 million tonnes CO_2e.

In addition to actions on coal, Manitoba Hydro has extended the power grid to nine remote northern communities, reducing the number of communities that are served by diesel generation to four. In addition to restricting coal use, the CCERA also tasked Manitoba Hydro with facilitating the reduction, or elimination, of diesel generation in those remaining four communities. A steering committee, comprised of representatives from Manitoba Hydro, the Province of Manitoba, and Aboriginal Affairs and Northern Development Canada, is currently assessing options and proposals.

To ensure customer needs are met under all circumstances, especially under the lowest possible water flows, Manitoba Hydro will continue to operate a small fleet of thermal generating units and rely on the potential to import electricity. In addition to reliability, Manitoba Hydro's thermal electric generators also provide the following system functions: system stability, voltage regulation, and responding to generation and transmission outages. The availability of natural gas generating units also allows Manitoba Hydro to firm up additional export sales of electricity, essentially guaranteeing the electricity will be available to fulfill contracts regardless of water conditions.

4.2 RENEWABLE GENERATION DEVELOPMENT

Renewable electrical generation facilities have allowed Manitoba Hydro to operate one of the cleanest generation systems in the world. Manitoba Hydro currently manages approximately 5,200 MW of hydroelectric generation with the majority of this capacity being located in northern Manitoba. In the near-term, there is an opportunity to add approximately 2,200 MW of capacity in Manitoba through the development of two new hydropower facilities: Keeyask and Conawapa generating stations.

The 200 MW Wuskwatim G.S., located on the Burntwood River, was completed in 2012. The Wuskwatim Generation Project represented the first time Manitoba Hydro has entered into a partnership with a First Nations community on a generating station project. Wuskwatim's low-head design meant the project created less than one half of a square kilometre of flooding, all contained within the immediate forebay area.

Construction has begun on the 695 MW Keeyask Generation Project which is targeted for operation in 2019/20. The 1,485 MW Conawapa Generation Project is in the planning stages with multiple in-service dates being evaluated.

Wuskwatim, Keeyask, and Conawapa Generation Projects are all models of sustainable hydropower development, including minimal flooding (approximately 50 km^2 cumulatively), incorporation of low environmental impact design features, and collaboration with local First Nation communities.

These generating stations are estimated to contribute to the following annual global emission reductions and passenger vehicle GHG emission reductions estimates [U.S. EPA, 2014]:

- Wuskwatim G.S.: GHG emission displacement equivalent to approximately 1,000 kt of CO_2e annually, the equivalent of 211,000 cars,
- Keeyask G.S.: GHG emission displacement equivalent to 3,000 kt of CO_2e annually, the equivalent to 632,000 cars.
- Conawapa G.S.: GHG emissions displacement equivalent to 4,700 kt of CO_2e annually, the equivalent to 989,000 cars.

Hydro opportunities typically come in large increments, often exceeding several hundred megawatts. These increments are much larger than current domestic load forecast requirements and as such it is critical to find export markets for the surplus energy until Manitoba grows into their full utilization. Electricity exports to neighbouring states and provinces contribute to significant GHG reductions outside of the province. Since 2005, annual electricity exports by Manitoba Hydro have averaged approximately 10,000 GWh per year.

In addition to hydropower, Manitoba Hydro has also pursued wind resources in the province. Currently Manitoba Hydro has over 250 MW of contracted capacity in service at the St. Leon and St. Joseph wind farms, under the terms of long-term Power Purchase Agreements. A total of 63 wind turbines, capable of delivering 99 MW, were erected in 2005 over a 93 km^2 area in St Leon. St. Joseph wind farm was constructed in 2010, with 60 wind turbines covering 125 km^2. With a rated capacity of 138 MW, St. Joseph is the largest wind farm in the province, generating enough power to meet the needs of 50,000 homes. The second phase of St. Leon, with an additional 16.5 MW of wind capacity, began generating electricity in 2012. The emissions reductions associated with wind are included in Manitoba Hydro's accounting of net emissions displaced from exports.

Manitoba Hydro also considers a wide array of additional emerging electricity technologies in its generation planning and actively researches and supports their concept development. This work helps to ensure that Manitoba Hydro's development plans continue to make the most sense from economic, environmental, technical, and social perspectives. Emerging energy technologies being studied and evaluated by Manitoba Hydro include, but are not limited to:

- Bio-energy: including direct combustion, gasification, pyrolysis, landfill gas to energy, anaerobic digestion, and biofuels
- Microturbines
- Energy storage including: batteries, capacitors, pumped hydro, compressed air, fly wheels, solar thermal, and superconducting magnetic energy storage
- Solar Energy: both photo-voltaic and thermal
- Thermal to electric conversion technologies such as enhanced geothermal and small steam
- Fuel cells including: hydrogen, metal, direct carbon, phosphoric acid, and redox flow

Manitoba Hydro stays informed on emerging technologies through detailed evaluations of their potential implications. These evaluations take many forms and may include in-house research, consultants' reports, and literature searches as well as collaborations with academia and industry associations.

4.3 THE POWER SMART PROGRAM

In 1991, Manitoba Hydro established Power Smart*, the customer oriented brand for all of Manitoba Hydro's demand side management (DSM) programs, initiatives, and activities. DSM resource options are assessed and are included in Manitoba Hydro's Integrated Resource Planning process. Energy conservation initiatives are designed to reduce domestic customer energy requirements through energy-efficient measures that use less energy to obtain comparable or superior services. These programs demonstrate the economic benefits of efficiency and proactively addressing climate change for Manitoba Hydro's customers, Manitoba Hydro, and the province.

Manitoba Hydro's Power Smart* strategy typically focuses on creating a sustainable market change where energy efficient technologies and practices become the standard. The Power Smart DSM initiative is designed to encourage the efficient use of energy in the commercial, agricultural, residential, institutional, and industrial customer sectors. More than fifty-five incentive based, customer service, cost-recovery, and rate-based initiatives and programs have been offered over the last twenty-five years with impact evaluations of all incentive-based programs prepared regularly. A number of examples follow that demonstrate the breadth of the program offerings.

- The Home Insulation Program was launched in May 2004 and is designed to encourage homeowners to upgrade insulation levels and air sealing in their homes' attics, walls, and foundations. Upgrading insulation offers significant energy savings, reduces customers' monthly utility bills, and provides a more comfortable living space.

- Manitoba Hydro approved the Power Smart Load Displacement Program (LDP) in April 2014. The LDP is earmarked to develop 94.5 MW and 639 GWh, by the year 2029/30, via converting waste streams and biomass into useful energy. A significant majority of the distributed energy available from the LDP is anticipated within the next 5 to 8 years. LDP is a complement to Manitoba Hydro's Power Smart Bioenergy Optimization Program. This Program is geared towards distributed generation projects that are less than 1 MW whereas the LDP is geared to distributed generation projects larger than 1 MW. Efforts are also underway to expand the availability of biomass fuels in Manitoba to permit more penetration into the heating fuel market. Heating comprises approximately 45% of the energy use in Manitoba when all fuels are considered (transportation, light & power, and heating). Biomass is a renewable form of energy that is carbon neutral.

- The New Buildings Program is an 8-year program that began in 2010. Its primary objective is to transform the commercial new construction industry in preparation for pending building codes which will require significant improvements in overall building energy efficiency. The program offers technical assistance and financial incentives for customers designing and constructing new, energy efficient commercial buildings. To date, there have been 33 buildings constructed that meet the Power Smart requirement of at least 33% more energy efficient than the Model National Energy Code of Canada for Buildings 1997.

Manitoba Hydro's Power Smart program has become a continental leader in energy efficiency programming and has resulted in a total annual energy savings of 2,512 GWh of electricity and 93 million m^3 of natural gas to date. These energy savings reduce GHG emissions globally by approximately 1,871 kt of CO_2e per year. This is comparable to removing approximately 394,000 vehicles from the road. The majority (91%) of these GHG emission reductions results from electric Power Smart program activity through indirect emission reductions from Manitoba Hydro export sales displacing coal and natural gas fuelled generation outside of Manitoba. The remaining 9% of emission reductions are direct reductions that occur as a result of lower natural gas consumption in Manitoba.

4.4 SUPPLY SIDE ENHANCEMENTS

Manitoba Hydro also considers efficiency opportunities within internal electric generation operations. Opportunities to upgrade generating facilities in order to enhance the supply of power are often referred to as Supply Side Enhancement (SSE) projects. In general, SSE projects are not undertaken during routine maintenance programs, but are more often coupled with extended planned outages for major equipment upgrades. Because SSE projects are opportunity-based, they are often subject to economic and financial evaluations, similar to other major resource projects.

By enhancing the generation output of its existing generating facilities and transmission systems, Manitoba Hydro is able to maximize the production and availability of renewable electricity. This results in the displacement of fossil-fuel fired electric generation both within the province and in Manitoba Hydro's export region. Activities done to date include the refurbishment of some of the oldest generation equipment in the system at Great Falls, Pine Falls, Seven Sisters and Grand Rapids generating stations and the recently completed Kelsey Rerunnering Project. Also, a number of SSE initiatives are currently underway along the Winnipeg River system, as described below.

The Kelsey Rerunnering Project was a recent major upgrade of the Kelsey G.S. that consisted of the replacement of all seven turbine runners and generator windings, and modifications to the draft tubes from 2006 to 2014. The work increased the powerhouse discharge capability by over 35% resulting in greater utilization of Nelson River inflows, reducing the frequency of plant spill and increasing the plant generating capacity by about 77 MW.

There are also several planned rerunnering opportunities on the Winnipeg River, as these plants are 50 to100 years old and are in need of major equipment maintenance and repairs. The six Winnipeg River generating stations were originally built with a combined installed capacity of 560 MW, which has degraded somewhat over the years. Currently there are SSE projects in various stages of planning for the Pointe du Bois, Pine Falls, Great Falls and Slave Falls generating stations. For example, a Great Falls Unit 4 overhaul is currently underway, in which the rerunnering of the unit could add about 4 MW in the near-term. Over the next 2 to 3 years, it is also expected that Pine Falls Units 3 and 4 will be rerunnered for a capacity increase of about 8 to 9 MW.

4.5 OTHER CORPORATE ACTIONS

There are a number of additional actions that Manitoba Hydro has taken to lower corporate GHG emissions and promote reduced emissions from employees.

The corporation's world class and state-of-the-art energy efficient head office building project in downtown Winnipeg illustrates Manitoba Hydro's desire to develop a workplace that provides an excellent work environment with low energy consumption. The natural synergies of bringing people together from several locations into one reduces travel time for meetings and helps to lower GHG emissions. A number of green transportation options for employees working in the new head office were also implemented.

The building is one of the most energy efficient buildings in North America and was designed to achieve a 65% reduction over the Model National Energy Code for Buildings. With a host of other sustainable features Manitoba Hydro's head office has received many awards including:

- The annual Council on Tall Buildings and Urban Habitat Best Tall Building award. Manitoba Hydro was the winner of the America's for 2009. This award recognized Manitoba Hydro Place as the number one office tower in North America with regard to design, quality of space, urbanism, sustainability, and energy efficiency.z
- Received the Leadership in Energy & Environmental Design Platinum award in 2012 (becoming the first office tower in Canada to receive a platinum level)
- Canadian Architect Award of Excellence (2006)

Vehicle Electrification

Manitoba Hydro also has a keen focus on new electric transportation technologies that could result in major market fuel shifts. Plug-In hybrid electric vehicles (PHEVs) are plug-in battery electric vehicles that also have an internal combustion engine capable of improving range, performance, or both. A PHEV offers most of the environmental benefits of clean battery electric vehicle operation without giving up the advantages of a fossil fueled vehicle, such as the ability to utilize the existing fossil fuel refueling infrastructure. PHEVs have the potential to change the way Manitobans travel and commute by dramatically lowering gasoline consumption and substituting it with renewable electricity.

Manitoba Hydro has purchased several regular hybrid vehicles for its fleet and has even converted some into PHEVs. Manitoba Hydro has also been evaluating alternative transportation fuels, such as biodiesel, for fleet vehicle use. As one of the partners of the Manitoba Electric Bus Project team, Manitoba Hydro helped design and install the first overhead direct current electric bus rapid charging station. Following cold weather testing by Manitoba Hydro the electric bus is now fully integrated into the Winnipeg Transit system.

Engaging Employees

There are a number of internal initiatives at Manitoba Hydro to inform staff of corporate activities and to assist employees in reducing their own GHG emissions. Although most of the benefits to the company are indirect, potentially including higher productivity or efficiency through improved staff morale, these initiatives are consistent with the corporation's commitment to sustainable business practices.

Manitoba Hydro actively participates in Winnipeg Transit's Ecopass program. Under this program, the cost of monthly transit pass is reduced by over 50% to promote transit ridership thereby reducing carbon emissions related to employee commuting. More than 50% of the approximately 1,800 employees working downtown at Manitoba Hydro Place commute regularly via Transit.

Manitoba Hydro also provides support for active transport options, such as walking, running, and bicycling, with many success indicators showing high numbers of active commuting employees. For example, there have been more than 10,000 individual cycle commuting trips into Manitoba Hydro Place's secure parkade, where bikes park for free, since tracking was started. Also, every year from 2010 through 2015, Manitoba Hydro was awarded the gold medal in the Commuter Challenge as a result of high employee participation.

5 SUPPORT GHG POLICY AND MARKET DEVELOPMENT

Ultimately, GHG policies that deliver broad emission reductions will be required to achieve global climate change objectives. Manitoba Hydro has participated in and supported provincial, regional, and national GHG policy dialogues for nearly twenty years. Manitoba Hydro has also nurtured the development of carbon markets through its participation in the design and operation of the Chicago Climate Exchange (CCX). Through Manitoba Hydro's expertise in energy technologies and practical experience in environmental markets, the corporation strives to enable practical policies that are environmentally effective and economically efficient. GHG policies that deliver a meaningful carbon price for emissions, such as a carbon tax or cap-and-trade program, are the most flexible and economically efficient ways to reduce emissions. By increasing the variable costs of fossil fuel energy sources these policies improve the economicsfor non-emitting and renewable resources.

Climate change first emerged as a policy issue in 1988 when the U.S. Senate held a hearing on the issue and the United Nations formed the IPCC. At the Rio Earth Summit in 1992 world leaders, including George H.W. Bush, signed the United Nations Framework Convention on Climate Change. This provided an international framework for measuring and reporting national emissions as well as committing developed nations to hold emission at 1990 levels by 2000. In 1997 the Kyoto Protocol took this further by establishing individual national reduction targets from 1990 levels. While this protocol came into force internationally, the U.S. never ratified or signed on to the protocol and more recently Canada withdrew from the Protocol. In the 2010 Copenhagen Accord both Canada and the U.S. pledged to reduce their emissions by 17% from 2005 levels.

One way to reduce GHGs across the economy is to establish a price on carbon emissions. Over the past 20 years, various national cap-and-trade frameworks were proposed and designed in Canada but were never implemented. Similarly in the U.S., several cap-and-trade bills were proposed by both Democrat and Republican members of Congress; however none of these were passed into law. Instead, governments in both countries are using their regulatory authority to pursue GHG reductions.

The U.S. EPA is moving forward with regulating GHG emissions from major stationary sources, including power plants. Draft regulations to limit GHG emissions from new, modified, and existing power plants have been released, and could be finalized in the summer of 2015. These, and other regulations that manage air and water pollutants, could put significant constraints on electricity sector emissions should they withstand a variety of legal and legislative challenges.

The Government of Canada aligned its GHG reduction targets with those of the U.S. and is also pursuing a sector-by-sector regulatory approach. In September 2012, Canada published its “Reduction of Carbon Dioxide Emissions from Coal-Fired Generation of Electricity Regulations”. These regulations effectively phase out conventional coal-fired electricity generation over the long-term. New coal plants built after July 1, 2015, and coal units that have reached the end of their economic life, must meet the GHG emissions performance standard of a natural gas combined cycle generator. Continuing this approach, the government may move to regulate emissions from natural gas-fired power plants in the electricity sector.

In addition to federal legislation and regulation, state and provincially led GHG cap-and-trade initiatives have also been pursued. The Western Climate Initiative (WCI) partner jurisdictions developed a cap-and-trade initiative to reduce regional GHG emissions to 15 per cent below 2005 levels by 2020. Under the initiative, both California and Quebec established cap-and-trade regulations; they linked their respective markets on January 1, 2014. In April 2015, Ontario signalled its intent to join the WCI as well. The Regional Greenhouse Gas Initiative (RGGI), which took effect in January 2009, called for a 10% reduction in GHG emissions from 2005 levels by 2018 for nine participating Northeastern states. Following a comprehensive program review in 2011, RGGI states agreed to reduce the emissions cap by 45% and cancel unused allowances from 2012 and 2013 to correct oversupply issues. The cap will continue to decline by 2.5% each year from 2015 to 2020.

Besides regional cap-and-trade initiatives, some provinces have implemented alternative carbon pricing mechanisms. British Columbia has a revenue-neutral carbon tax, applied to all fossil fuels. Manitoba has an emissions tax on coal. Alberta requires large emitters in the province to reduce their emission intensity by 12% from their 2003–2005 average emission intensity. If they do not reduce their intensity enough they must purchase credits, carbon offsets, or contribute to a Climate Change and Emissions Management Fund. Alberta recently regulated an increase, to become effective in 2017, in the reduction percentage from 12% to 20%, as well as a doubling of the cost of contributing to the Fund.

Some provinces have also implemented regulatory approaches to reduce emissions such as Manitoba’s regulation that only allows coal-fired electricity generation to support emergency operations and Ontario’s coal retirement mandate. Ontario shut down the last of its existing coal-fired generating facilities in 2014.

Over the years, Manitoba Hydro has actively participated in and contributed to prominent policy fora that addressed climate change and participated in activities to encourage and demonstrate the feasibility of carbon markets. The corporation continues to advocate for GHG price signals that capture the environmental externalities associated with climate change and create a financial incentive for renewable resources.

5.1 POLICY DEVELOPMENT

Opportunities to reduce emissions depend on the development of a coherent set of coordinated regional or national policy frameworks that will create an appropriate incentive to develop more low and non-GHG emitting energy resources. Manitoba Hydro actively collaborates with a number of stakeholders from both inside and outside of the electricity sector on various regional, national and international initiatives. This includes direct engagement with the Canadian and U.S. federal governments, provincial, and state governments, along with variety of energy policy stakeholders at regional, national, and international levels.

Highlighted below is a list of GHG policy frameworks that Manitoba Hydro is actively engaged in:

Canadian GHG Policy

In the past, the Canadian government had a comprehensive climate change process which Manitoba Hydro played a significant role in by co-chairing the Electricity Table and providing one of the leading authors for its Tradable Permits Working Group. Today, Manitoba Hydro continues to participate in Canadian national GHG policy development directly and through initiatives coordinated by the CHA, Canadian Electrical Association (CEA) and the Province of Manitoba. Through these fora, Manitoba Hydro has the opportunity to directly consult with the federal government or otherwise influence national dialogue around GHG regulations for the electricity sector.

United States Federal and State Government

Manitoba Hydro is in active discussion with U.S. utilities and policymakers to explain the role that hydroelectricity can play in helping the U.S. meet its energy needs and climate policy goals. There are several features of Manitoba Hydro's existing and potential exports which are communicated to U.S. stakeholders:

- As demonstrated through recent LCAs (refer to Section 3.6), hydropower is virtually GHG free electricity and can assist in achieving emission reductions and renewable energy goals.
- Expanding U.S. and Canadian hydropower could provide a portion of the resources necessary to transition towards vehicle electrification.
- Hydropower offers unique operational flexibility which is well positioned to complement development of intermittent renewable electricity generation technologies such as wind and solar.

There are several avenues through which Manitoba Hydro engages policymakers in the U.S.: Manitoba Hydro participates in various conferences and other policy fora such as those sponsored by Powering the Plains, the Great Plains Institute, the Midwest Governors' Association, the Minnesota Chamber of Commerce, and the Minnesota Pollution Control Agency. Manitoba Hydro also meets with policy leaders including politicians, political staff, think tanks and non-governmental organizations (NGOs). Meetings, events, presentations and communication pieces are often coordinated through the Canadian Embassy and industry associations.

Regional Climate Initiatives

Climate policy models developed on a smaller regional level have the capacity of obtaining national attention and are typically designed with the objective of providing a model for future national emissions-reduction programs. Manitoba Hydro, both individually and in cooperation with the Province of Manitoba, has participated in a number of regional climate initiatives, as described below.

The WCI cap-and-trade program was launched in February 2007, signaling a long-term commitment by participating states and provinces to significantly reduce regional GHG emissions. The partners share a commitment to identify, evaluate, and implement collective and cooperative ways to address climate change through a regional reduction of GHGs. Manitoba Hydro participated in the WCI through stakeholder consultations. Currently only California and Quebec are implementing this cap-and-trade program, but Ontario signalled its intent to join in April 2015.

In 2001, the non-profit Great Plains Institute convened a diverse group of stakeholders, including Manitoba Hydro, to launch its Powering the Plains program. The culmination of this work is documented in the roadmap report which represents a consensus among leaders from Iowa, Manitoba, Minnesota, North Dakota, and South Dakota on how best to meet the energy needs of a growing Midwestern economy while reducing the GHG intensity of regional energy production.

Manitoba Hydro has engaged with the Midwest Governors Association (MGA) on a number of climate initiatives. For example, the Midwestern Greenhouse Gas Reduction Accord (Midwestern Accord) was a regional agreement by members of the MGA and the Premier of Manitoba to reduce GHG emissions to combat climate change. The Midwestern Accord aimed to establish GHG reduction targets and to develop a market-based and multi-sector cap-and-trade mechanism to help achieve those reduction targets. After releasing a model cap-and-trade rule in 2010, the participating states and Manitoba did not continue pursuing their GHG goals through the Midwestern Accord.

5.2 CARBON MARKETS AND PROGRAMS

In North America, voluntary GHG emission reduction programs have emerged as opportunities for proactive companies to transition towards a carbon constrained economy. Participation in these initiatives not only provides valuable tactical market experience, it also displays Manitoba Hydro's commitment to climate change leadership along with providing an opportunity to shape emerging mandatory policy frameworks.

Chicago Climate Exchange (CCX)

Manitoba Hydro participated in the design of the CCX and was an active member for the duration of the program, from 2003 through 2010. The program met all of its significant objectives such as demonstrating that a rules-based cap-and-trade program can be cost effectively delivered and managed. The program was very influential in the establishment of the European Trading System, the RGGI, and the WCI. By 2010, the members of CCX had completed eight years of continuous progress in reducing GHG emissions through a rules-based market.

Manitoba Hydro's participation in CCX was based on the understanding that a carbon trading scheme would be an effective and practical path forward in managing GHG emissions. The Corporation's participation in the CCX committed Manitoba Hydro to progressively step up its CO_2e emission reductions to 6% of its baseline emissions (defined as average emissions over the 1998-2001 period) through 2010. With respect to the CCX commitment, Manitoba Hydro maintained full compliance with these legally binding emission reduction targets. Manitoba Hydro also participated in the committee structure that managed the CCX including serving as the chair of the Offset Committee. Some of the benefits to Manitoba Hydro of participating in the CCX included:

- Reduced emissions through high compliance standards and standardized third party verification.
- Better understanding of carbon markets, through practical, hands-on experience.
- Establishment of an early track record in reductions and experience with carbon and GHG markets.
- Demonstrated climate change leadership.

Voluntary Challenge and Registry

The Climate Change Voluntary Challenge and Registry (VCR) Program was a formal national initiative created in 1995 that called on Canadian organizations to voluntarily take actions to limit or reduce net GHG emissions. It was a joint initiative of federal, provincial, and territorial governments. Under this program, Manitoba Hydro began to report its emissions and made a voluntary commitment to reduce its average corporate net GHG emissions to 6% below the 1990 level. Manitoba Hydro's emission reduction obligations under the VCR program were met. Average net emissions during the program prior to its conclusion in 2007 were 36% below the 1990 level, far exceeding the 6% commitment. During Manitoba Hydro's participation in the VCR, Manitoba Hydro received Gold Champion Level recognition five consecutive times from the VCR for its emission reduction reporting and activities. In 2003, Manitoba Hydro received the VCR Leadership Award in the electric utility category, recognizing the corporation's outstanding contributions in voluntarily meeting Canada's commitment to reduce GHG emissions. Manitoba Hydro's commitment was also recognized by the Pembina Institute, in their last assessment of VCR reports, to be the best of all Canadian utilities.

Greenhouse Emission Reduction Trading Pilot (GERT)

The GERT Pilot Project was a collaborative effort between provincial and federal government agencies, industry associations, and environmental and nongovernmental agencies. The Pilot was launched in June 1998 with the objective of learning about emission reduction credit trading through experimentation. Manitoba Hydro participated in this process to gain practical experience with this market-based approach and to foster the development of strategies and policies for meeting Canada's international climate change commitments.

Renewable Electricity Energy Markets

Climate change and related energy policy development can also have a direct impact on the supply and demand for renewable electrical energy. There exists a close relationship and overlap between existing and potential carbon and renewable energy polices and markets. Approximately thirty U.S. states have enacted renewable portfolio standards (RPS) that obligate utility companies to meet mandatory renewable energy targets. These affected companies must provide the required number of renewable energy certificates (RECs) to correspond with their RPS obligations in a specific year. RECs are tradable commodities that represent proof that 1 MWh of electricity was generated from a qualifying renewable energy source. Qualifying renewable technologies differ by state and program type and are driven by a variety of motivations. Manitoba Hydro has been actively marketing RECs associated with its electricity exports since 2008 in both the RPS and voluntary green power markets.

6 ADAPT AND PLAN

Climate change has the potential to influence Manitoba Hydro's resource plans and future operations. Several key inputs to the integrated resource planning process may be sensitive to a changing climate or the human response that may arise in response to climate change. These resource planning considerations include the projections of changes to runoff, the load forecast, and the market price for electricity. Manitoba Hydro is in the process of investigating how best to factor climate change impacts into long-term planning and operation of its system.

The intent is to explore the sensitivity of these inputs to climate change and determine the robustness of Manitoba Hydro's development plans. Similarly, where there appears to be implications for Manitoba Hydro's operations, adaptation strategies will be considered.

6.1 RESOURCE PLANNING

Manitoba Hydro is one of the largest hydropower utilities in North America. Manitoba Hydro has the advantage of operating downstream of four major river systems located within a very large geographic region spanning a diverse range of climate zones and physiographic regions. For that reason, Manitoba Hydro's water supply will likely experience diverse impacts from climate change, i.e. some river basins may experience lower average flows while others may see higher flow.

Based on current research and studies, Manitoba Hydro has projected ranges associated with future runoff under climate change. These ranges may be used as sensitivities in resource planning studies. Manitoba Hydro's projections are continuously improving compared to those made in the past as a result of more comprehensive modeling, understanding, and climate science. While Manitoba Hydro is at the forefront of hydrologic and hydroclimatic studies, there is still a significant amount of work to be done. Over the next several years the modeling work that is currently underway will enhance Manitoba Hydro's understanding and planning projections even further. This capability may give Manitoba Hydro the opportunity to supplement its historical records over the last 100 years with a range of potential outcomes over the next 100 years.

It is important to acknowledge that even as Manitoba Hydro's capabilities increase over time there will always be a range of uncertainty associated with climate change due to the complexity and variability of key factors such as inflow variability, and the frequency and intensity of system-wide drought. Through ongoing research and analyses, Manitoba Hydro will continue to advance the state of knowledge about the range of potential climate change impacts at the system-wide scale and improve their understanding of how these impacts could affect existing and proposed facilities.

6.2 ENERGY DEMAND

Temperature changes can impact electrical energy and natural gas demand patterns. As average temperatures increase, the demand for energy to heat buildings in winter decreases while the demand for energy to cool buildings in summer increases.

Projected climate change impacts on weather affected energy demand have been studied using sensitivity analyses and using GCM output. In both cases, Manitoba weather affected energy demand is modeled using Winnipeg temperature data since Winnipeg is central to most of the weather dependent load. Other factors such as population are held constant to isolate the weather effect.

Sensitivity analyses indicate that a uniform +1 C change in daily average temperature across all months would have the following impacts: Winters would experience a reduction of 225 GWh of electrical energy, a reduction of 47 MW in peak electric demand and a reduction of 48,000,000 m^3 in natural gas demand. Summers would experience an increase of 248 GWh of electrical energy and an increase of 103 MW in peak electric demand.

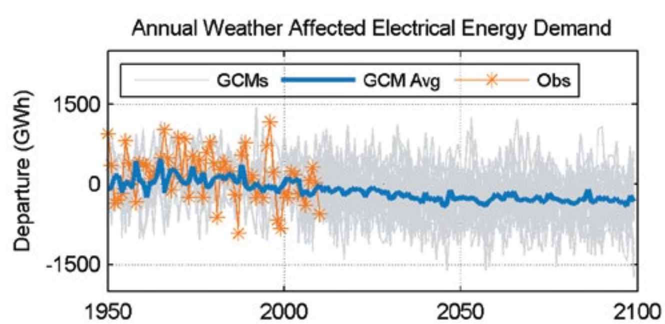
GCM studies indicate that temperature changes may not be uniform across all months and that winters may experience greater increases than summers. The ensemble average, from a 27 GCM simulation study, projected the following impacts by the 2050s time period:

- Annual average temperature would increase by 2.5 C.
- Winters would experience a reduction of 756 GWh of electrical energy, a reduction of 176 MW in peak electric demand and a reduction of 157,000,000 m^3 in natural gas demand.
- Summers would experience an increase of 486 GWh of electrical energy and an increase of 300 MW in peak electric demand.

However, like other climate change studies, there are many sources of uncertainty and the GCM ensemble average is surrounded by a range.

In general, the change in annual weather affected electrical energy demand is small relative to Manitoba's total electric energy demand, while changes to weather affected natural gas demand are more pronounced. Changes to peak demand are a function of extreme temperature changes, an area with even greater uncertainty. Another important note for Manitoba is the existence of large year-to-year variability in weather affected energy demands which can mask the climate change signal. Future projections of weather affected electrical energy demand show a similar year-to-year variability as shown in Figure 39. Analysis of results is ongoing and can inform climate change adaptation and planning at Manitoba Hydro.

FIGURE 39: ANNUAL WEATHER AFFECTED TOTAL ENERGY DEMAND DEPARTURE PLOT



6.3 GENERATION OPERATIONS AND TRANSMISSION/DISTRIBUTION

From an operational perspective, investigating how climate and hydrology of Manitoba Hydro's river basins have changed and will change are both key to understanding and adapting to the potential vulnerability and opportunities of Manitoba Hydro's system. Any climate changes that may have occurred to date have been accommodated by current operating practices. At this time it is not feasible to prescribe future operational changes. However, unlike the design and construction of a completed generating station, operating practices are not fixed and may change and adapt over time. At this time Manitoba Hydro's key activities focus on improving hydrologic modeling for forecasting upcoming water conditions and possible extreme events.

The improved hydrologic inflow forecasting data is proving to be a useful tool for maintenance scheduling and major hydro project construction activities. An example of this is the water forecasts being provided for the Pointe Du Bois Spillway Replacement Project and Keeyask Generation Project so construction activities can be coordinated to minimize risk due to adverse water conditions. To facilitate project scheduling, 21-day forecast data have been issued weekly since November 2011 and May 2014 respectively. This data supported the construction of the Pointe du Bois spillway access bridge, as well as plant operations and commissioning of the new spillway during the 2014 Winnipeg River flood event. The data provided by these forecasts has also supported cofferdam construction and Stage I river diversion activities for the Keeyask G.S.

Understanding and predicting the potential nature of extreme weather events through hydrological modeling activities provides operations groups with information needed to plan for such events, particularly from a dam safety perspective. The hydrologic inflow forecasting data can be utilized in probable maximum flood studies. These studies are required as part of both existing operations for dam safety and for providing estimates for future generation. The WATFLOOD models along with the CaPA precipitation mapping are being developed into the new modeling tool of choice for these dam safety studies.

Potential severe weather related disruptions to Manitoba Hydro's electrical distribution and transmission systems also underscore the importance of furthering the understanding and prediction of severe weather resulting from climate change. With possible increasing frequency, duration, and intensity of extreme weather events, projects which increase system reliability such as the new Bipole III HVDC line and the Riel Reliability Project provide additional climate change adaptation benefits.

6.4 GHG PRICE IMPLICATIONS

GHG pricing policies, typically presented either through a cap-and-trade program or carbon tax framework, will impact the domestic cost of operating Manitoba Hydro's fossil-fuel fired thermal electric generating stations as well as export electricity market resources and pricing. To ensure the impacts of a carbon premium are included in long-term planning projections, a "GHG component" is embedded in Manitoba Hydro's integrated resource planning activities

The nature of GHG price forecasting is inherently uncertain and is dependent on a range of potential GHG emission policies and how those policies are applied. However, even if future legislation requirements for carbon emissions were known, there would still be significant uncertainty as to the cost of carbon emission allowances and the associated impact on power prices.

GHG price forecasts are dependent on complex assumptions regarding potential abatement opportunities and associated costs. While Manitoba Hydro generally assumes that North American GHG price signals will converge or harmonize in the longer term, there will likely be short-term local or regional discrepancies due to differences in timing and policy details. Resources within Manitoba will face GHG pricing and other constraints that depend on the circumstances and policies specific to Canada and/or Manitoba such as the possible adoption of a broad carbon tax consistent with British Columbia's approach or the potential membership in a cap-and-trade program such as the WCI that Quebec and Ontario are pursuing. The cost of coal generation within Manitoba already accounts for Manitoba's tax on emissions from coal. As of January 1, 2012, coal used in Manitoba is subject to a provincial emissions tax equal to \$10 per tonne of CO_2e emissions.

The implications of GHG policies implemented outside of Manitoba in export regions are embedded in Manitoba Hydro's Export Price Forecast. The specific details of Manitoba Hydro's electricity price forecast; including details on specific pricing factors such as the assumptions regarding CO_2 premiums, are confidential. Manitoba Hydro has a consultant services agreement with each of the electricity export price forecast consultants, and the services agreement has confidentiality requirements that prevent Manitoba Hydro from publically releasing the forecast reports.

Projecting the future impact of GHG policies ensures that the appropriate costs and revenues are included in the integrated resource planning process for the evaluation of future resource options and development plans.

REFERENCES

Brattle Group, 2014. CO_2 Emission Displacement Resuting from Increased Manitoba Hydro Exports to Miso, from: http://www.pub.gov.mb.ca/nfat/pdf/ir/CAC-MH%20Round%202, (starts page 206)

Chen, C., Jenkins, E., Epp, T., Waldner, C., Curry, P. & Soos, C., 2013. Climate Change and West Nile Virus in a Highly Endemic Region of North America. Int. J Environ Res Public Health, 10(7), 3052–3071.

Chen, J., F.P. Brissette, A. Poulin, and R. Leconte, 2011. Overall uncertainty study of the hydrological impacts of climate change for a Canadian watershed. Water Resources Research, 47, W12509, doi:10.1029/2011WR010602.

Chu, C., Mandrak, N.E. & Minns, C.K., 2005. Potential impacts of climate change on the distributions of several common and rare freshwater fishes in Canada. Diversity Distrib, 11, 299–310.

Derocher A.E., Lunn, N.J. and Stirling, I. 2004. Polar bears in a warming climate. Integr. and Comp. Biol. 44, 163-176.

Déry, S. J., Mlynowski, T. J., Hernàndez-Henríquez, M. A. & Straneo, F., 2011. Interannual Variability and Interdecadal Trends in Hudson Bay Streamflow. Journal of Marine Systems, 88, 341-351.

Déry, S. J., & Wood, E. F., 2005. Decreasing River Discharge in Northern Canada. Geophysical Research Letters, 32, 1-4.

Ehsanzadeh, E., va der Kamp, G. & Spence, C., 2011. The impact of climatic variability and change in the hydroclimatology of Lake Winnipeg watershed. Hydrol. Process. DOI: 10.1002/hyp.8327.

Environment Canada., 2012. Recovery strategy for the woodland caribou (Rangifer tarandus caribou), Boreal population, in Canada. Species at Risk Act Recovery Strategy Series. Environment Canada, Ottawa., xi + 138.

Environment Canada, 2013. Global Warming Potentials (Last Modified 2013-12-29), From: http://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=CAD07259-1.

Environment Canada, 2013b. Reporting to the Greenhouse Gas Emissions Reporting Program (Last Modified 2014-10-15), from: http://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=F3E7B38E-1

Environment Canada, 2015. National inventory report: 1990-2013, Greenhouse Gas Sources and Sinks in Canada, The Canadian Government's Submission to the UN Framework Convention on Climate Change, (available at http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/8812.php)

Environment Canada and Manitoba Water Stewardship. 2011. State of Lake Winnipeg: 1999 to 2007

Frigon, A., B. Music, and M. Slivitzky, 2010. Sensitivity of runoff and projected changes in runoff over Quebec to the update interval of lateral boundary conditions in the Canadian RCM, Meterologische Zeitschrift, 19, .225-136.

Henderson, N. & Sauchyn , D. (eds.)., 2008. Climate Change Impacts on Canada's Prairie Provinces: A Summary of our State of Knowledge. Prairie Adaptation Research Collaborative, No. 08-01

Hopkinson, R. F.; McKenney, D. W.; Milewska, E. J.; Hutchinson, M. F.; Papadopol, P.; Vincent, L. A., 2011. Impact of aligning climatological day on gridding daily maximum-minimum temperature and precipitation over Canada. Journal of Applied Meteorology and Climatology, 50, 1654-1665.

Hutchinson, M. F., D.W. McKenney, K. Lawrence,J.H. Pedlar, R.F. Hopkinson, E. Milewska, and P. Papadopol, 2009. Development and testing of Canada-wide interpolated spatial models of daily minimum/maximum temperature and precipitation 1961–2003. J. Appl. Meteor. Climatol., 48, 725–741

International Organization for Standardization, 2006, Standard 14040: Environmental management – Life cycle assessment – Principles and Framework

IPCC, 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2014. Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Lemmen, D. S., Warren, F.J., Barrow, E., Schwartz, R., Andrey, J., Mills, B., & Riedel, D., 2004. Climate Change Impacts and Adaptation: A Canadian perspective (Natural Resources Canada). Ottawa, ON: Retrieved February, 2015 from http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/pdf/perspective/pdf/report_e.pdf

Manitoba Hydro, 2014. An Overview of Climate Change Impacts and what it means to Manitoba. [Available Online]. Retrieved February, 2015 from http://www.pub.gov.mb.ca/nfat_hearing/NFAT%20Exhibits/MH-191.pdf.

Meehl, G.A., Stocker, T.F., Collins, W.D., Friedlingstein, P., Gaye, A.T., Gregory, J.M., Kitoh, A., Knutti, R., Murphy, J.M., Noda, A., Raper, S.C.B., Watterson, I.G., Weaver A.J., & Zhao, Z.C., 2007. Global Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. & Miller, H.L. (eds.)]. Cambridge University Press, Cambridge, UnitedKingdom and New York, NY, USA.

Natural Resources Canada Adaptation Platform from: http://www.nrcan.gc.ca/environment/impacts-adaptation/adaptation-platform/10027

National Academy of Sciences, 2014. Climate Change: Evidence and Causes. [Available Online]. Retrieved February, 2015 from http://dels.nas.edu/resources/static-assets/exec-office-other/climate-change-full.pdf.

National Oceanic and Atmospheric Administration, 2014. Climate Change: Minimum Arctic Sea Ice Extent. [Available Online]. Retrieved March, 2015 from https://www.climate.gov/news-features/understanding-climate/climate-change-minimum-arctic-sea-ice-extent.

van Oldenborgh, G.J., Collins, M., Arblaster, J., Christensen, J.H., Marotzke, J., Power, S.B., Rummukainen, M. & Zhou, T., 2013. Annex I: Atlas of Global and Regional Climate Projections in Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Decluse, P., Fyfe, J., & Taylor, K. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Page, E., & Levesque, L., 2011. State of Lake Winnipeg: 1999 to 2007. Environment Canada and Manitoba Water Stewardship. Winnipeg, MB.

Pembina Institute, 2003, Life Cycle Evaluation of GHG Emissions and Land Change Related to Selected Power Generation Options in Manitoba.

Pembina Institute, 2010, Keeyask Generating Station - A Life Cycle Assessment of Greenhouse Gases and Select Criteria Air Contaminants .

Pembina Institute, 2013, Conawapa Generation Project - A Life Cycle Assessment of Greenhouse Gases and Select Criteria Air Contaminants.

Price, J. & Glick., P., 2002. The Birdwatcher's Guide to Global Warming. American Bird Conservancy and National Wildlife Federation, Virginia.

Price, D.T., Alfaro, R.I., Brown, K.J., Flannigan, M.D., Fleming, R.A., Hogg, E.H., Girardin, M.P., Lakusta, T., Johnston, M., McKenney, D.W., Pedlar, J.H., Stratton, T., Sturrock, R.N., Thompson, I.D., Trofymow, J.A. & Venier, L.A. 2013. Anticipating the consequences of climate change for Canada's boreal forest ecosystems. Environmental Reviews, 21, 322-365.

Province of Manitoba, 2008, The Climate Change and Emissions Reduction Act, C.C.S.M. c. C135, (Modified 2013), Last Accessed March 30th, 2015: http://web2.gov.mb.ca/laws/statutes/ccsm/_pdf.php?cap=c135

Racey, G.D. 2005. Climate change and woodland caribou in Northwestern Ontario: a risk analysis. Rangifer, Special Issue No. 16, 123-136.

Regehr, E.V., Lunn, N.J., Amstrup, S.C., & Stirling, I., 2007. Effects of earlier sea ice breakup on survival and population size of polar bears in western Hudson Bay. Journal of Wildlife Management, 71(8), 2673-2683.

Sauchyn, D. & Kulshreshtha, S., 2008. Chapter 7: Prairies in From Impacts to Adaptation: Canada in a Changing Climate 2007, [Lemmen, D.S., Warren, F.J., Lacroix, J. & Bush, E. (eds.)] Government of Canada, Ottawa, ON, p. 275-328.

Sillmann, J., V. V. Kharin, F. W. Zwiers, X. Zhabng and D. Bronaugh, 2013. Climate extreme indices in the CMIP5 multimodel ensemble: Part 2. Future climate projections, J. Geophys. Res. Atmos., 118, 2473-2493

SREX, 2012. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA.

St. Jacques, J.-M., Huan, Y.A., Zhao, Y., Lapp, S.L., & Sauchyn, D.J., 2011. The Effects of Atmosphere-Ocean Climate Oscillations on and Trends in Saskatchewan River Discharges. Prairie Adaptation and Research Collaborative, 49pp. Retrieved April 25, 2014 from http://www.parc.ca/rac/fileManagement/upload/The_Effects%20of%20Atmosphere_Ocean_Climate_Oscillations_on_and_Trends_in_Saskatchewan_River_Discharges.pdf.

Stirling, I. & Derocher, A.E. 1993. Possible impacts of climatic warming on polar bears. Arctic, 46, 240-245.

Stirling, I., Lunn, N.J. & Iacozza, J. 1999. Long-term trends in the population ecology of polar bears in Western Hudson Bay in relation to climatic change. Arctic, 52, 294-306.

Stirling, I., & Parkinson, C.L., 2006. Possible Effects of Climate Warming on Selected Populations of Polar Bears. Arctic, 59, 261-275.

Tremblay A., Varfalvy L., Roehm C. and Garneau M., 2004, The Issue of Greenhouse Gases from Hydroelectric Reservoirs: From Boreal to Tropical Regions, from http://www.un.org/esa/sustdev/sdissues/energy/op/hydro_tremblaypaper.pdf

U.S. Energy Information Administration, 2015, State Electricity Profiles 2013, from: http://eia.gov/electricity/state/unitedstates/

U.S. EPA, 2014 Calculations and References: Passenger Vehicles per Year (Last modified 2014-09-09), from: http://www.epa.gov/cleanenergy/energy-resources/refs.html

Venema, H.D., Oborne, B. & Neudoerffer, C., 2010. The Manitoba Challenge: Linking Water and Land Management for Climate Adaptation. International Institute for Sustainable Development. 79pp. Retrieved April 25, 2014 from http://www.iisd.org/pdf/2009/the_manitoba_challenge.pdf.

Warren, F.J. and Lemmen, D.S., editors, 2014. Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation; Government of Canada, Ottawa, ON, 286p. Retrieved March 2015 at: http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earth-sciences/pdf/assess/2014/pdf/Full-Report_Eng.pdf

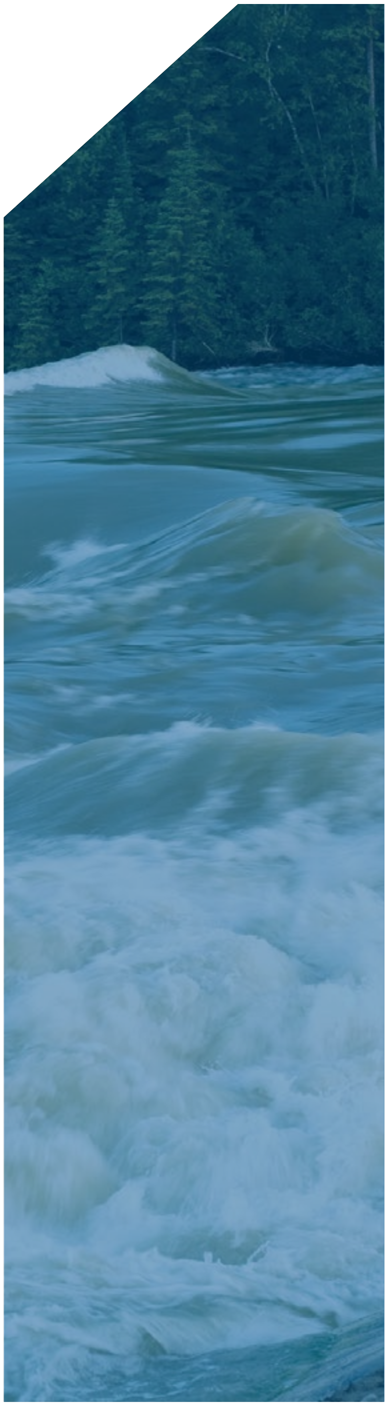
Watflood Model from: www.watflood.ca

Westmacott J. R. & Burn, D. H., 1997. Climate change effects on the hydrologic regime within the Churchill-Nelson River Basin. Journal of Hydrology, 202, 263-279.

Zhang, X., Brown, R., Vincent, L., Skinner, W., Feng, Y. & Mekis, E., 2011. Canadian climate trends, 1950-2007. Canadian Biodiversity: Ecosystem Status and Trends 2010, Technical Thematic Report No. 5. Canadian Councils of Resource Ministers. Ottawa, ON. Retrieved April 25, 2014 from: http://www.biodivcanada.ca/default.asp?lang=En&n=137E1147-0.

GLOSSARY

AR5 - IPCC's Fifth Assessment Report
CAMP - Manitoba Hydro/Manitoba's Coordinated Aquatic Monitoring Program
CanESM2 - Canadian Center for Climate Modeling Analysis Canadian Earth System Model
CCX - Chicago Climate Exchange
CEA - Canadian Electrical Association
CEPEI - The Canadian Energy Partnership for Environmental Innovation
CGA - Canadian Gas Association
CH_4 - Methane
cm - Cubic Metres
CMIP3 - Coupled Model Intercomparison Project Phase 3
CMIP5 - Coupled Model Intercomparison Project Phase 5
cms - Cubic Metres Per Second
CO_2 - Carbon Dioxide
CO_2e - Carbon Dioxide Equivalent
dec. - Decade
DSM - Demand Side Management
EPA - U.S. Environmental Protection Agency
G.S. - Generating Station
GCMs - Global Climate Models
GERT - Greenhouse Emission Reduction Trading Pilot
GHG - Greenhouse Gas
GWP - Global Warming Potential
IAWG - The Provincial Inter-Departmental Climate Adaptation Working Group
IPCC - Intergovernmental Panel on Climate Change
km - Kilometres
kt - Kilotonnes
LCAs - Life Cycle Assessments
LDP - Power Smart Load Displacement Program
MGA - Midwest Governors Association
mm - Millimetres
N_2O - Nitrous Oxide
NGOs - Non-Governmental Organizations
NRCan - National Resources Canada
PHEVs - Plug-In Hybrid Electric Vehicles
ppm - Parts Per Million
RCMs - Regional Climate Models
RCPs - Representative Concentration Pathways
RECs - Renewable Energy Certificates
RGGI - Regional Greenhouse Gas Initiative
RPS - Renewable Portfolio Standards
SF_6 - Sulphur Hexafluoride
SREX - IPCC's Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change
SSE - Supply Side Enhancement
U.S. - United States
VCR - Climate Change Voluntary Challenge and Registry
WC - Western Climate Initiative
yr - Year



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