MANITOBA HYDRO'S CLIMATE CHANGE REPORT

Insight into the strategies making Manitoba Hydro an industry leader in responding to climate change

Manitoba Hydro

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CLIMATE CHANGE STRATEGY

CLIMATE CHANGE AFFECTS US ALL

International efforts like the Paris Agreement bring humanity closer to solutions, but realities like increased greenhouse gases in our atmosphere and continued global industrialization mean that some climate change effects are inevitable. Our interaction with climate change is two-way: we can be impacted by physical changes in the climate and our operations can impact greenhouse gas emissions that contribute to climate change.

- As earth's climate changes, our environment is also changing, which can affect our water supply, infrastructure, energy demand, and other things. These effects of climate change may require us to adapt in order to continue meeting Manitobans' energy expectations.
- Renewable energy like hydropower is environmentally friendly and helps mitigate climate change. We continually strive to maintain our leadership in reducing global greenhouse gas emissions.

5 STRATEGIES HELP SHAPE OUR RESPONSE

1 UNDERSTAND

Earth's climate is warming and temperature changes affect many of the planet's natural processes like precipitation, streamflow, and wind patterns. We collaborate with leading researchers and apply rigorously reviewed scientific knowledge to more thoroughly understand historical climate records and future climate projections.

AVERAGE AMERICAN UTILITY'S CO_2 PER GWh **459** TONNES

AVERAGE CANADIAN UTILITY'S CO_2 PER GWh **135** TONNES

MANITOBA HYDRO'S CO_2 PER GWh **0.4** TONNES

2 REPORT

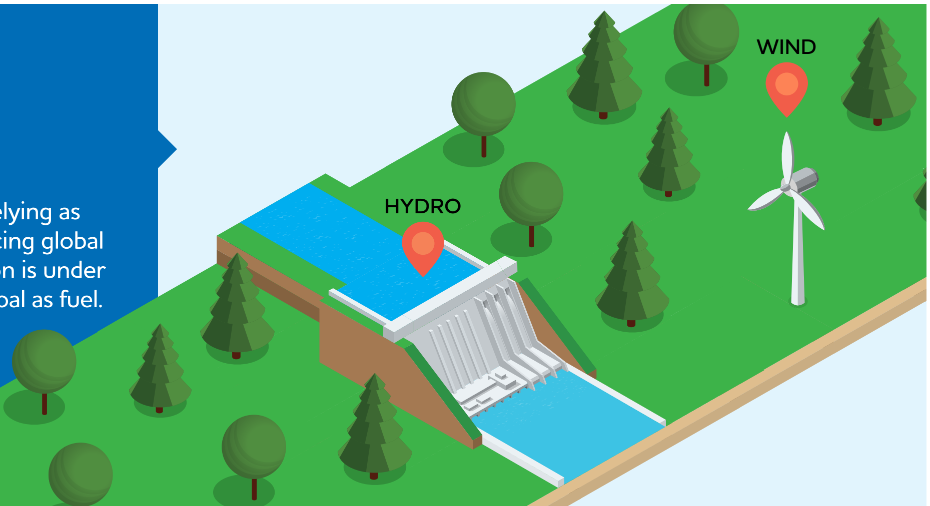
Canadian governments now require large companies to report their greenhouse gas emissions, but we began voluntarily reporting in 1995. Reporting on emissions helps us see how we're doing and how we can improve.

3

REDUCE

Greenhouse gas emissions cause climate change. By relying as much as possible on renewable resources we are reducing global emissions. The Keeyask hydroelectric generating station is under construction and we have ceased all generation using coal as fuel.

Our hydro energy is often abundant and hydropower systems offer flexibility. Exporting extra electricity to neighbouring provinces and states can help reduce their emissions too.



100+ YEARS OF RENEWABLE ENERGY EXPERIENCE

4

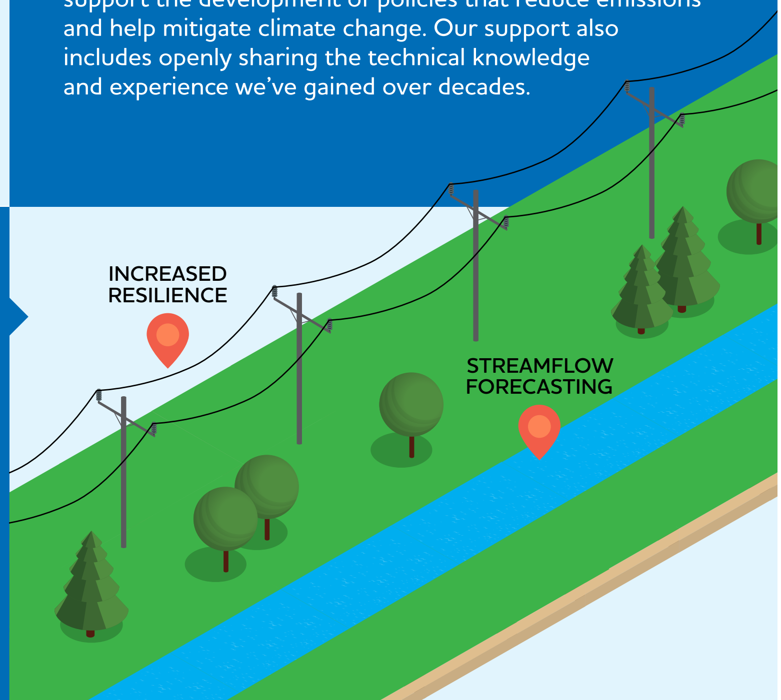
SUPPORT

Everyone needs to help reduce greenhouse gas emissions. Through engagement with governments, industry groups, non-government organizations, and other stakeholders, we support the development of policies that reduce emissions and help mitigate climate change. Our support also includes openly sharing the technical knowledge and experience we've gained over decades.

5

ADAPT

Whether it's increasing our system's resilience or enhancing our streamflow forecasting capabilities, applying climate information helps us reduce weather-related risks, manage reliability, and capitalize on opportunities. We're continuing our work to identify, assess, prioritize, and study climate change's effect on our world and our business. Areas of interest include energy generation, energy demand, environmental sustainability, and infrastructure.



WE'RE IN IT TOGETHER

Manitoba Hydro is committed to helping the world reduce emissions and mitigate the effects of climate change. As the climate continues to change, we are adapting our processes to ensure we continue delivering reliable, renewable energy to Manitobans.

Manitoba Hydro

INTRODUCTION

Earth's climate is dynamic. Changes result from internal (natural) forcing – such as oceanic oscillations – and external forcing such as volcanic eruptions, solar activity, and atmospheric greenhouse gas (GHG) concentrations. The likely dominant cause of recently observed warming since the mid-20th century is human-caused increases in GHG emissions ultimately leading to increased GHG concentrations in the atmosphere [IPCC, 2014]. International efforts like the Paris Agreement bring humanity closer to solutions, but increased GHGs in our atmosphere and continued global industrialization mean some effects of climate change are inevitable. As an energy utility, our interaction with climate change is two-way: physical changes in the climate system impact us, and our operations can impact GHG emissions that contribute to climate change.

Climate change has been on our radar since the 1980s. This report provides an update to our climate change activities including research, greenhouse gas emission reporting, greenhouse gas reductions, policy support, and adaptation activities. This is the third climate change report, which builds on previous versions (Manitoba Hydro, 2013a; Manitoba Hydro, 2015a). Additional details on some of our past activities, not included in this report, can be found in those reports.

Up to now we have focused on building a foundation of knowledge and tools that enable us to conduct climate change impact studies. We employ sophisticated climate models and downscaling techniques to develop future climate scenarios and examine resulting impacts on business practices. Future water supply remains a large focus of our work and these assessments use advanced hydrological models for watersheds of interest to help simulate potential future hydrological conditions.

"Warming of the climate system during the Industrial Era is unequivocal, based on robust evidence from a suite of indicators. Global average temperature has increased, as have atmospheric water vapour and ocean heat content. Land ice has melted and thinned, contributing to sea level rise, and Arctic sea ice has been much reduced."

Canada's Changing Climate Report [ECCC, 2019a]

It's more than water – our impact studies are expanding to help us understand how climate change might affect all our operations. This understanding will help us adapt to continue meeting Manitobans' energy expectations in the face of climate change.

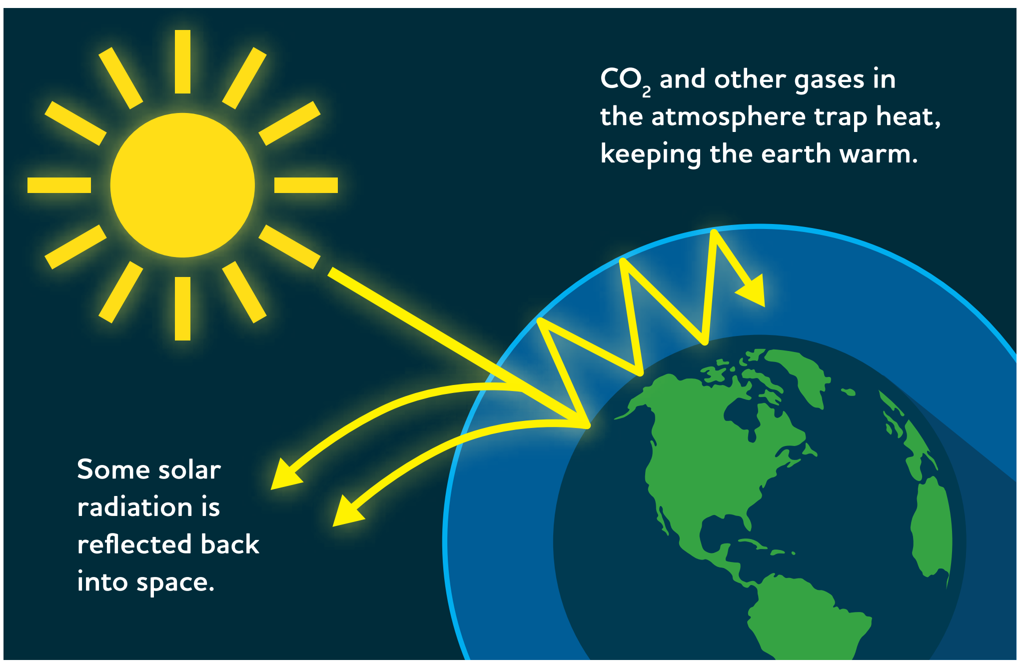
Our low-emitting renewable power also mitigates global climate change. Meeting global climate targets means relying on renewable energy, like hydropower, and the power we export helps mitigate emissions from other forms of energy.

We also assist in shaping policy frameworks, guiding development of efficient technologies, and helping domestic customers make wise choices regarding their energy use.

CLIMATE CHANGE SCIENCE

To understand how GHGs influence the Earth's temperature, consider the Earth's energy balance. It is driven mainly by radiation from the sun. Approximately 30% of sunlight that reaches Earth's atmosphere is reflected back into space. The rest is absorbed and is converted from light energy into heat. Keeping the energy roughly in balance, Earth radiates heat back to space as longwave (infrared) radiation. GHGs (e.g. water vapor; carbon dioxide CO_2; methane CH_4; and nitrous oxide N_2O) absorb the reflected infrared radiation, acting as a partial blanket. By trapping heat, these gases act like the glass in a greenhouse, warming Earth's surface. This results in the common name for the GHG-caused climate change: "the greenhouse 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. But an excess of GHGs in the atmosphere presents problems.

FIGURE 1 Schematic of the greenhouse effect



Burning fossil fuels like coal, natural gas, and oil releases additional heat-trapping gases. Since the industrial revolution, humans have burned more fossil fuels each successive decade. This intensifies the greenhouse effect, changing the Earth's climate. A key atmospheric indicator is the accumulation of CO_2 in the atmosphere. The average concentration measured at Mauna Loa in 2019 was 411.44 ppm [Trans and Keeling, 2019]. 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.

International efforts to reduce GHG emissions will help limit the impacts of climate change but warming due to historic emissions will persist for centuries and will continue to cause long-term changes in the climate system [IPCC, 2018].

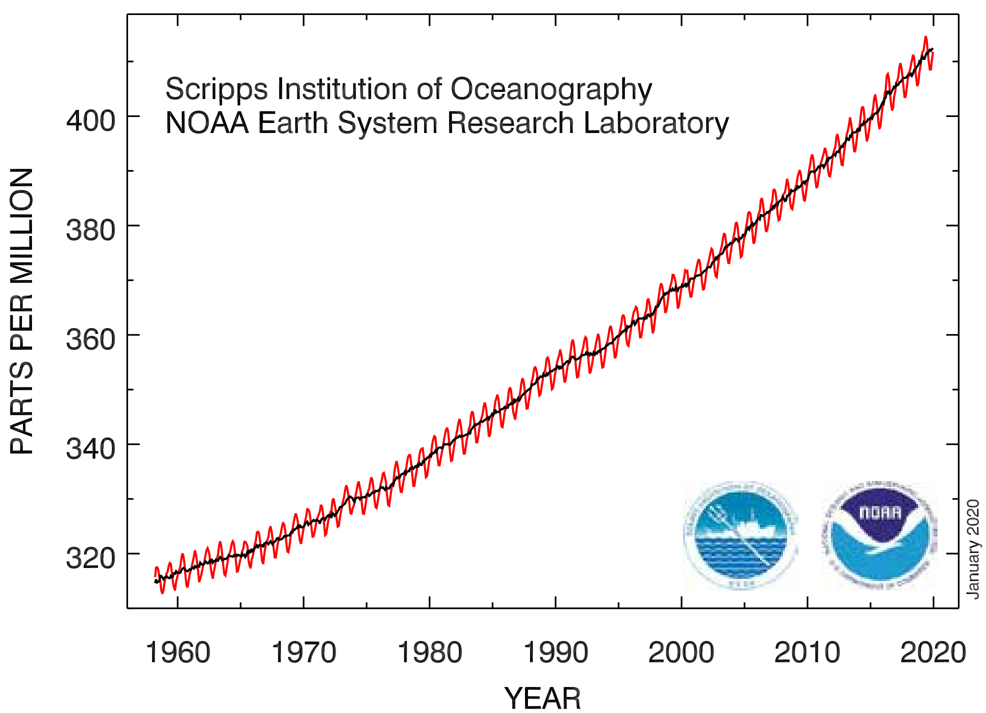
"Human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels, with a likely range of 0.8°C to 1.2°C. Global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate. (high confidence)".

IPCC Special Report [IPCC, 2018]

FIGURE 2

Monthly mean carbon dioxide at Mauna Loa Observatory, Hawaii [Trans and Keeling 2019]

Atmospheric CO_2 data on Mauna Loa constitutes the longest record of direct measurements of CO_2 in the atmosphere.



CLIMATE CHANGE INDICATORS

Physical and biological indicators can help us measure changes to the Earth's environment. Surface temperatures measured on land and at sea for more than a century show a long-term warming trend in globally averaged temperature. The spatial extent of Arctic sea ice is another useful indicator as ice grows and shrinks over the course of the year. Throughout summer, increased solar radiation and higher temperature typically result in sea ice shrinking to its minimum extent each September. Sea ice responds to warmer temperature by retreating further. Minimum sea ice (observed in September) has declined by an average of 13% per decade compared to the 1981–2010 average [Derksen et al., 2018]. Reduced ice and snow cover decreases the amount of sunlight reflected from Earth's surface and allows for more absorption of heat, which contributes to additional warming. This is an example of "positive feedback", which reinforces the warming cycle.

Studies conducted nationally and regionally have also presented other indicators of a changing climate [ECCC, 2019a; Henderson and Sauchyn, 2008; Lemmen and Warren, 2004; Meehl et al., 2007; van Oldenborgh et al., 2013; Sauchyn and Kulshreshtha, 2008; Warren and Lemmen, 2014]. Some regional studies show that changes that may be attributed to climate change are already being observed in specific components of the environment (Table 1). For example, shifts in seasonality are evident in the observed shortening of the winter season [Vincent et al., 2018], increases in vegetation growth [Ballatyne and Nol, 2015], and decreases in the establishment of perennial lake ice in Northern regions [Paquette et al., 2015]. Seasonal shifts are prominent during the melting season and indicated by earlier ice break up and earlier spring peak streamflow [Bonsal et al., 2019; Derksen et al., 2018; Du et al., 2017]. Due to challenges in attribution studies, longer observational time frames are typically required before more confident statements can be drawn linking detected changes in some indicators to climate change.

Climate change studies can often be hindered by short time frames of available observations. Indigenous peoples of regions with observable climate change impacts can provide insights into these challenges through the application of Traditional Knowledge Systems. Traditional knowledge is a separate way of knowing and is the "cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment" [Berkes, et al., 2000]. Traditional Knowledge Systems can provide distinct ways of understanding climate change, identifying indicators as well as preparing and applying innovative adaptation techniques.

TABLE 1

Sample of climate change indicators and references

Climate Change Indicators	Observation	Climate Seasonality
Climate Seasonality	Shorter winter season	Vincent et al., 2018
Permafrost Thaw Rates	Increasing depth of active layer above permafrost	Derksen et al., 2018
Aquatic Animals & Habitat	Increases in algal production	Paterson et al., 2017
Terrestrial Animals & Habitat	Decrease in nesting density of whimbrels (shore bird) due to increases in shrub cover Increase in Canada goose population	Ballatyne and Nol, 2015
Lake & Sea Ice Cover	Earlier break up of lake ice	Derksen, et al., 2018; Du et al., 2017
	Unusual loss of perennial lake ice cover	Paquette et al., 2015
	Decrease in sea ice extent	Kirchmeier-Young, et al., 2017
	Decrease in extent of ice and snow cover	Mudryk, et al., 2018
Streamflow	Earlier spring peak streamflow Higher winter and spring flows	Bonsal et al., 2019

CLIMATE CHANGE STRATEGIES

It is clear our activities as humans are resulting in climate change. Reducing GHG emissions and avoiding risks associated with climate change requires a variety of actions to address local and global challenges. We strive to understand and manage risks, liabilities, and opportunities related to climate change. The following five climate change strategies have been established to shape our response to climate change:

1. Understand
2. Report
3. Reduce
4. Support
5. Adapt

UNDERSTAND

We strive 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 we can plan for and adapt to a changing physical environment.

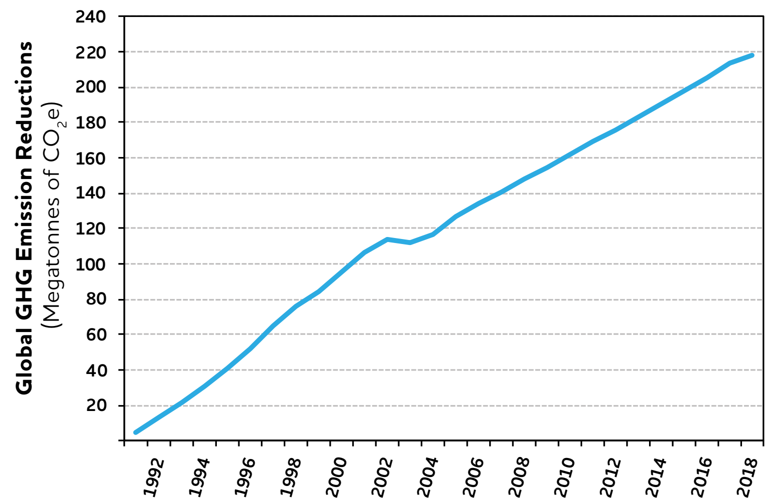
REPORT

Accurately reporting our GHG emissions is essential for us to understand our liabilities and to help us discover opportunities for further mitigation. Reporting also allows the public and governments to see how we are doing, and follow our progress. Estimating the emissions of our major projects provides transparency and clarifies their overall impact.

FIGURE 3

Global implications of Manitoba Hydro operations
[Manitoba Hydro, 2019]

Net cumulative greenhouse emission reductions.



REDUCE

Our operations have always had low GHG emissions intensity relative to other electrical utilities but our entire inventory is still emitting at historically low levels. This is because we have continued to pursue hydropower, wind generation, and demand-side management and removed coal power from our portfolio. Our overall operations continue to significantly help reduce global GHG emissions, far outweighing the impact of any direct emissions we cause.

SUPPORT

We all need effective strategies to mitigate the effects of climate change and achieve necessary GHG reductions. For more than 25 years, we have lent our technical and market expertise to support the development, evaluation, and implementation of standards, regulations, legislation, voluntary programs, and markets that aim to reduce GHG emissions. We continue to support local, regional, national, and international climate and energy policy dialogues, striving to encourage policies that are both environmentally effective and economically efficient.

ADAPT

Responding to a changing physical environment means we need robust plans for potential climate scenarios, and we need to position our operations to adapt to changing parameters like flow conditions and electrical loads. We 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.

1

UNDERSTAND

The physical environment is critical to our core business. We continue to invest resources to ensure we understand the changing climate and the potential range of climate change impacts. This positions us to adapt accordingly.

1.1 GLOBAL CLIMATE CHANGE

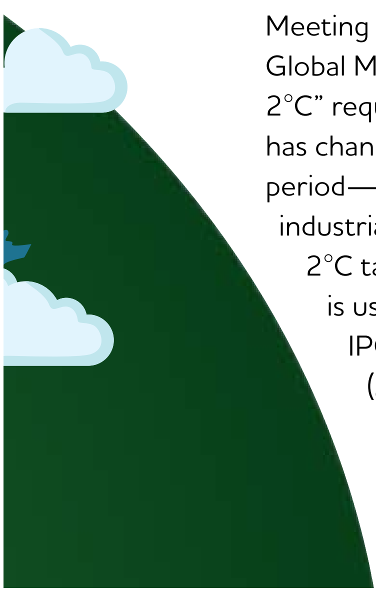
Understanding the difference between weather and climate is critical to studying climate change.

- **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 challenging to predict on a daily basis.
- **Climate** 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 many factors including: latitude, vegetation cover, distance to large bodies of water, topography, and other significant geographic features.

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].

The United Nations Environment Programme and the World Meteorological Organization established the **Intergovernmental Panel on Climate Change (IPCC)** in 1988. The IPCC was created to provide policymakers with regular scientific assessments on climate change, its implications and potential future risks, as well as to put forward adaptation and mitigation options. Along with other reports, the IPCC brings together many of the world's leading scientists to prepare comprehensive Assessment Reports about the state of scientific, technical and socio-economic knowledge on climate change; the IPCC is currently working on their sixth Assessment Report.

Meeting the Paris Agreement target of holding Global Mean Temperature (GMT) "well below 2°C" requires an understanding of how GMT has changed historically and is projected to change in the future. The pre-industrial period—until approximately 1750—corresponds to the time before large-scale industrial activity involving fossil fuel combustion and is used as a reference for the 2°C target. However, due to limited observations during this time, 1850–1900 is used by the IPCC to approximate pre-industrial GMT [IPCC, 2018]. The IPCC also commonly reports more recent baseline periods. Kirtman et al., (2013) reported a GMT increase of 0.61°C from the pre-industrial period to 1986–2005. And using the average of multiple datasets, Allen et al., (2018) estimates GMT increases of 0.63°C, 0.64°C and 0.87°C for the 1986–2005, 1981–2010, and 2006–2015 periods respectively.



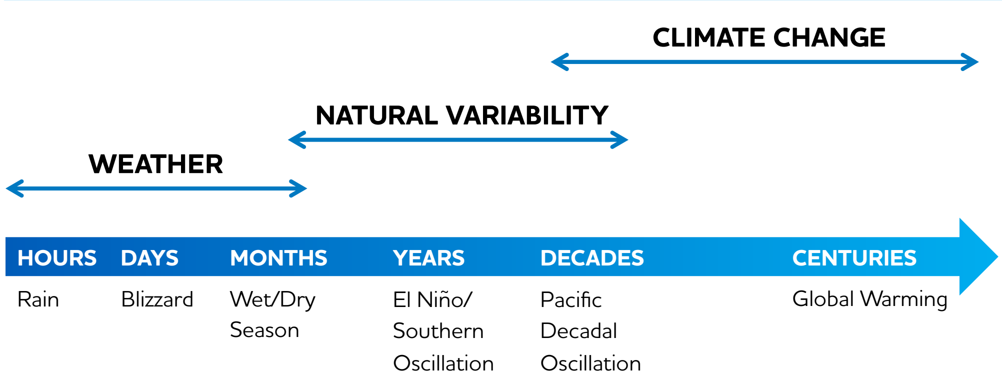
"This Agreement... aims to strengthen the global response to the threat of climate change...by holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change"

The Paris Agreement [United Nations, 2015]

Temperature is not expected to increase uniformly in space or time and there is an interest in understanding impacts at the regional and local scales, but evaluating historic changes can be challenging due to limited observations. For example, the Hadley Centre – Climatic Research Unit Version 4 dataset [Morice et al., 2012] used in Kirtman et al. (2013) and Allen et al. (2018) is gridded at 5° latitude by 5° longitude and has 11 grids that intersect Manitoba. Of these 11 grids, the earliest observation is 1872 in the grid containing Winnipeg. Considering the 1981–2010 period and using 1872–1900 as a proxy for pre-industrial times, Winnipeg has warmed approximately 2.3°C. Adjusted and Homogenized Canadian Climate Data (AHCCD) [Vincent et al., 2015] from Environment and Climate Change Canada suggests 2.6°C of warming over the same periods. Cowtan and Way (2014) applied kriging interpolation to fill gaps in the Hadley Centre – Climatic Research Unit Version 4 dataset and show an increase of 1.7°C at Winnipeg from 1850–1900 to 1981–2010, which highlights some of the uncertainty in quantifying historic changes.

Global Climate Models (GCMs) can also be used to compare projected local changes relative to increases in GMT. Following a time sampling approach [James et al., 2017] the median of 40 GCM simulations projects 2°C of GMT warming (0.61°C observed plus 1.39°C projected from 1981–2010) to occur in the 2030–2059 period. This future period corresponds to 2.4°C of additional warming at Winnipeg, relative to 1981–2010. Similarly, the average scaling relationship between GMT increase and local change developed from 40 GCM simulations project Winnipeg to warm at approximately 1.7 times the rate of GMT which is consistent with supplementary information in Seneviratne et al. (2016). Li et al. (2018) found that Canada as a whole is projected to warm at about twice the rate of GMT and shows how several extreme climate indices are projected to change. Overall, it is evident that changes in climate can occur more rapidly at the local scale relative to global average change.

FIGURE 4 **Examples of weather, natural climate variability, and climate change time scales**

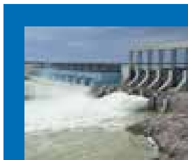


1.2 CLIMATE CHANGE & MANITOBA HYDRO

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 energy utilities like us, these changes have the potential to influence a wide variety of corporate functions (Figure 5).

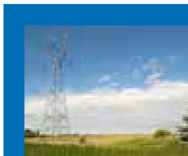
We plan, construct, and operate physical assets based on historical climatic and hydrologic conditions, and changes in climate may alter their performance. Transmission and distribution systems may be exposed to a number of vulnerabilities of climate change such as extreme weather events. We are striving to assess the risks associated with climate change and determine how best to adapt to future conditions.

FIGURE 5 Impacts of climate change on Manitoba Hydro

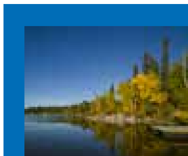


ENERGY SUPPLY
- Resource availability (water, wind)
- Generation planning and operations
- Financial planning
- Export markets

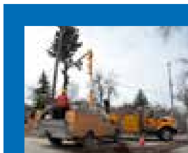
ENERGY DEMAND (Electricity and Natural Gas)
- Decreased winter heating
- Increased summer cooling
- Policy and technology changes



INFRASTRUCTURE DESIGN & MANAGEMENT
- Spillways, powerhouses, dykes, transmission and distribution towers, electrical stations, etc.
- Dam safety and asset management
- Changing codes and standards



ENVIRONMENTAL ASSESSMENTS
- Physical environment studies
- Life cycle assessment and greenhouse gas reporting
- Stakeholder engagement



HUMAN RESOURCES & CUSTOMER SERVICE
- Safety and emergency preparedness
- Working conditions for field staff
- Communication availability

We consider several study domains when conducting climate change studies. Hydrological studies consider all of the basins in the Nelson-Churchill Watershed which supply approximately 97% of our energy in the form of water. This watershed is 1.4 million km^2 which covers a sizable portion of central North America and includes a range of different ecozones and geographic areas. The average water volume and energy supplied from each of the major sub-basins is illustrated in Figure 6 as a percentage of the entire Nelson-Churchill Watershed. Other climate change studies, such as those concerning the impact of atmospheric variables on infrastructure, may consider a smaller domain such as the province of Manitoba.

1.3 MANITOBA HYDRO'S CLIMATE CHANGE STUDIES

We have initiated a series of comprehensive studies to increase our knowledge of the implications of future climate change. The main objectives of these studies is to incorporate results into long-term planning, operations, and risk management and to adapt infrastructure and business practices to continue serving our core functions.

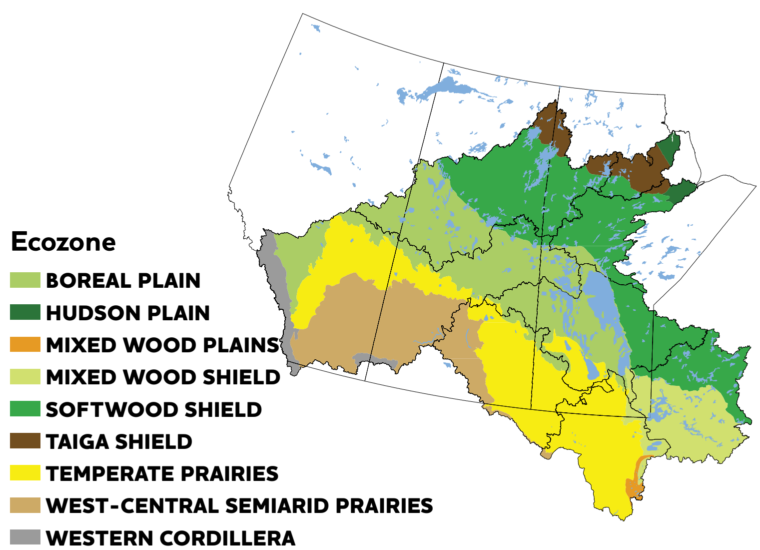
FIGURE 6

Nelson-Churchill Watershed characteristics

- Panel A illustrates the major sub-basin names and general flow direction.
- Panel B illustrates Ecozones [Commission for Environmental Cooperation, 1997].

A Major sub-basin names and general flow direction

B Ecozones



The approach to these studies is to couple impact models with outputs from reputable climate change modelling centres. We have been working with leading experts (such as those involved in the Ouranos consortium; Section 1.4) in climatology, hydrology, and atmospheric sciences. As new models and tools become available, the ability to project changes in climatic variables at the regional level will evolve.

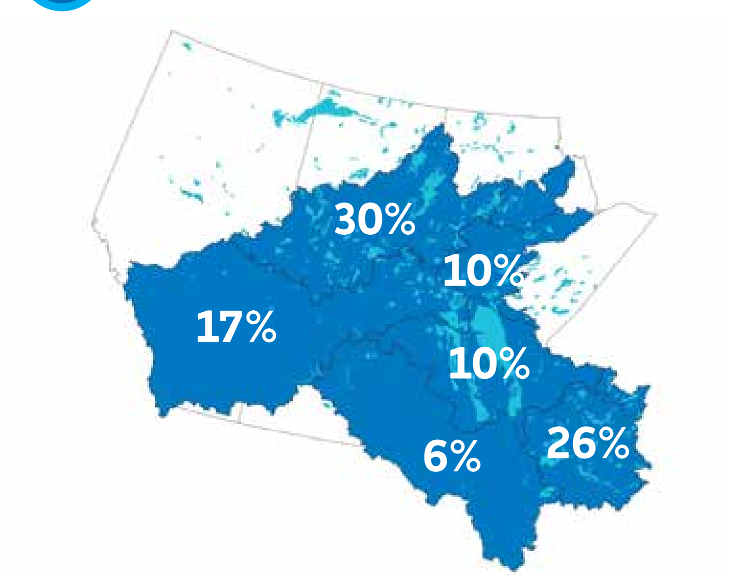
Nelson-Churchill Watershed characteristics (continued)*

- Panel C illustrates contribution of total water supply.
- Panel D illustrates contribution of total energy supply.

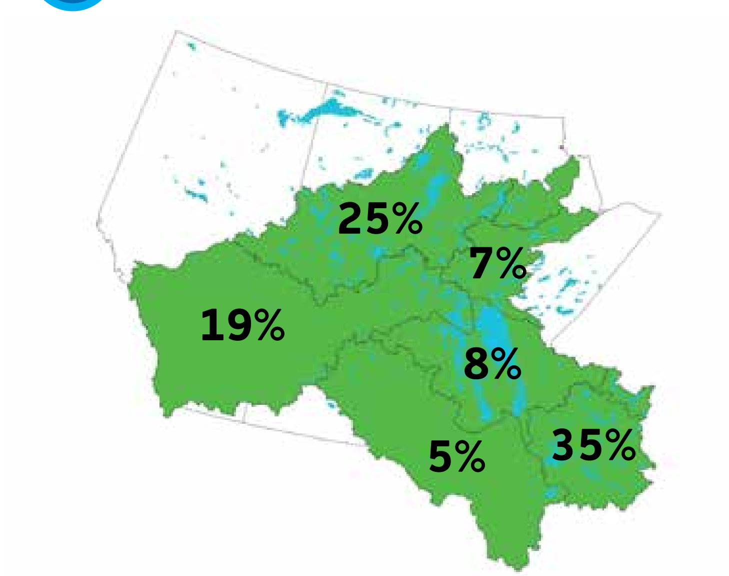
Percentages are based on 1981–2010 average inflows available for outflow. For the Churchill River, only a portion of the inflow available for outflow is diverted into the Nelson River.

*Totals may not add up to 100% due to rounding

C Contribution of total water supply (%)



D Contribution of total energy supply (%)



1.3.1 HYDROCLIMATIC MONITORING & ANALYSIS

Monitoring & analysis is an important step for characterizing the historical hydrology and climate (hydroclimate) conditions in the Nelson-Churchill Watershed. This information provides the foundation for understanding future hydroclimatic variability and change.

MONITORING

We monitor changes in the regional climate and hydrology using meteorological and hydrometric information. This information includes measurements of temperature, precipitation, wind speed, and streamflow provided by our Hydrometrics Program Environment, and Climate Change Canada (e.g., Meteorological Service of Canada and Water Survey of Canada), and other gridded and modelled datasets. Under Manitoba Hydro/Manitoba's Coordinated Aquatic Monitoring Program, we also monitor additional environmental parameters including water quality (more than 50 parameters are analyzed including temperature, dissolved oxygen, pH, etc.), phytoplankton (algae), fish community, benthic invertebrates, and sediment quality.

NORMALS (1981–2010)

In general, the annual average temperature in the Nelson-Churchill Watershed ranges from −6.5°C in the northeast to +6.1°C in the southwest. Total precipitation ranges from 323 mm in the west to 777 mm in the east with some Rocky Mountain regions exceeding 1,000 mm annually. The Nelson-Churchill Watershed shows strong seasonal patterns with colder temperatures and less precipitation in the winter, and warmer temperatures and greater precipitation in the summer. Spring and fall are shoulder seasons with temperature and precipitation normals falling between those observed during winter and summer.

Climate normals represent the average climatic conditions over a certain time period at a certain location.

The figures on the following page illustrate annual temperature and total precipitation normals across Manitoba and the Nelson-Churchill Watershed. These annual normals are also supplemented with seasonal normals. Data used to generate these figures is interpolated from observed stations to a 10 km × 10 km grid. A Canadian dataset archived by Natural Resources Canada [Hopkinson et al. 2011, Hutchinson et al. 2009] was merged with a U.S. dataset [Livneh at al., 2013] by Ouranos.

Similar to meteorological conditions, hydrological conditions (e.g., annual water supply) within the Nelson-Churchill Watershed is also spatially diverse.

FIGURE 7

Annual climate normals for average temperature (left) and total precipitation (right) (1981–2010)

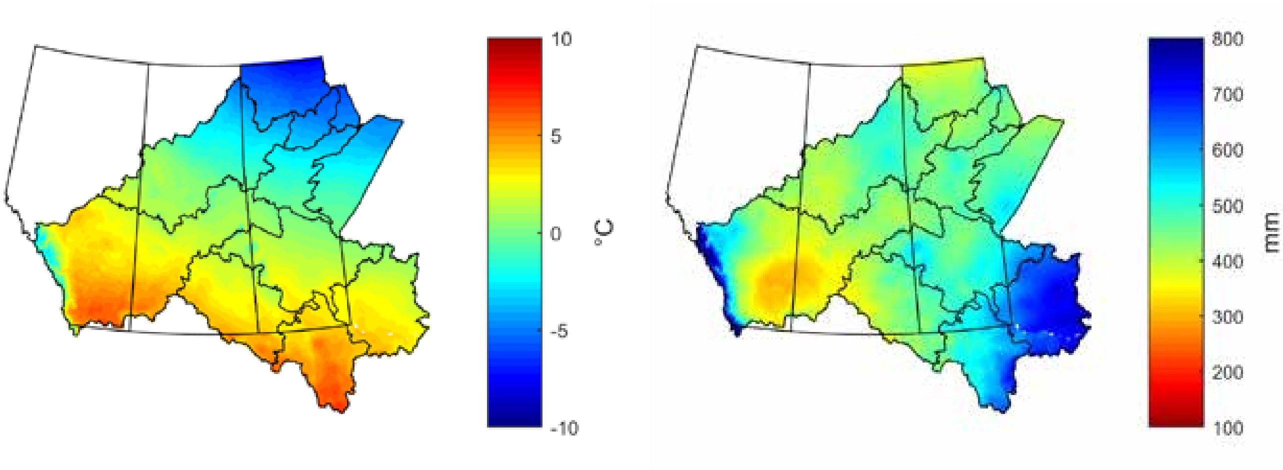


FIGURE 8

Seasonal average temperature normals (1981–2010)

Seasons are winter (DJF), spring (MAM), summer (JJA), and fall (SON).

Winter Spring Summer Fall

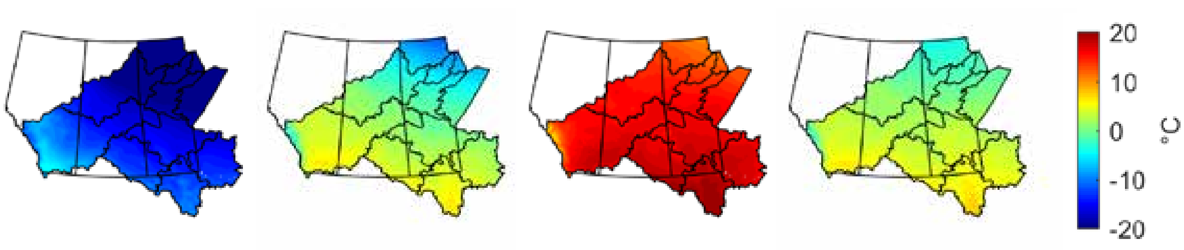


FIGURE 9

Seasonal precipitation normals (1981–2010)

Seasons are winter (DJF), spring (MAM), summer (JJA), and fall (SON).

Winter Spring Summer Fall

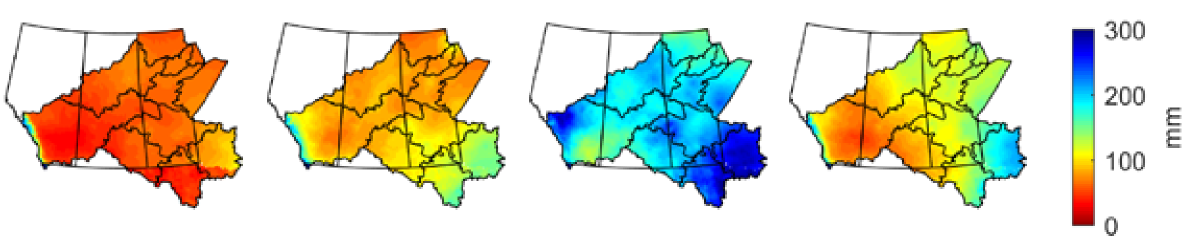


Table 2 summarizes the average streamflow conditions for contributing sub-basins of the Nelson-Churchill Watershed for the 1981–2010 period. Average streamflow near the outlets of each basin varies from 48 cubic metres per second (m^3/s) from the Assiniboine River Basin to 947 m^3/s from the Winnipeg River Basin.

TABLE 2

Average annual streamflow near basin outlets (1981–2010)

Basin	Station Name	Outlet Gauge ID	Annual Streamflow (m^3/s)		
			Min	Mean	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	05PF063	458	947	1415
Lake Winnipeg[c]	East and West Channels	05UB008 05UB009	1139	2181	3566
Churchill River	Churchill River above Leaf Rapids	06EB004	574	844	1321
Nelson River[c,d]	Nelson River at Kettle Rapids	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

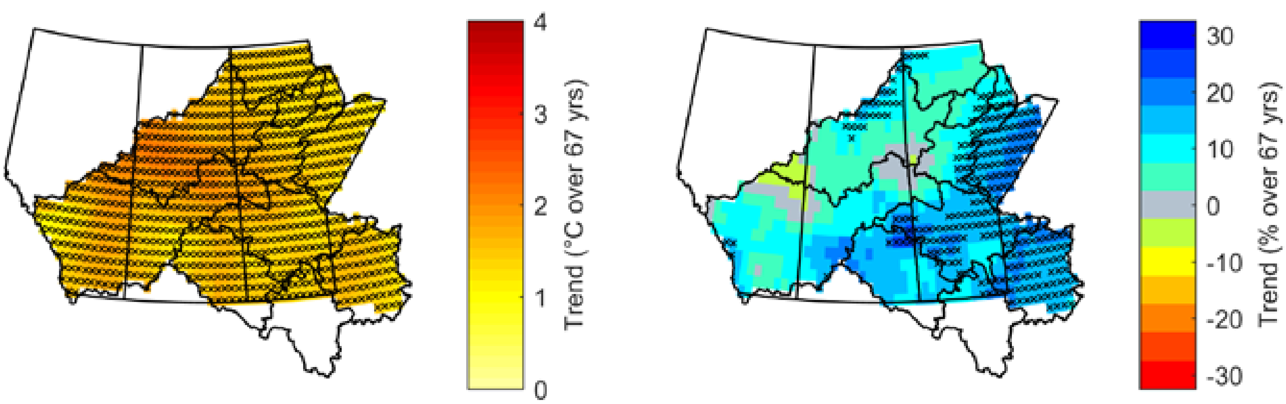
TRENDS

A gridded version of Environment and Climate Change Canada's AHCCD is used to evaluate temperature and precipitation trends. All grids within Manitoban and Canadian portions of the Nelson-Churchill Watershed show statistically significant increasing mean temperature trends over the 1948–2014 period. Statistically significant changes to precipitation were also found in some regions, however, the results are less spatially consistent (Figure 10). Most grids show increasing precipitation trends but decreasing trends can also be found. Despite the variability in precipitation trend direction and magnitude, there seems to be evidence that precipitation has increased in eastern portion of the Nelson-Churchill Watershed. Vincent et al. (2015) presents seasonal trends, examines different time periods, and looks at additional variables such as the snowfall ratio, snow cover, snow depth, and streamflow.

FIGURE
10

Historic trends for mean annual temperature (left) and mean annual precipitation (right) (1948–2014)

Hatching indicates statistically significant trends at the 5% level. This dataset does not contain information for the United States.

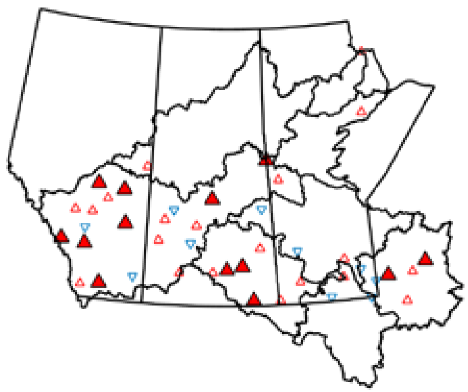


Regional and global trends in extreme events are described in the IPCC's Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change [SREX, 2012] which generally reports greater confidence in temperature-related extremes. Trends in extreme events vary spatially throughout Manitoba. Figure 11 illustrates trends in extreme low temperatures using point values from Environment and Climate Change Canada's AHCCD, for stations with suitable data from 1948 to 2014. Results show increases throughout a large portion of the Nelson-Churchill Watershed with only a few stations reporting insignificant trends. Results are similar for other temperature-related variables including decreases in frost and ice days, increased growing season length, and reduced cold spell durations.

FIGURE
11

Historic trends in extreme minimum temperature using Adjusted and Homogenized Canadian Climate Data (1948–2014)

Triangle orientation indicates the direction of the trend. Larger filled triangles indicate statistically significant trends, while smaller open triangles indicate stations where trends are not statistically significant. Colours also indicate trend direction where red shows an increase in temperature and blue shows a decrease. This dataset does not contain information for the United States.



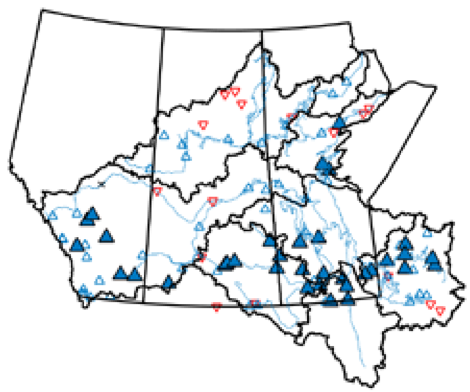
Trends in extreme precipitation events are less consistent in space, but show some instances of statistically significant increases in the number of cumulative wet days, and reduced number of cumulative dry days. Some other precipitation-related extreme indices show varied results with increases in some regions and decreases in other 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 about. Vincent et al. (2018) provides a more comprehensive view of changes to extreme indices derived from daily temperature and precipitation data.

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 unadjusted Water Survey of Canada data, statistically significant increasing trends in mean annual streamflow were detected for a number of streamflow gauges in the Nelson-Churchill Watershed (Figure 12). Special interpretation is required at some sites due to anthropogenic influences such as diversions in the Winnipeg River Basin and on the Burntwood and Nelson rivers.

FIGURE 12

Historic trends for mean annual streamflow using unadjusted water survey of Canada data (1975–2014)

Triangle orientation indicates the direction of the trend. Large filled triangles indicate statistically significant trends, while smaller open triangles indicate stations where trends are not statistically significant. Colours also indicate trend direction where blue shows an increase in flow and red shows a decrease. This dataset does not contain information for the United States.



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 variability. Trend analysis results 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.

ADDITIONAL DATA SOURCES

We also use a number of additional data sources to understand historic climate. These data sources include paleoclimate data, oceanic oscillations, reanalysis products from numerical models, and remote-sensed data from satellites.

Paleoclimate data is recognized as a potential source for extending observed records back in time. Sources of paleoclimate data include tree rings and lake sediments which can be correlated to hydroclimatic variables and used as proxy records. We are interested in exploring the use of these datasets in our hydroclimatic studies, but direct applications are currently limited due to availability of long term spatially consistent proxy records and uncertainties in reconstructed hydroclimatic time series, especially in watersheds as large and diverse as the Nelson-Churchill Watershed. We follow the advances of paleoclimatic reconstruction techniques and explore potential applications of paleoclimatic records to better inform our decision making.

We also seek to understand connectivity between observed phenomena (such as oceanic oscillations and sun spots) and hydroclimate in the Nelson-Churchill Watershed. While some variability may be explained through study of these relationships, there are challenges in operationalizing the information throughout the entire hydraulic system due to spatial variability and the absence of a single signal that accurately predicts water supply in all hydrological conditions (i.e. wet, dry, and average flow years).

1.3.2 CLIMATE CHANGE SCENARIOS

In addition to leading research, compiling information, and providing climate change study guidance, the IPCC also brings together international modelling agencies that have developed GCMs to conduct assessments. The IPCC's Fifth Assessment Report was released in 2013 and is the most recent report available. Work is currently underway for the Sixth Assessment Report and it is scheduled for publication in 2021 and 2022. The Fifth Assessment Report was based on results using a 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. Simulations and analyses are currently underway for CMIP6, which include a number of special experiments such as an abrupt quadrupling of CO_2 simulation [Eyring et al., 2016].

Representative Concentration Pathways (RCPs) represent socio-economic and emission scenarios used as inputs for climate models to explore plausible future conditions. RCPs consider multiple factors including population, technology, energy use, and emissions of greenhouse gases. Four RCPs describe a range of future worlds and their associated warming potential as a function of radiative forcing measured in watts per square meter (W/m^2). RCP8.5 is a high end scenario (high energy intensity, high population growth, limited technology development, and limited climate policy) and is associated with an increase of 8.5 W/m^2 of additional warming on the earth's surface.

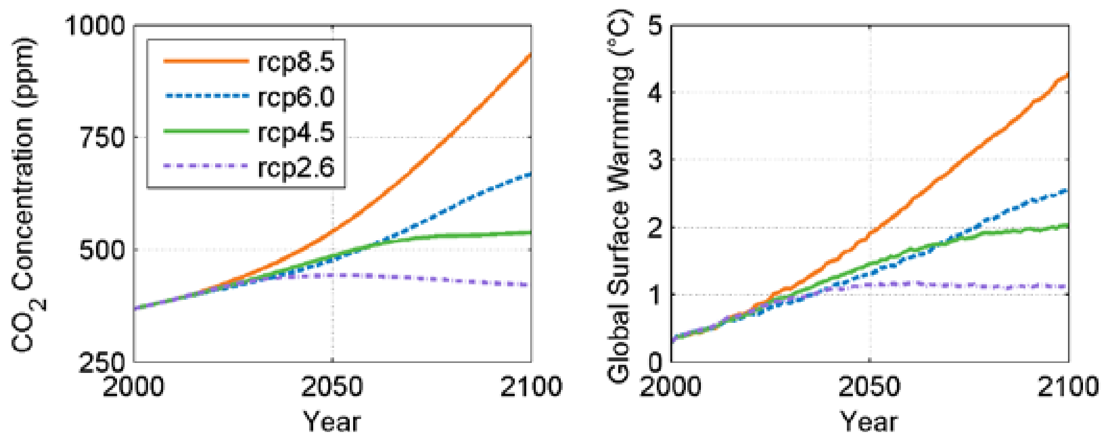
GCMs are numerical models used to translate future atmospheric forcing (e.g. GHG concentrations) scenarios into physically consistent effects on the climate. GCMs compute energy and mass balances based on physical equations and are the most advanced tools for projecting future climate. GCM is used herein as a generic term referring to Atmosphere-Ocean General Circulation Models and Earth System Models. GCMs couple multiple sub-models which simulate various processes including the atmosphere, ocean, land surface, sea ice, and biosphere. Common variables of interest such as air temperature, precipitation, pressure, and wind are products of the atmospheric sub-model. Hydrology is represented coarsely within land surface schemes which output variables such as runoff and soil moisture.

GCMs are forced by Representative Concentration Pathways (RCP) [van Vuuren et al., 2011] 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

13

Trajectories of CO_2 concentration and modelled global surface warming from various Representative Concentration Pathways



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 which can make it challenging to interpret projected changes at finer scales. 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. 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 23 and 24 illustrate the resolution of the Canadian Centre for Climate Modelling and Analysis Canadian Earth System Model version 2 (CanESM2) compared to two RCMs.

Manitoba Hydro (2015a) employed a GCM simulation ensemble of opportunity (147 simulations from 18 GCMs available at the time) to develop future climate projections. Reflected in this report, the GCM simulation selection process was recently improved to provide a more democratic ensemble [Sanderson et al., 2015]. Future climate projections are based on an ensemble of 40 simulations from 18 GCMs, shown in Table 3.

The selection captures GCM simulations with both RCP4.5 and RCP8.5 forcing scenarios that contain monthly output for variables of interest (minimum, maximum, and mean temperature, precipitation, evapotranspiration, runoff, and wind speed) spanning 1981–2099. The selection process reduces over-representation of GCMs with multiple member runs and modelling agencies with multiple GCMs. The Kullback-Liebler Divergence [Knutti et al., 2013] was used to guide GCM simulation selection and ensure that a wide range of GCM projection uncertainty was sampled. Figure 14 illustrates the difference between the original 147 simulation ensemble and the new ensemble (sub-set) of 40 simulations. This particular comparison shows that the 40 simulation ensemble forecasts a similar, but slightly warmer and wetter, future compared to the original ensemble on an annual basis. For certain studies, RCMs such as the Canadian Regional Climate Model or the Weather Research Forecast Model are also used and allow analysis at finer spatial resolution.

TABLE 3

Global Climate Models [Flato et al., 2013]*

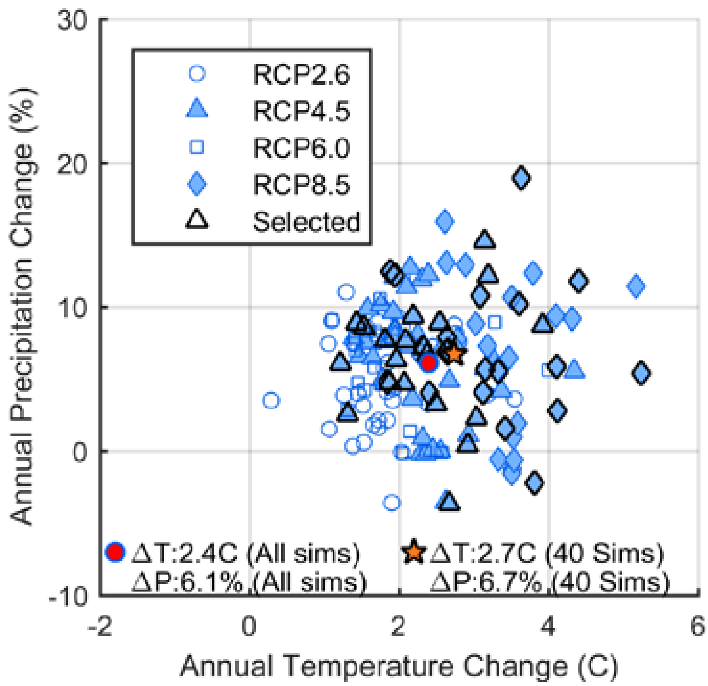
Model	Country	Number of Simulations		Ensemble Representation by Model Agency
		RCP4.5	RCP8.5	
BCC-CSM1.1	China	1	1	10%
BCC-CSM1.1(m)	China	1	1	
BNU-ESM	China	1	1	5%
CanESM2	Canada	2	2	10%
CMCC-CM	Italy	1	1	5%
CSIRO-Mk3.6.0	Australia	2	2	10%
GFDL-ESM2g	USA	1	1	10%
GFDL-ESM2m	USA	1	1	
GISS-E2-H	USA	1	1	10%
GISS-E2-R	USA	1	1	
INM-CM4	Russia	1	1	5%
IPSL-CM5a-MR	France	1	1	10%
IPSL-CM5b-LR	France	1	1	
MIROC5	Japan	1	1	10%
MIROC-ESM	Japan	1	1	
MPI-ESM-LR	Germany	1	1	10%
MPI-ESM-MR	Germany	1	1	
MRI-CGCM3	Japan	1	1	5%

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

FIGURE
14

Projected changes in annual precipitation and temperature within the Nelson-Churchill Watershed for the 2050s relative to 1981–2010

Each point represents a Global Climate Model simulation with the selected 40 simulations outlined in black. Red circle marker denotes the ensemble average from all simulations while the orange star marker denotes the ensemble average from the sub-set of 40 simulations.

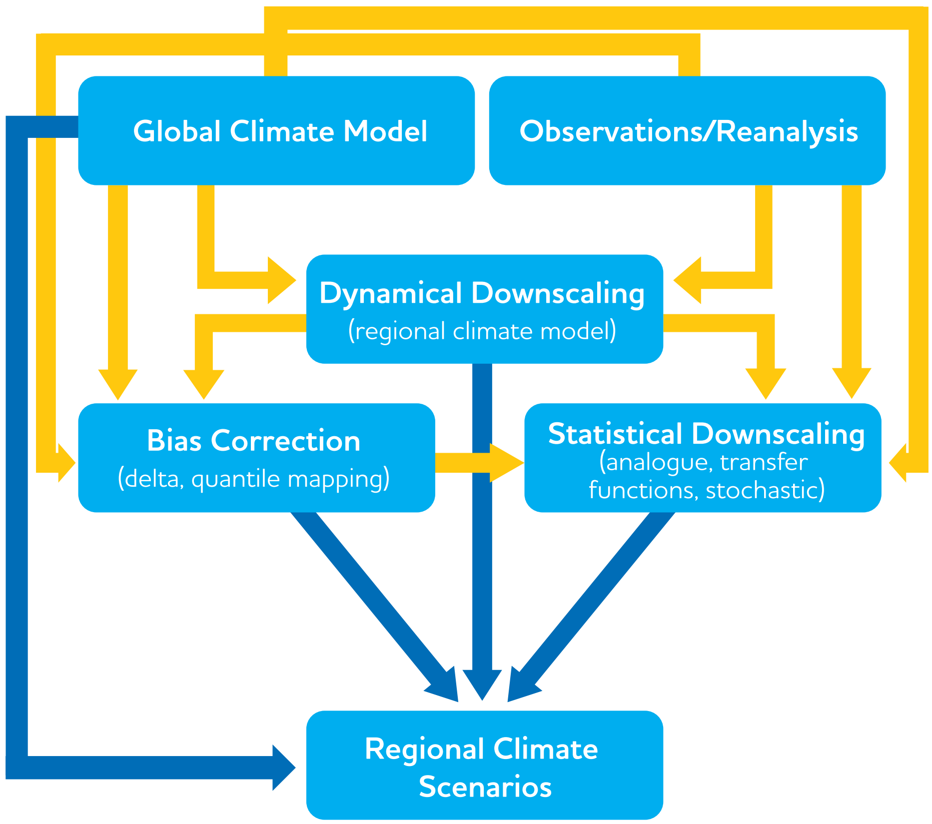


Most climate models (GCMs and RCMs) have a tendency to underestimate or overestimate baseline climate conditions. These differences in climate models are called biases when they occur consistently. Applying adjustments to raw climate simulations before they are used in a regional climate analyses is one way we handle these biases. We apply various methods to develop regional scenarios such as dynamic downscaling with a RCM, bias correction with quantile mapping, and the delta method (Figure 15). Bias correction methods aim to adjust the climate simulation time series such that it better matches historic observations while delta methods add the change computed from climate simulations to the observed record [Huard et al., 2014]. 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.

To assist with developing quality regional climate change (downscaled) projections we have become an affiliated member of the Ouranos consortium (Section 1.4). Through its affiliation we gain access to expert guidance for analytical processes used to resolve key features of regional climate and Ouranos' Canadian RCM data.

FIGURE 15

Downscaling methods



For the Nelson-Churchill Watershed the GCM ensemble median (using the 40 simulation ensemble of RCP4.5 and RCP8.5) projected changes (deltas) in minimum, maximum, and mean temperature, precipitation, evaporation, runoff, and wind speed for the 2050s (2040–2069) are presented in Table 4, and Figures 16, 17, 19, 20, and 21. Figures present deltas obtained from raw GCM data that have been interpolated to a common grid of 1° latitude by 1° longitude. Future streamflow projections can be found in Section 1.3.3.

Agreement among GCM projections can provide a measure of confidence. For example, mean annual temperature in the Nelson-Churchill Watershed will likely increase as all GCM projections are in agreement on this direction of change. Some literature refers to this type of information as a measure of robustness or evidence supporting a signal. The IPCC [Mastrandrea et al., 2010] provides guidance on treating uncertainty and suggests qualifiers to express confidence and likelihood (virtually certain; very likely; likely; about as likely as not; unlikely; very unlikely; and, exceptionally unlikely). Since we rely on an ensemble of GCM simulations, we use agreement among these simulations about the direction of projected change to characterize the climate change signal:

- strong increase or strong decrease describes signals where 90% to 100% of GCM projections are in agreement;
- moderate increase or moderate decrease describes signals where 76% to 89% of GCM projections are in agreement;
- weak increase or weak decrease describes signals where 61% to 75% of GCM projections are in agreement;
- no signal describes instances where only 50% to 60% of GCM projections are in agreement.

These definitions provide a simple means of better understanding certainty in the direction of change but do not provide information about the magnitude of change. The GCM ensemble median is used as a best guess for the magnitude.

Projections are presented and discussed separately, by climate variable, below. Projections are tabulated in Tables 4 to 7 and illustrated in Figures 16, 17, 19, 20, and 21.

TABLE 4 **Global Climate Model ensemble median annual projections for the 2050s relative to 1981–2010**

Watershed	Temperature			Precipitation	Evaporation	Runoff	Wind Speed
	Min	Mean	Max				
Churchill River	3.1°C ↑	2.7°C ↑	2.5°C ↑	7.1% ↑	8.4% ↑	4.0% ↑	-0.7% ↓
Saskatchewan River	2.6°C ↑	2.5°C ↑	2.3°C ↑	6.9% ↑	7.8% ↑	6.2% ↑	-0.9% ↓
Assiniboine River	2.9°C ↑	2.7°C ↑	2.5°C ↑	7.6% ↑	8.5% ↑	-1.2% ↓	-0.5% ↓
Red River	2.9°C ↑	2.8°C ↑	2.6°C ↑	5.6% ↑	7.3% ↑	-1.1% ↓	-0.5% ↓
Winnipeg River	3.1°C ↑	2.8°C ↑	2.4°C ↑	6.9% ↑	8.2% ↑	3.3% ↑	-0.4% ↓
Lake Winnipeg	3.1°C ↑	2.8°C ↑	2.6°C ↑	7.1% ↑	9.1% ↑	2.3% ↑	-0.3% ↓
Nelson River	3.2°C ↑	2.9°C ↑	2.6°C ↑	6.2% ↑	8.0% ↑	1.4% ↑	0.1% ↑
Nelson-Churchill Watershed	2.9°C ↑	2.7°C ↑	2.5°C ↑	6.8% ↑	7.8% ↑	4.6% ↑	-0.7% ↓

TEMPERATURE

GCMs show a strong signal that temperature will increase in the future at annual and seasonal scales. Annually, the Nelson-Churchill Watershed is projected to experience mean temperatures that are 2.7°C warmer than the baseline. This corresponds to slightly greater changes in the average minimum temperature relative to changes in the average maximum temperature.

Seasonally, the Nelson-Churchill Watershed is projected to experience greater temperature increases in the winter relative to other seasons. This is supported in literature suggesting that reduced snow cover in a warmer climate provides lower reflectance (surface albedo) of incoming solar radiation and therefore more absorption of heat by the land surface.

Similarly, northern areas are projected to experience greater temperature increases relative to southern areas. One exception to this projection is during summer months where southern areas may experience slightly greater increases than northern areas. This behaviour is possibly due to the absence of precipitation which reduces capacity for evaporative cooling in the summer.

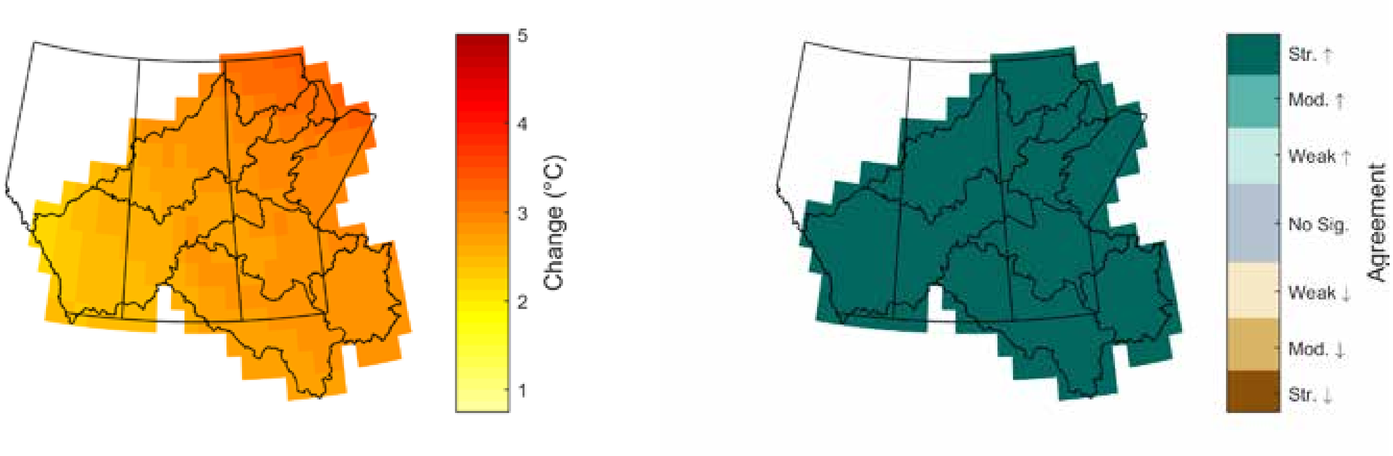
TABLE 5 **Global Climate Model ensemble median seasonal temperature projections for the 2050s relative to 1981–2010**

Watershed	Winter	Spring	Summer	Fall
Churchill River	3.8°C ↑	2.4°C ↑	2.2°C ↑	2.8°C ↑
Saskatchewan River	3.1°C ↑	2.1°C ↑	2.5°C ↑	2.5°C ↑
Assiniboine River	3.5°C ↑	2.3°C ↑	2.6°C ↑	2.8°C ↑
Red River	3.5°C ↑	2.3°C ↑	2.6°C ↑	2.7°C ↑
Winnipeg River	3.4°C ↑	2.4°C ↑	2.6°C ↑	2.7°C ↑
Lake Winnipeg	3.6°C ↑	2.5°C ↑	2.5°C ↑	2.8°C ↑
Nelson River	3.9°C ↑	2.6°C ↑	2.3°C ↑	2.9°C ↑
Nelson-Churchill Watershed	3.4°C ↑	2.3°C ↑	2.4°C ↑	2.7°C ↑

FIGURE
16

Global Climate Model ensemble median projected change (left) and agreement (right) for 2050s mean annual temperature relative to 1981–2010 (top panels)

Seasonal projected change and agreement shown in lower panels. Seasons are winter (DJF), spring (MAM), summer (JJA), and fall (SON).

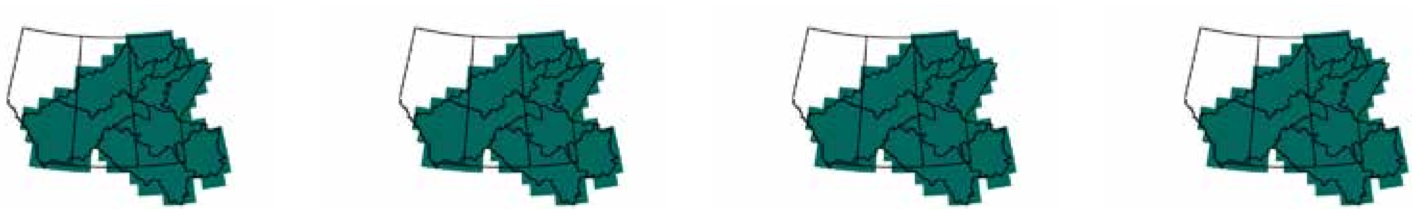


SEASONAL PROJECTED CHANGE

Winter	Spring	Summer	Fall

SEASONAL AGREEMENT

Winter	Spring	Summer	Fall



PRECIPITATION

Annually, the GCM ensemble shows a moderate to strong signal that annual precipitation will increase in the Nelson-Churchill Watershed. The ensemble median projects a spatially averaged 6.8% increase.

The GCM ensemble shows moderate to strong signals that precipitation will increase in winter and spring accompanied with weak to strong signals that precipitation will increase in fall. Southern (northern) basins project decreasing (increasing) summer precipitation but the agreement is weak.

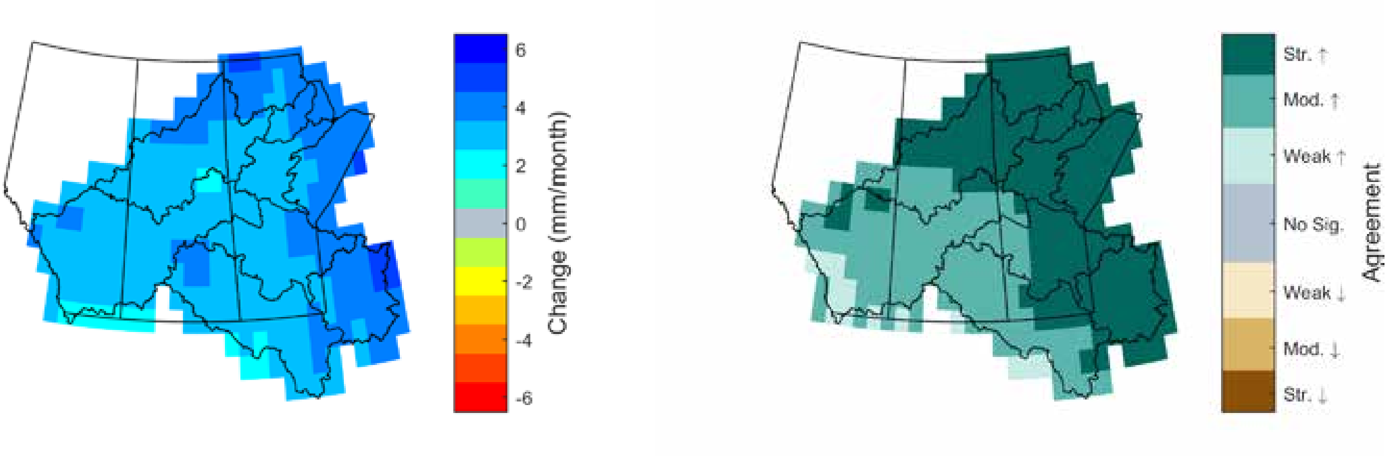
TABLE 6 **Global Climate Model ensemble median seasonal precipitation projections for the 2050s relative to 1981–2010**

Watershed	Winter	Spring	Summer	Fall
Churchill River	11.3% ↑	10.5% ↑	4.7% ↑	8.1% ↑
Saskatchewan River	9.2% ↑	14.3% ↑	-0.4% ↓	5.6% ↑
Assiniboine River	9.2% ↑	16.8% ↑	-1.7% ↓	8.3% ↑
Red River	7.7% ↑	11.7% ↑	-0.8% ↓	5.0% ↑
Winnipeg River	11.3% ↑	11.5% ↑	-0.1% ↓	5.7% ↑
Lake Winnipeg	11.3% ↑	12.2% ↑	0.0% ↔	7.6% ↑
Nelson River	12.8% ↑	10.7% ↑	2.1% ↑	6.5% ↑
Nelson-Churchill Watershed	10.9% ↑	14.0% ↑	0.1% ↑	7.8% ↑

FIGURE 17

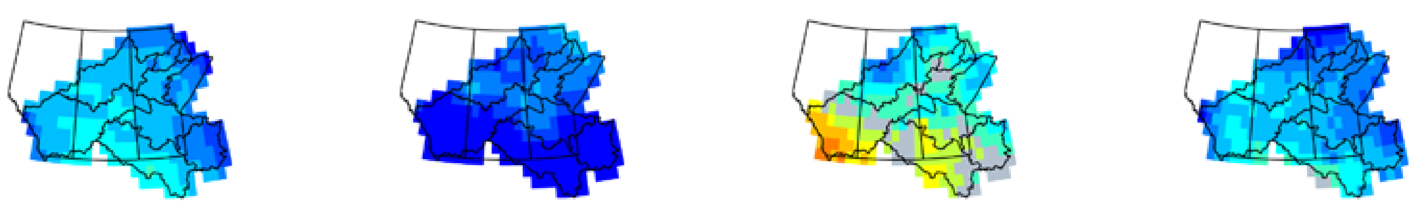
Global Climate Model ensemble median projected change (left) and agreement (right) for 2050s mean annual precipitation relative to 1981–2010 (top panels)

Seasonal projected change and agreement shown in lower panels. Seasons are winter (DJF), spring (MAM), summer (JJA), and fall (SON).



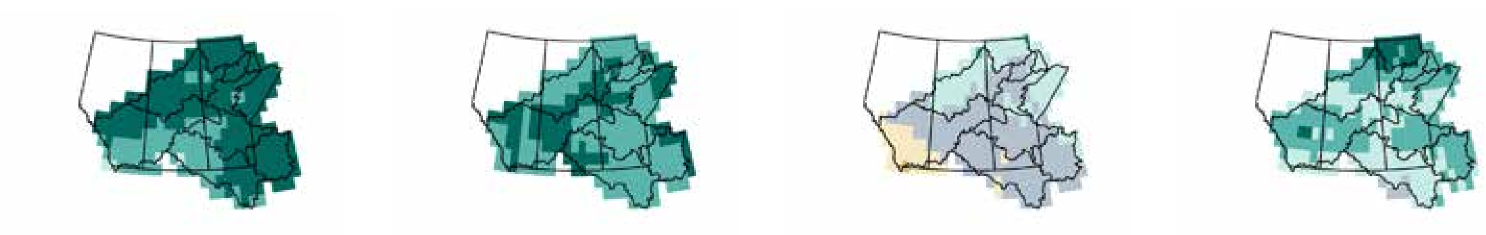
SEASONAL PROJECTED CHANGE

Winter	Spring	Summer	Fall



SEASONAL AGREEMENT

Winter	Spring	Summer	Fall



EVAPORATION

The GCM ensemble shows moderate to strong signals that evaporation will increase in the future annually as well as in winter and spring. Increases are also projected for summer and fall, but there are regions of less agreement (weaker signals; Figure 19).

This is largely due to evaporative potential being driven by temperature and precipitation.

FIGURE 18

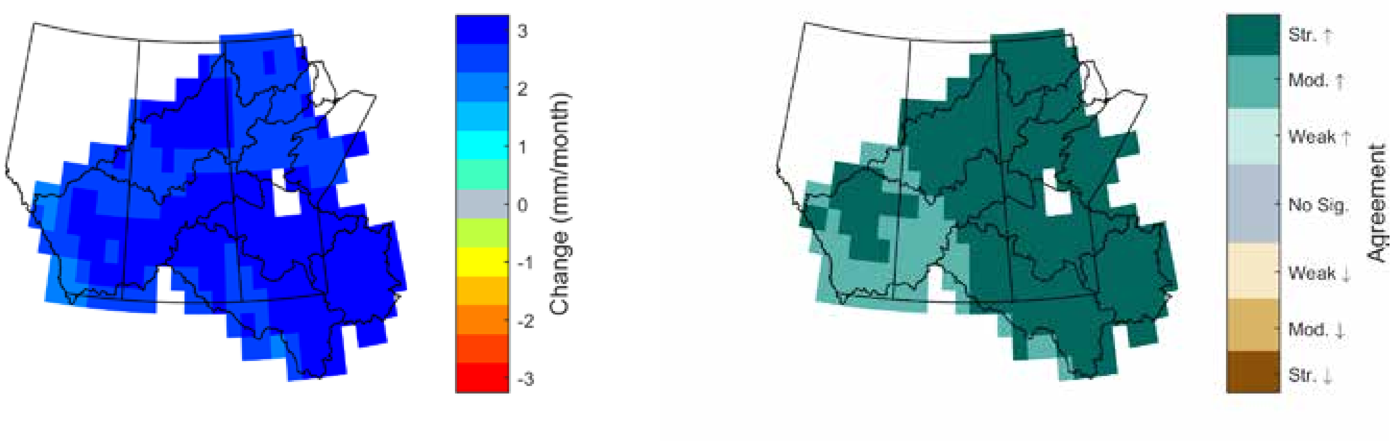
January morning evaporation near the Long Spruce generating station

Despite frigid air temperatures, evaporation can still occur in winter. When cold, dry air blows over a (relatively) warm water body, it is heated by the water's surface and humidified through evaporation. This relatively warm air quickly cools as it rises from the water surface, causing the water vapour in the air to condense into a thick fog.

FIGURE 19

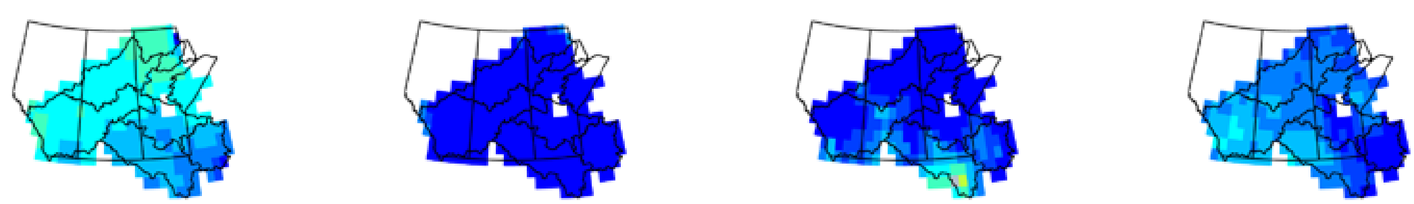
Global Climate Model ensemble median projected change (left) and agreement (right) for 2050s mean annual evaporation relative to 1981–2010 (top panels)

Seasonal projected change and agreement shown in lower panels. Seasons are winter (DJF), spring (MAM), summer (JJA), and fall (SON). Some grids are masked due to differences in GCM land surface schemes and representation of large water bodies like Lake Winnipeg.



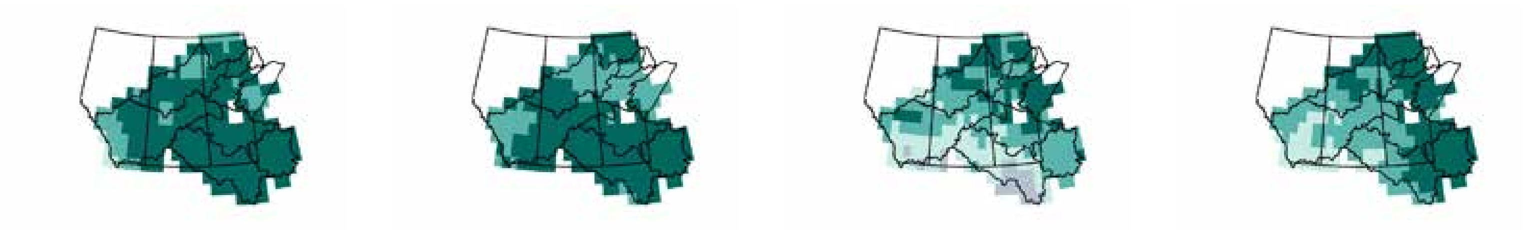
SEASONAL PROJECTED CHANGE

Winter	Spring	Summer	Fall



SEASONAL AGREEMENT

Winter	Spring	Summer	Fall



RUNOFF

GCM runoff is used as a basic measure of water availability [Frigon, 2010] to better understand changes in water supply. Due to limitations in GCM representations of hydrological processes (e.g., coarse resolution and lack of routing) GCM runoff is used as a preliminary variable, providing a broad view of how runoff is projected to change over large geographic areas. GCM runoff projections are complemented with more thorough hydrological modelling to examine finer details such as seasonal shifts in timing at finer temporal and spatial resolutions. This is covered in Section 1.3.3.

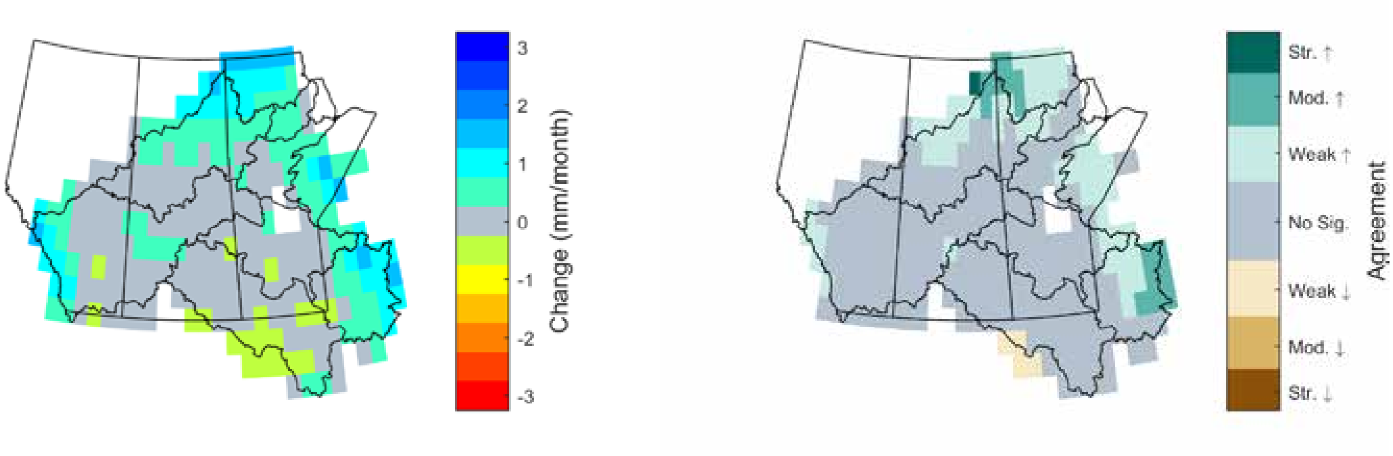
The GCM ensemble median projects a 4.6% increase in mean annual runoff in the Nelson-Churchill Watershed, but there is little agreement among GCM simulations in most areas. Some northern and eastern parts of the watershed show weak to moderate agreement that runoff will increase annually and a small area in the south shows weak agreement that runoff will decrease. Similar signals are seen for summer and fall.

In contrast, a strong signal is seen throughout a majority of the basin indicating that winter runoff will increase. This is likely due to warmer temperatures reducing the duration when precipitation is stored as snow and not contributing to runoff. Warmer temperatures may also lead to increased rain-on-snow events and snowmelt which contribute to runoff. GCMs also show weak agreement in a large portion of the watershed that spring runoff will decrease. This behaviour can likely be attributed to reduced snowpack accumulated over the winter or increased temperatures causing more evaporation. It is important to note that for large basins, seasonal runoff changes may not directly correspond to streamflow changes in the same season as there is often a lag due to river routing, lake attenuation, and regulation.

FIGURE 20

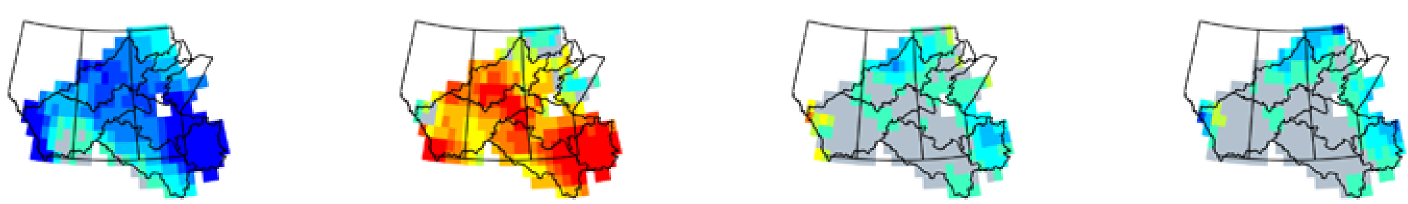
Global Climate Model ensemble median projected change (left) and agreement (right) for 2050s mean annual runoff relative to 1981–2010 (top panels)

Seasonal projected change and agreement shown in lower panels. Seasons are winter (DJF), spring (MAM), summer (JJA), and fall (SON). Some grids are masked due to differences in GCM land surface schemes and representation of large water bodies like Lake Winnipeg.



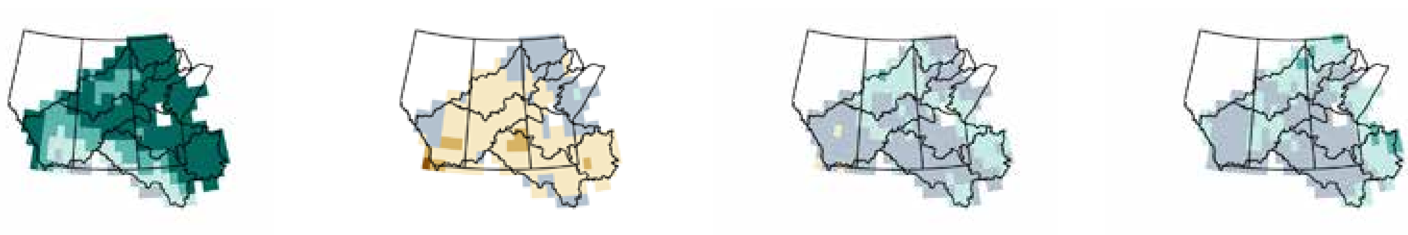
SEASONAL PROJECTED CHANGE

Winter	Spring	Summer	Fall



SEASONAL AGREEMENT

Winter	Spring	Summer	Fall



WIND SPEED

The GCM ensemble shows little evidence of changes to mean wind speed in a majority of the Nelson-Churchill Watershed. A few signals emerge but should be interpreted with caution due to associated uncertainty.

Overall, a small decrease in mean annual wind speed is projected for southern regions. There is evidence of decreases in mean summer wind speed throughout a majority of the basin, but the signal varies from weak to moderate. There is also some evidence of increasing wind speed in coastal regions neighbouring the Hudson Bay in the winter.

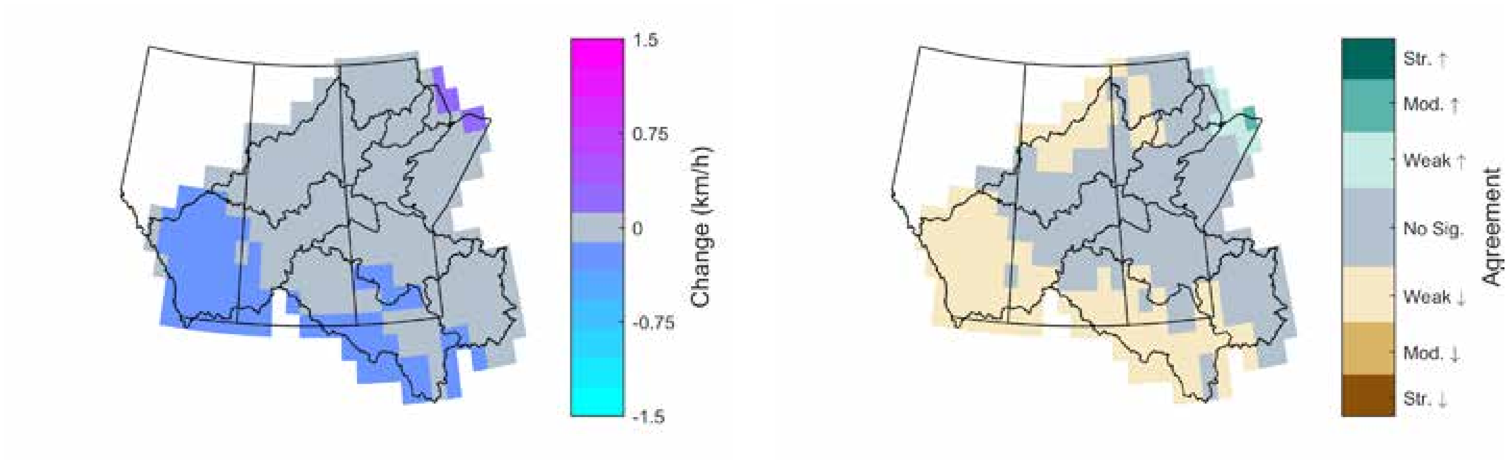
TABLE 7 **Global Climate Model ensemble median seasonal wind speed projections for the 2050s relative to 1981–2010**

Watershed	Winter	Spring	Summer	Fall
Churchill River	0.3% ↑	-0.5% ↓	-2.1% ↓	0.4% ↑
Saskatchewan River	-0.6% ↓	-1.0% ↓	-3.2% ↓	0.0% ↔
Assiniboine River	-1.0% ↓	-1.1% ↓	-3.1% ↓	-0.4% ↓
Red River	-0.6% ↓	-0.4% ↓	-2.8% ↓	-1.2% ↓
Winnipeg River	-0.2% ↓	0.1% ↑	-1.7% ↓	-0.6% ↓
Lake Winnipeg	-0.1% ↓	-0.7% ↓	-1.8% ↓	-0.4% ↓
Nelson River	1.9% ↑	0.1% ↑	-1.4% ↓	0.3% ↑
Nelson-Churchill Watershed	-0.7% ↓	-0.8% ↓	-2.8% ↓	-0.3% ↓

FIGURE 21

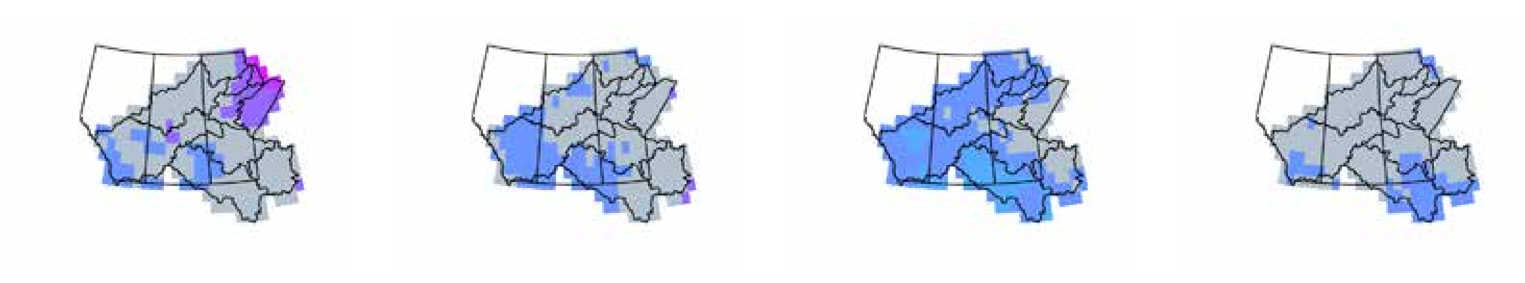
Global Climate Model ensemble median projected change (left) and agreement (right) for 2050s mean annual wind speed relative to 1981–2010 (top panels)

Seasonal projected change and agreement shown in lower panels. Seasons are winter (DJF), spring (MAM), summer (JJA), and fall (SON).



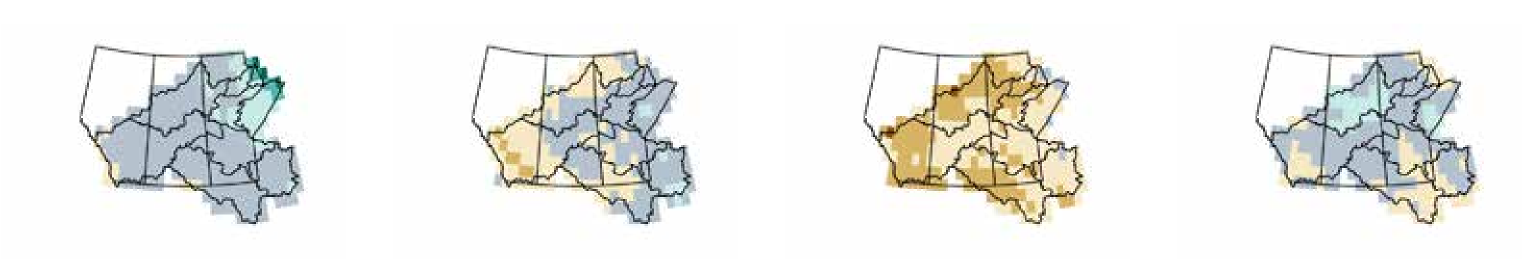
SEASONAL PROJECTED CHANGE

Winter	Spring	Summer	Fall



SEASONAL AGREEMENT

Winter	Spring	Summer	Fall



EXTREME EVENTS

Projections of extreme events and their associated impacts are important, but greater uncertainty surrounds studies of future extremes than surrounds studies projecting changes in mean climatic conditions. The definition of an extreme event may also vary from group to group.

Our analysis of extreme events is ongoing. We combine regional analysis with peer-reviewed and published scientific literature [e.g. Li et al., 2018; Sillmann et al., 2013; SREX, 2012].

Generally, climate models are projecting more pronounced changes in temperature-based extreme indices, especially minimum daily temperature for the RCP8.5 scenario. 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. Typically, 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 typically assigns a low confidence in their projections [SREX, 2012].

Vieira (2016) used GCMs to examine projected changes in multi-year hydrological drought severity and duration in the Nelson-Churchill Watershed. Results varied by GCM simulation with some showing decreases in drought severity and duration and others showing increases. Lack of agreement among GCM simulations underscores the uncertainty and need for additional study.

Clavet-Gaumont et al. (2017), Ouranos (2015), and Sagan (2017) used RCMs to examine projected changes in future probable maximum precipitation and probable maximum floods in various basins across Canada. Results varied by RCM simulation with some showing increased floods peaks and others showing decreased flood peaks. While the median for the Nelson River showed minimal to no change in the probable maximum flood, a lack of agreement among simulations underscores the uncertainty and need for additional study.

Il Jeong et al. (2018) used an RCM driven by three GCM simulations to examine projected changes in extreme radial ice accumulation and wind loads for transmission lines across Canada. While the model is able to reproduce historic spatial patterns of freezing rain, future projections of ice loading over Manitoba were not in agreement.

In a similar study, Il Jeong et al., (2019) shows projected changes to design radial ice thickness in Manitoba are sensitive to natural climate variability. The average projection from a 50 member ensemble (one RCM driven by one GCM with 50 different initial conditions) shows most of Manitoba to experience a near-zero change in design ice thickness at various warming levels. However, the range in projections from the 50 members shows some potential increases and some potential decreases.

Using downscaled GCM data, Cheng et al. (2014) projected changes in the frequency of wind gusts across Canada. Results show potential for more frequent wind gusts in the regions overlapping Manitoba by the end of the 21st century with considerable uncertainty for large gusts. Results also show considerable variability depending on the season, gust speed, location, GCM, and emission scenario which underscores uncertainties.

Using an RCM driven by two GCMs, Il Jeong and Sushama (2018) assessed how future design wind loads are projected to change across Canada. Results for Manitoba show considerable variability depending on the driving GCM and emission scenario with some showing increases and others showing decreases. The authors conclude with a recommendation to explore a larger ensemble of RCMs and GCMs for future studies.

FIGURE 22 **Winter storm 2019**

REGIONAL CLIMATE MODELLING

Regional Climate Models are similar to GCMs but cover a limited geographic area and often use finer resolution. The limited spatial coverage requires forcing at lateral boundaries which is often provided by a GCM and results in a dynamically downscaled simulation. The finer resolution offered by an RCM provides better representation of topographic features (e.g., mountains and lakes) and enables simulation of smaller-scale climate phenomena.

The Canadian Regional Climate Model version 5 (CRCM5) [Martynov et al., 2013; Šeparović et al., 2013] is the current operational version developed at the Université du Québec à Montréal and has been used by the Ouranos consortium to dynamically downscale select GCM simulations over North America. CRCM5 is based on Environment and Climate Change Canada's Global Environmental Multiscale model which is also used for numerical weather prediction. CRCM5 employs the Canadian Land Surface Scheme version 3.5 (CLASS3.5) and implements a one-dimensional freshwater lake model. At the operational resolution of 22 km, CRCM5 captures lakes that were previously unresolved in GCM and past RCM initiatives. We collaborated with Ouranos to ensure lakes of appropriate size in the Nelson-Churchill Watershed were resolved.

The National Center for Atmospheric Research conducted two 13-year climate simulations using the Weather Research and Forecasting (WRF) [Liu et al., 2017] model over a large portion of North America. A Control simulation was driven by reanalysis data to represent current climate conditions from October 2000 to September 2013. A second, Pseudo Global Warming, simulation was driven by reanalysis data adjusted by a climate change signal to project future conditions.

The signal was derived from an average of 19 GCMs under RCP8.5 for 2071–2100 relative to 1976–2005. This WRF experiment implements a 4 km convection-permitting spatial resolution and advanced microphysics schemes. Results from this experiment have been used in several research projects and are presented herein to illustrate differences between RCMs and GCMs.

As an illustrative example, Figures 23 and 24 show seasonal projected changes from a single GCM simulation and two RCMs. Projections for 2071–2100 relative to 1976–2005 for the RCP8.5 scenario are shown to highlight an extreme case while keeping consistent with available WRF data. As such, these single-model realizations are considerably different than the multi-model median projections shown elsewhere in this report. Comparison of CanESM2 and CRCM5 panels show the spatial detail gained by dynamically downscaling with a RCM. This is particularly apparent in areas with lakes and elevation changes. Similar to Šeparović et al. (2013), there are notable differences in summer precipitation projections: CanESM2 shows near zero and moderate precipitation reductions, while CRCM5 shows greater precipitation reductions in the entire Nelson-Churchill Watershed. Šeparović et al. (2013) suggests these differences may be attributable to the use of different deep convection parameterizations.

Compared to CanESM2 and CRCM5, WRF projects less warming and some different patterns of precipitation change. This is partially expected as the models are distinct and CanESM2's temperature response to CO_2 forcing is greater than many other CMIP5 models [Yoshimori et al., 2016].

FIGURE
23

Projected changes in seasonal mean temperature by CanESM2 (RCP8.5), CRCM5 (driven by CanESM2 RCP8.5) and WRF (Pseudo Global Warming vs Control)

Changes represent 2071–2100 relative to 1976–2005. Seasons are winter (DJF), spring (MAM), summer (JJA), and fall (SON). WRF data does not cover the entire domain.

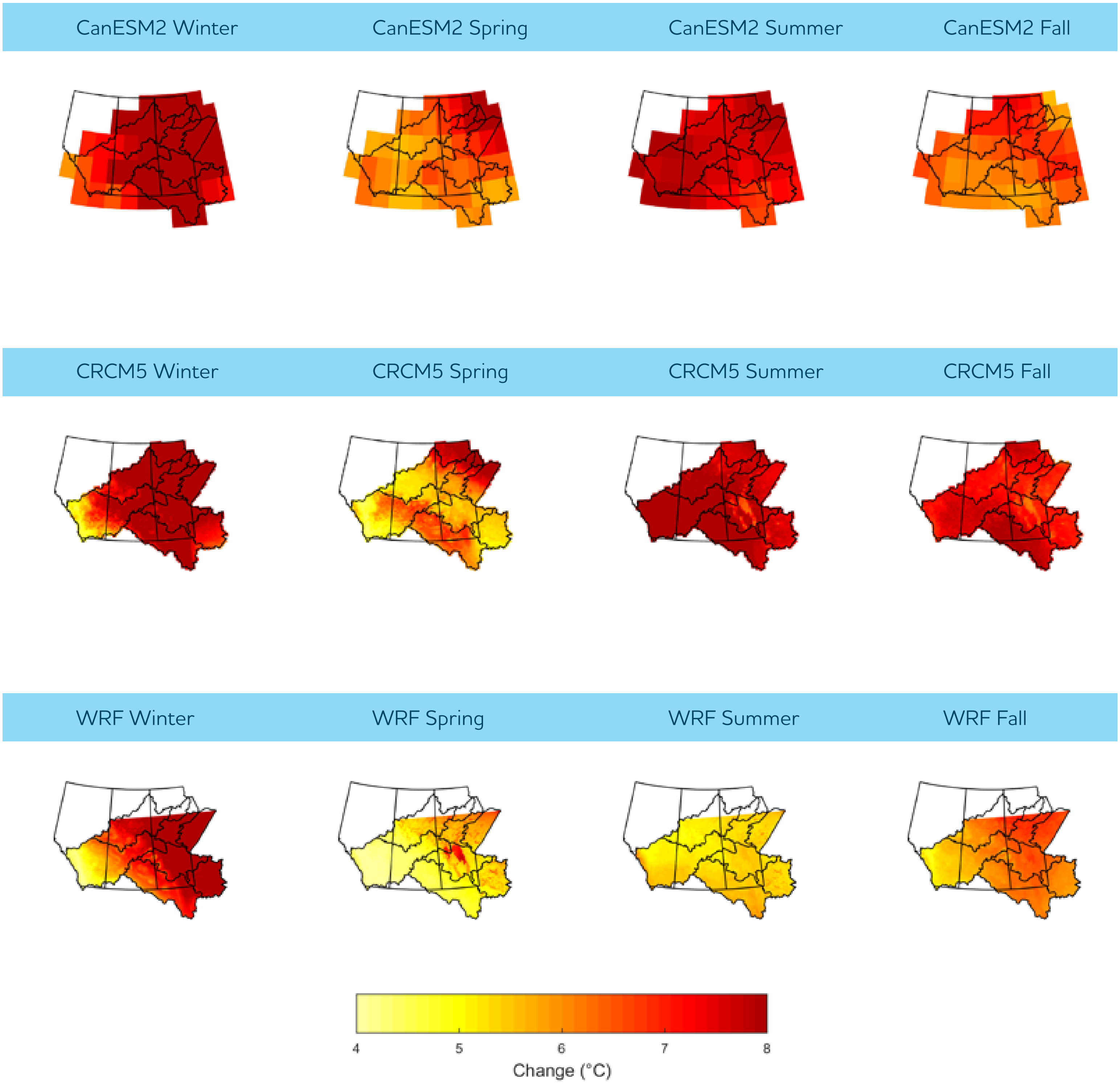
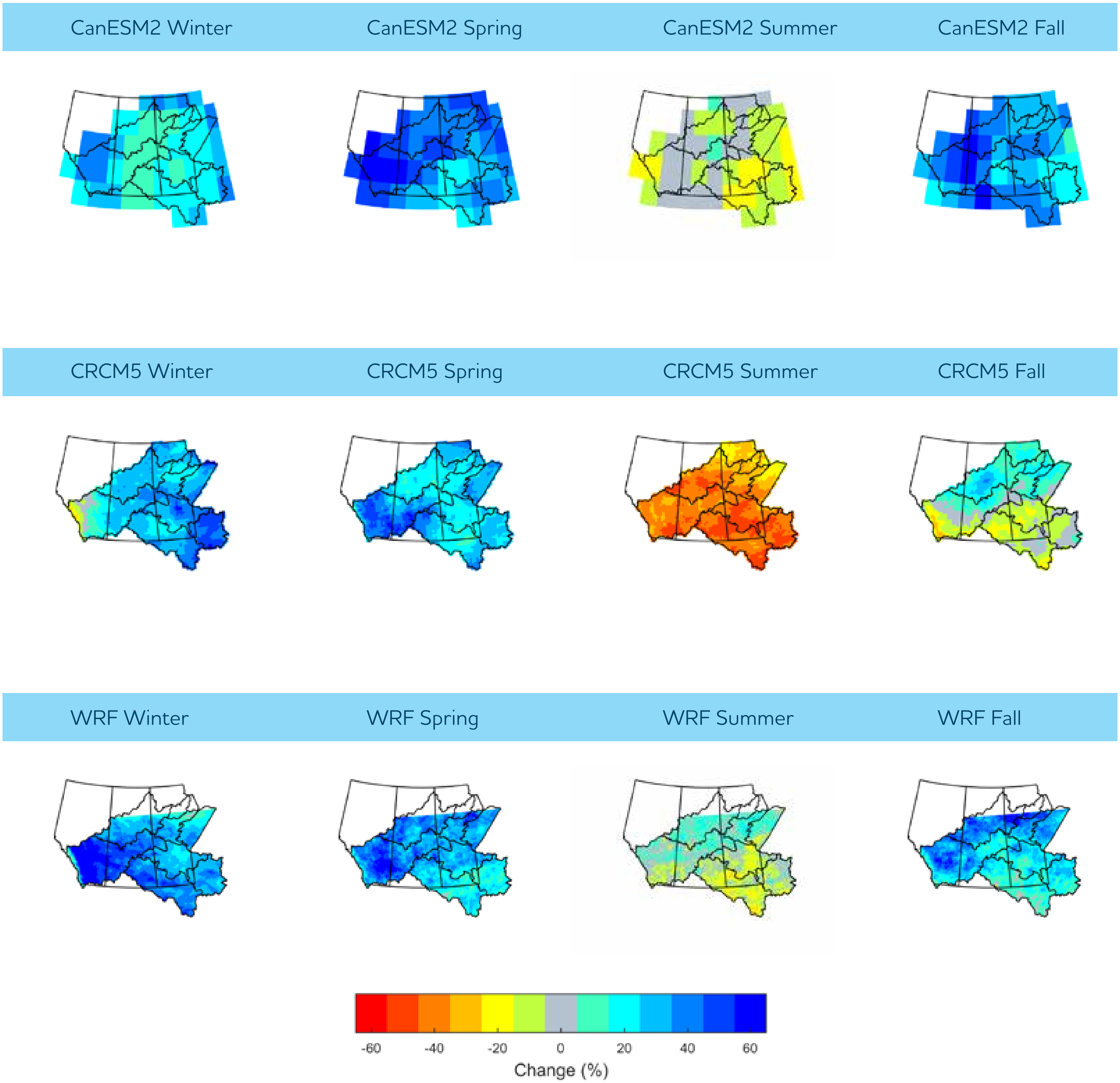


FIGURE 24

Projected changes in seasonal precipitation by CanESM2 (RCP8.5), CRCM5 (driven by CanESM2 RCP8.5) and WRF (Pseudo Global Warming vs Control).

Changes represent 2071–2100 relative to 1976–2005. Seasons are winter (DJF), spring (MAM), summer (JJA), and fall (SON). WRF data does not cover the entire domain.



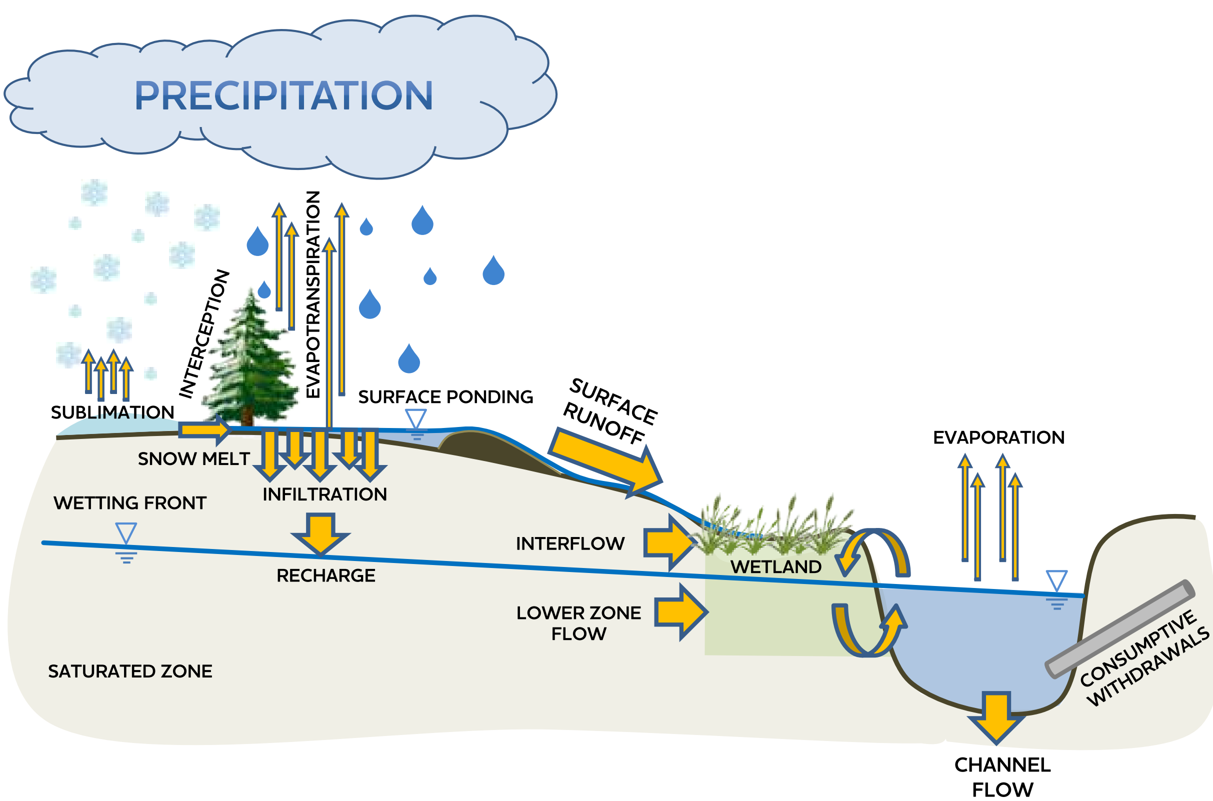
1.3.3 HYDROLOGICAL MODELLING

Hydrologic models are simplified representations of the hydrologic cycle used for simulation and for understanding hydrologic processes. These models numerically represent physical processes observed in the real world including the generation of surface runoff, subsurface flow, evaporation, transpiration, and routing of flow through rivers and lakes.

Land surface schemes within GCMs and RCMs include representations of the hydrological cycle. And while these models have improved over time, coarse spatial resolution, lack of routing, bias, and data availability create challenges for using their output directly in detailed hydrological studies. To overcome some of these issues and for use in other applications, we are developing more detailed hydrological models for each of the basins within the Nelson-Churchill Watershed.

The WATFLOOD hydrological model is employed for these studies as it is partially physically based is distributed, maintains a high computational efficiency, and can accommodate specialized processes. Watershed. A schematic of the general hydrologic processes simulated by the WATFLOOD model are shown in Figure 25.

FIGURE 25 Schematic of the processes simulated by WATFLOOD



WATFLOOD models for major sub-basins in the Nelson-Churchill Watershed are being set up using best available input data (e.g., topography, vegetative cover, surficial material, and hydrography) and heuristic knowledge. Using the 10 km × 10 km gridded temperature and precipitation data described in Section 1.3.1 (e.g., Figure 7) [Hopkinson et al. 2011; Hutchinson et al. 2009; Livneh at al., 2013], WATFLOOD models were calibrated and validated to observed data from periods between 1981 and 2010, with each period capturing a range of wet and dry years to assess model performance.

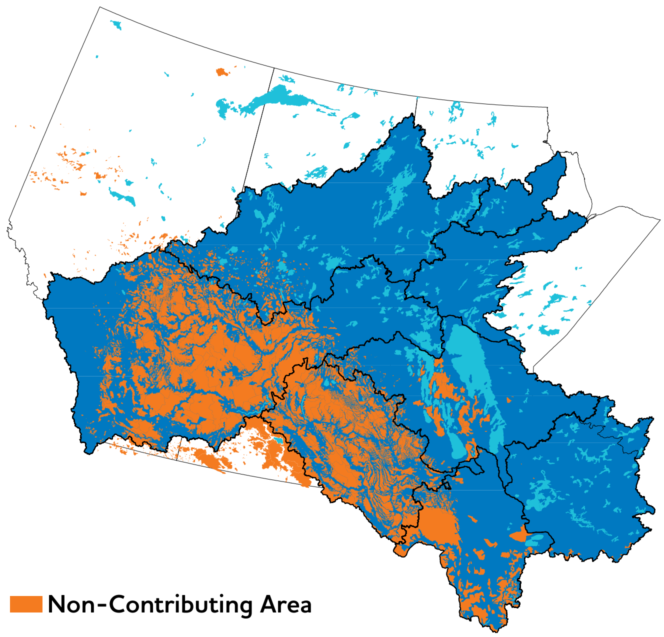
In order to focus on the climate change signal, WATFLOOD is configured to represent naturalized conditions. Diversions, artificial drainage, irrigation, and withdrawals were not modelled. Regulated reservoirs (e.g., Lake of the Woods and Reindeer Lake) were simulated as natural lakes using pre-development rating curves where available. This modelling approach was selected to focus on changes in long-term water supply volume. Incorporation of regulation effects are expected to change intra-annual flow patterns, and may have limited impacts on the overall projected changes in volume. Understanding the uncertainty of future regulation is a subject for future study.

Experience has led to WATFLOOD improvements such as the definition of hydrological parameters based on both vegetative classes (i.e., land cover) and soil material from surficial maps. This improvement better accounts for spatial variability of soil conditions over large areas with few dominant land classes and helps resolve parameterization issues where considering vegetative cover alone does not adequately represent the spatial heterogeneity of hydrological responses.

Non-contributing areas (NCAs) in the Saskatchewan, Red, Assiniboine, and Lake Winnipeg basins (Figure 26) create challenges for simulating runoff as NCAs may not contribute surface runoff under average or dry conditions but begin to contribute runoff to the main stem under wet conditions. Previous attempts to model NCAs using a “fill and spill” concept improved model performance but were unable to capture basin behavior under a wide range of dry and wet conditions. Alternative methods to classify NCAs are being explored. New approaches intend to capture a more realistic, dynamic, runoff response that better fits observations in the historic period and improve our understanding of future impacts.

FIGURE 26

Non-contributing areas in the Nelson-Churchill Watershed [Martin, 2001]



Several approaches contribute to our understanding of how climate change is projected to impact streamflow in the Nelson-Churchill Watershed. These approaches rely primarily on WATFLOOD generated data and use GCM runoff data to aid in interpretation.

WATFLOOD DRIVEN BY GCM DELTAS

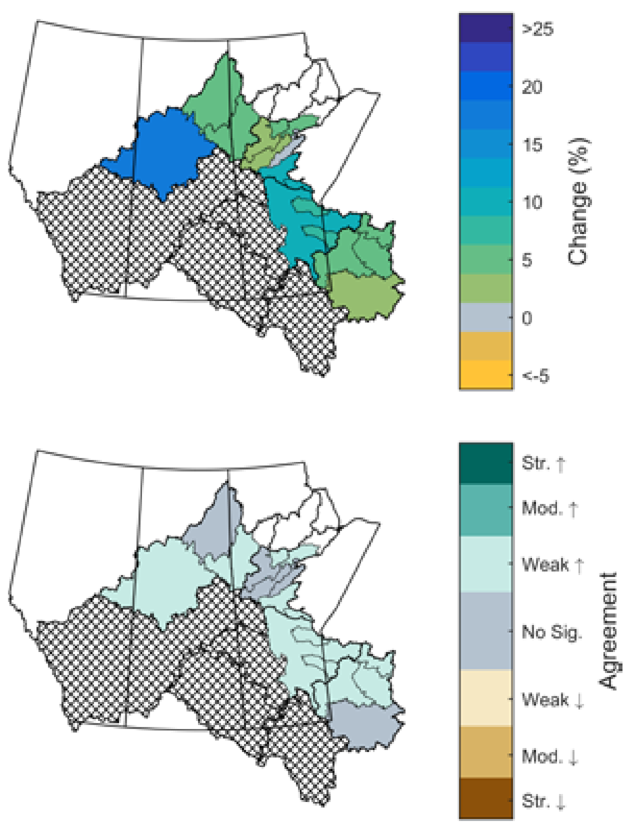
The delta method was used to generate future climate projections using the same 40 GCM simulation sub-set presented in Section 1.3.2. Monthly deltas for minimum temperature, maximum temperature, and precipitation were derived from individual GCM simulations on the GCM's grid. We then applied these deltas to a dataset of observed daily values at the 10 km × 10 km resolution [Hopkinson et al. 2011; Hutchinson et al. 2009; Livneh at al., 2013]. Bi-linear interpolation was then applied to generate data on the WATFLOOD model grid, which varies by basin. This process produced future climate scenarios for the 2050's time period (2040–2069) with a sequencing of events similar to the baseline period (1981–2010).

Results from these simulations are presented in several ways. Similar to Section 1.3.2, Figure 27 illustrates the GCM ensemble median projected change as well as the GCM ensemble agreement on the direction of change. Unlike Section 1.3.2 which presented projections on a regular grid, WATFLOOD projections are shown by sub-basin. Due to current challenges in simulating NCAs, projections for the Saskatchewan, Assiniboine,and Red rivers, and portions of the Local Lake Winnipeg sub-basins are excluded.

FIGURE 27

WATFLOOD generated streamflow changes showing the Global Climate Model ensemble median projection (top) and agreement (bottom) for 2050's mean annual streamflow relative to 1981–2010

Hatched sub-basins are still under development.

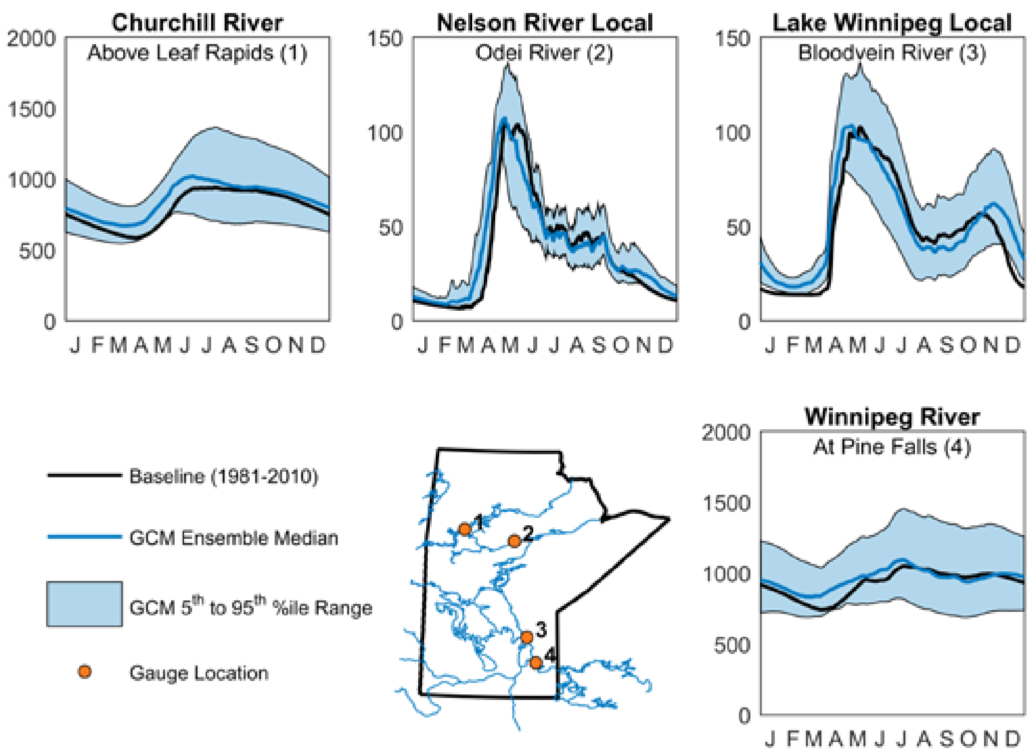


As with other climate change projections presented in this report, it is important to consider the various sources of uncertainty. While hydrological modelling adds value to our understanding of potential streamflow changes, additional uncertainties (e.g., observed meteorological data, post-treatment method, hydrological model selection, and parameterization) are introduced into the modelling chain. As such, there is value in exploring WATFLOOD results as complementary to other available sources of information. These other sources include using direct runoff from GCMs (a basic measure of water availability) [Frigon, 2010] as well as published scientific literature using GCMs, RCMs, and Global-scale hydrological models that cover the Nelson-Churchill Watershed.

In general, GCM runoff and published literature show similar increases in mean annual runoff for the Nelson-Churchill Watershed as a whole. However, the magnitude, spatial patterns, and agreement can vary, especially in more complex areas such as the Saskatchewan, Red, and Assiniboine sub-basins. Due to limitations in GCM representations of hydrological processes (e.g., coarse resolution and lack of routing), GCM runoff is used as a preliminary variable providing a broad view of how runoff is projected to change over large geographic areas. Global-scale hydrological models resolve some concerns with using GCM runoff directly but have their own limitations such as the use of broader calibration targets. As such, GCM runoff, other projections in scientific literature, and WATFLOOD are viewed as complementary to one another in order to help understand uncertainties.

One particular value of streamflow projections from hydrological models (such as WATFLOOD) is the ability to assess projected changes in seasonality and timing of streamflow, Figure 28 shows WATFLOOD projections as mean annual hydrographs for a few sample locations. This figure shows daily climatologies (30-year averages). The black line represents baseline conditions for the 1981–2010 period simulated in WATFLOOD. The light blue band illustrates the 5th and 95th percentile range from the ensemble of 40 GCM simulations, and the darker blue line represents the ensemble median. WATFLOOD simulations represent naturalized conditions. As such, the simulated hydrographs in some cases may exhibit a different intra-annual flow pattern in comparison to the observed record at a given location.

FIGURE 28 **WATFLOOD generated daily streamflow climatologies for 2050s relative to 1981–2010**



In general, the GCM-driven WATFLOOD ensemble median projection shows increasing mean annual flow, increasing winter flows, earlier spring freshet, and potential for decreasing flow in summer and fall, depending on the location. Direct GCM runoff projections (e.g., Figure 20) show similar seasonal patterns with increasing winter runoff and decreasing spring runoff, possibly due to reduced snowpack. Because of river and lake routing, reductions in spring runoff can materialize as reduced summer and fall flows downstream.

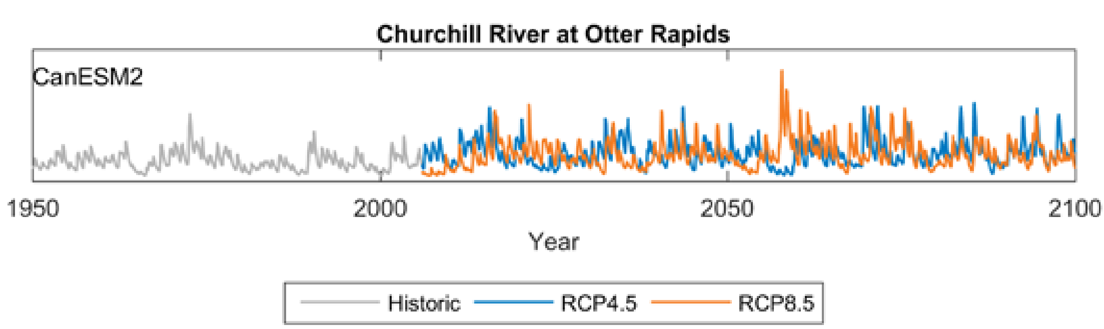
WATFLOOD DRIVEN BY STATISTICALLY DOWNSCALED GCM SCENARIOS

While the delta method presented above is a common and straightforward approach to determine projected changes in hydroclimatic variables, we also explore more sophisticated methods.

We are exploring driving WATFLOOD with future scenarios generated using alternative statistical downscaling and bias correction techniques. One such method is the Bias Correction/Constructed Analogues with Quantile Mapping reordering (BCCAQ) [Werner and Cannon, 2016]. BCCAQ data were produced by the Pacific Climate Impacts Consortium with coverage over Canada. Unlike the delta method, which assumes the historic sequence of events will occur in the future, BCCAQ scenarios are based on the GCM's internally simulated sequence of events (historic and future) and allow for a more thorough assessment of changes in the frequency and magnitude of hydrological events. It is important to note that BCCAQ scenarios do not intend to replicate meteorological conditions in the historic period and as such, one will notice that an observed wet year may not coincide with a modelled wet year. Interpretation of results should keep this limitation in mind.

Because of the spatial coverage, use of BCCAQ scenarios in certain sub-basins was not possible as some watersheds include portions of the USA. BCCAQ scenarios were however used to drive the Churchill River sub-basin WATFLOOD model. Results from a single GCM (CanESM2) are shown in Figure 29 for the Churchill River at Otter Rapids. This illustrative example shows how BCCAQ-driven scenarios can add value over the delta method by providing continuous time series (not time slices) and event sequences outside of the observed range. However, further study is required to complement understanding of results.

FIGURE 29 **WATFLOOD driven by BCCAQ Scenario from the CanESM2 Global Climate Model**



1.3.4 UNCERTAINTY IN FUTURE PROJECTIONS

Many uncertainties exist in modelling of future climate. We must consider these uncertainties when interpreting results. Sources of uncertainty include choice of RCP, GCM structure, natural climate variability, and downscaling technique [Chen et. al., 2011]. Figure 14 illustrates annual temperature and precipitation projections from the ensemble of GCM simulations for the Nelson-Churchill River Basin in the 2050s, helping illustrate some of the uncertainties. Future scenarios are typically summarized by presenting the ensemble mean or median, but 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, RCP4.5 and RCP8.5 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 that the RCPs only start to diverge around the 2050s (Figure 13) and over a shorter-term horizon, and so the climate change signal is generally masked by natural climate variability. As such, our climate change studies typically focus on the latter parts of the 21st century.

Additional sources of uncertainty exist in developing future streamflow scenarios. These uncertainties relate to hydrological model structure, parameter selection during calibration, 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 us can make the best decisions.

1.4 MEMBERSHIPS, WORKING GROUPS, AND RESEARCH & DEVELOPMENT

As part of our climate change strategy, we work with leading scientists in climatology and hydrology through memberships, working groups, and research and development projects to determine how climate change may affect our core business and the environment in which we operate. We are currently involved in the following collaborations.

FIGURE 30 Ouranas consortium

OURANOS CONSORTIUM

We are an affiliated member of the Ouranos consortium and actively participate in many of their research projects to stay informed about the latest advances in climate science. Ouranos is a non-profit 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 30). Its activities are principally determined by the issues and needs facing its members, as well as by Québec 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.

Ouranos is organized into two entities: Climate Science and Vulnerability, Impacts, and Adaptation (VIA). Within the Climate Science group, one area focuses on Simulations and Analyses, and another focuses on Scenarios and Services. Within the VIA group, there are ten themes [Huard et al., 2014]:

- agriculture;
- built environment;
- ecosystems & biodiversity;
- energy resources;
- forest resources;
- health;
- maritime environment;
- northern environment;
- tourism;
- water resources.

We have representatives that participate on the Energy Resources Program Committee.

WORKING GROUPS

Participation in working groups spurs knowledge transfer and communication among professionals in similar industries and jurisdictions. We participate in a number of working groups to collectively address challenges posed by climate change.

Within Manitoba, the Provincial Inter-Departmental Climate Adaptation Working Group is tasked to strategically position the Province of Manitoba to address climate change impacts to achieve climate-resilient and sustainable economic development.

At the national level, Natural Resources Canada's Climate Change Impacts and Adaptation Division leads the Adaptation Platform which brings together key groups from government, industry, and professional organizations to collaborate on climate adaptation priorities. We participate in the Plenary (coordinating forum) and the Energy Working Group. We also participate in the Canadian Electricity Association Climate Change Adaptation Committee which brings together generation, transmission, distribution, and integrated utilities to explore uniform ways to address climate change adaptation. We also participated in a Canadian Standards Association task force to review the Canadian Electrical Code and explore potential opportunities where climate change could be incorporated. This project was initiated by the National Research Council of Canada who is undertaking work to explore incorporation of climate change into various codes and standards including the National Building Code of Canada.

Internationally, the Centre for Energy Advancement through Technical Innovation (CEATI) Hydropower Operations and Planning Interest Group has formed a working group to address climate change adaptation specific to hydropower related topics. This group provides a forum for information sharing and review of international approaches with the goal of creating a more uniform climate adaptation solution for hydropower companies.

GLOBAL WATER FUTURES – CLIMATE-RELATED PRECIPITATION EXTREMES

Collaborators: University of Manitoba, University of Victoria, Pacific Climate Impacts Consortium, University of Saskatchewan, Université du Québec à Montréal, Wilfred Laurier University, Manitoba Hydro, and several other industry and government partners.

Precipitation extremes affect many Canadians and industries. This project employs high-resolution regional climate information to help better understand historic extreme precipitation events and future projections of precipitation extremes. The project involves a number of sectors including agriculture, electrical utilities, engineering design, health, and insurance.

We are working with the project team to evaluate the 4 km Weather Research Forecast Model and its ability to reproduce historic icing events in Manitoba that have impacted the electricity distribution system. Weather Research Forecast simulations driven by a Pseudo Global Warming scenario will also be used to explore how those same icing events may change into the future.

GLOBAL WATER FUTURES – INTEGRATED MODELLING FOR PREDICTION AND MANAGEMENT OF CHANGE IN CANADA'S MAJOR RIVER BASIN (IMPC)

Collaborators: University of Manitoba, University of Saskatchewan, University of Waterloo, McMaster University, Environment and Climate Change Canada, Manitoba Hydro, and several other industry and government partners.

Climate and environmental changes pose challenges to water management in Canada. The IMPC project assembles a diverse team including atmospheric scientists, hydrologists, social scientists, computer scientists, and engineers to develop modelling capability in support of water resources management within several Canadian river basins. This project aims to enhance the prediction of extreme events (e.g., floods and droughts).

We are participating in a project to compare the performance of hydrological models of various complexity in the Nelson-Churchill River Basin. This project aims to improve on existing model setups and help understand uncertainties introduced by different models and their calibrations. This project also intends to use hydrological models to explore optimizing our reservoir operations.

CLIMATE-INFORMED FLOOD DESIGN VALUES FOR DAM CONSTRUCTION AND MAINTENANCE

Collaborators: Ouranos, Manitoba Hydro, Rio Tinto, Hydro Québec, Ontario Power Generation, Natural Resources Canada, Fonds Vert, and the Québec Government.

Historical observations and climate change projections suggest the frequency and intensity of extreme precipitation events is increasing over Canada. This non-stationarity creates challenges for engineers involved in design of water resources infrastructure as stakeholder expectations are increasingly growing to require consideration of climate change in the design process.

This project follows the PMP/PMF project entitled "Probable Maximum Precipitation and Probable Maximum Flood under Changing Climate Conditions" and intends to develop methods to include climate change projections into 1,000- and 10,000-year design flood values in support of construction and maintenance of major dams and dykes. This project will research a simple method and a data-intensive method, and identify potential adaptation options.

WIND ENERGY CHANGE 2100 (WEC 2100)

Collaborators: Ouranos, Nergica, Manitoba Hydro, Hydro Québec, Ontario Power Generation, and the Québec Wind Energy Cluster.

Many Canadian wind turbines will approach the end of their service life in the 2020s, requiring investment for continued generation. Recognizing that climate change may impact wind and icing patterns across Canada, this project was initiated to explore future climate projections, the impact on wind energy resources, and options for economic evaluation regarding reinvestment. This project combines Ouranos' expertise in regional climate modelling with Nergica's expertise in modelling wind energy production.

We purchase wind energy from two independent power producers in southern Manitoba with a total capacity of over 250 MW. Due to the intermittent characteristics of wind power, we are interested in better understanding how confidence in average annual energy production and long-term capacity of wind energy assets are projected to change.

INTEGRATING CLIMATE CHANGE IN THE VALUE ASSESSMENT OF HYDROPOWER ASSETS

Collaborators: Ouranos, Manitoba Hydro, Brookfield Renewables, Hydro Québec, Ontario Power Generation, Inergex, and Natural Resources Canada.

At present, climate change impacts are not often incorporated into hydropower asset evaluation. And when climate change impacts are considered, the methodology is typically ad-hoc. This project aims to engage hydropower asset owners to understand industry needs and then explore a standardized approach to consideration of climate change into asset evaluation.

The overall intent is to establish a methodological framework that can be used to integrate climate change in the value assessment of hydropower assets. Multiple industry partners help provide a balanced view such that the methodology considers complexities that are unique to each individual hydropower company. For example, incorporation of climate change impacts in asset evaluation of a merchant hydropower plant may vary significantly from asset evaluations of a large, Crown corporation-owned hydropower system with a specific mandate.

PERSISTENCE

Collaborators: Ouranos, Université du Québec à Montréal, Université du Québec à Rimouski, L'Institut National de la Recherche Scientifique (INRS), Université Laval, Manitoba Hydro, and Hydro Québec.

Mean annual inflows for generation vary from year to year around a conceptual long-term mean. To reduce exposure to such variations, hydropower utilities have developed strategies such as storage, market exchanges, and a diversified portfolio of energy sources. These mechanisms may be compromised if below or above normal conditions persist over many years. Persistent conditions may be attributed to two causes: natural decadal variability or climate change.

Estimating the likelihood of persistent climate phenomena is possible through using long-term records (such as those from paleoclimate reconstructions) and future climate projections (such as those from GCMs). This project combines paleoclimate reconstructions and climate model projections to provide guidance on the analysis of future risks due to the persistence of wet or dry conditions. This knowledge can help hydropower companies better understand existing risks and projected changes to risk exposure due to climate change.

EXPOSURE AND ADAPTATION TO FOREST FIRES IN THE CANADIAN TAIGA

Collaborators: Ouranos, Université du Québec à Rimouski, Université du Québec en Abitibi Témiscamingue, Université Laval, Manitoba Hydro, and Hydro Québec.

Forest fires pose a particularly important risk to Canada's northern boreal forests. The risk extends to communities and infrastructure in or adjacent to forests. Electrical utilities often have infrastructure (e.g., generating stations, transmission lines, and distribution lines) in forested areas that are susceptible to fire and smoke damage. As the climate warms and precipitation patterns change, there is concern that forest fire risk may also change in the future.

The general objective of this project is to map the spatial variability of the probability of fires in select areas of Québec and northern Manitoba. The project also aims to provide cost-benefit analyses of adaptation measures for the strategically important components most vulnerable to forest fires.

BAYSYS – CONTRIBUTIONS OF CLIMATE CHANGE AND HYDROELECTRIC 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 Québec, Université du Québec à Rimouski, Laval University, Trent University, University of Calgary, and University of Northern British Columbia

BaySys is a collaborative research project to assess the relative effects of climate change and hydroelectric regulation on the physical, biological, and biogeochemical conditions in Hudson Bay. Six teams contribute to achieving the project goals, focusing on oceanographic monitoring, hydrological modelling, marine ecosystems, carbon cycling, contaminants, and oceanographic modelling.

Hydrological modelling is a core component of the BaySys project and feeds the assessments of other teams. The Swedish Meteorological and Hydrological Institute's HYPE model is applied in the Hudson Bay drainage basin as well as the Arctic drainage basin. HYPE is used to simulate historic flows, future climate change projections, and reservoir regulation. Utilization of HYPE helps us understand sensitivity of future projections of streamflow due to the use of various hydrological models.

2

REPORT

We began voluntarily reporting our GHG emissions in 1995. Estimating and reporting our emissions allows the public to see how we are doing and helps us find areas where we can improve. It also allows us to fulfill mandatory reporting requirements.

We also estimate and publish the impact on climate change of our major projects using Life Cycle Assessments (LCAs). All forms of electrical generation, even generation from renewable sources, influence climate change when a facility's entire life is considered.

FIGURE 31

Canadian and Manitoba greenhouse gas emissions (2017) [ECCC, 2019b]

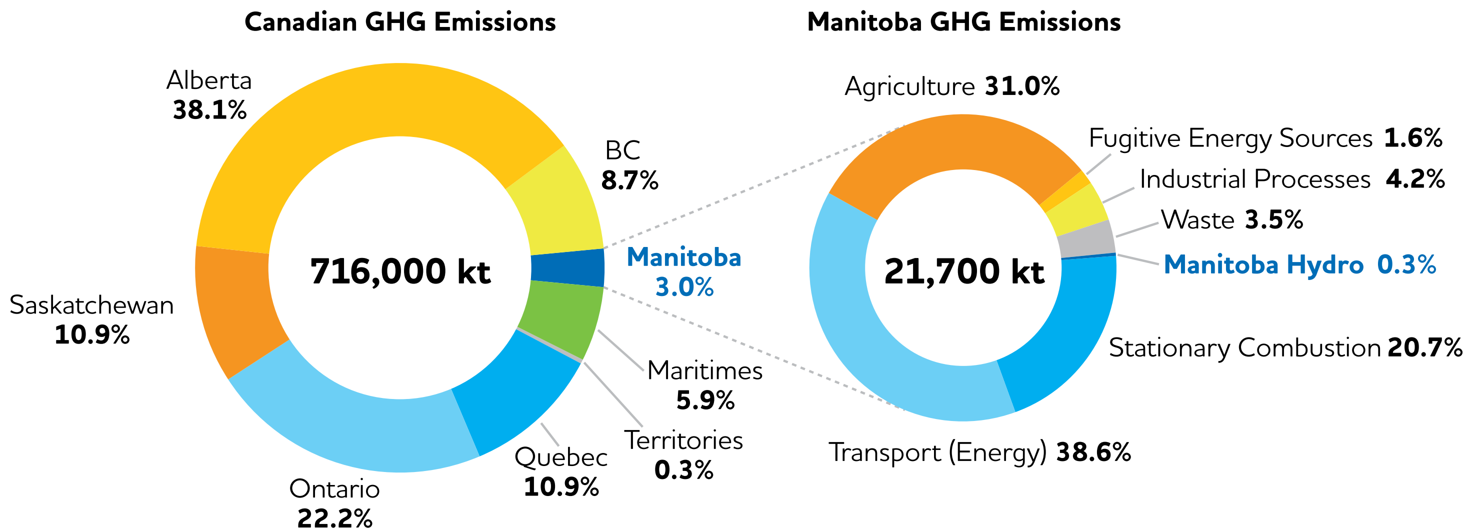
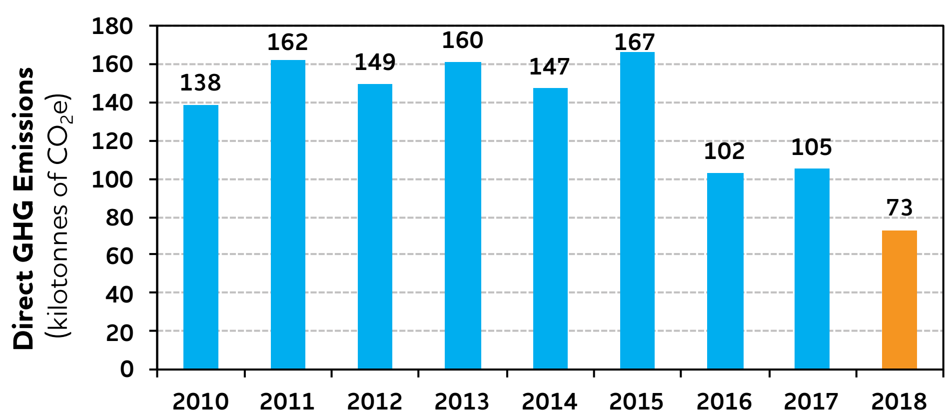


FIGURE 32

Manitoba Hydro's direct annual greenhouse gas emissions (2010–2018) [Manitoba Hydro, 2019]



CO_2e is shorthand for Carbon Dioxide Equivalent. While CO_2 is the main GHG, there are hundreds of others. A simple way to report or compare them is to convert all the GHGs to CO_2e. This is done by using each GHG's Global Warming Potential or GWP. As an example CH_4 has a 100-year GWP of 25 (as per IPCC's Assessment Report 4). This means 1 tonne of CH_4 has the same impact as 25 of CO_2 over the course of 100 years.

2.1 EMISSION TRENDS

We have always been a renewable-based utility with minimal emissions. But despite our historically low emissions, we've still achieved substantial GHG reductions over time. While annual national electricity sector emissions have, on average, increased 11% since 1990 (see Figure 34), we have achieved an average long-term emissions reduction of 26% over the same time period.

These reductions have mainly been due to a drop in our use of fossil fuel generation. Our main grid's fossil supply now only consists of two back-up natural gas generating stations. We stopped using coal generation completely August 1, 2018. The last unit to burn coal in Manitoba was Brandon generating station's Unit 5. We chose to stop generating with this fully functioning unit to, in part, further reduce emissions

Our GHG emissions are relatively small. They represent less than 1% of provincial emissions within a province that represents less than 3% of national emissions. In 2018 our total direct GHG emissions were estimated to be 73 kilotonnes (kt) of CO_2e, a very small amount considering the size of our operations. We are one of the least emissions-intense utilities in Canada and the world.

When tracking GHG emission reductions a baseline year or period must be selected for progress to be tracked over time. Around when we started tracking emissions, 1990 was the standard international baseline and was selected for the Kyoto Protocol. Canada's current emission reduction goals are based on 2005 emission levels. This was the baseline Canada used for the 2009 Copenhagen Accord, which was the follow up to the Kyoto Protocol.

FIGURE 33

Manitoba Hydro direct greenhouse gas emissions (1990–2018) [Manitoba Hydro, 2019]

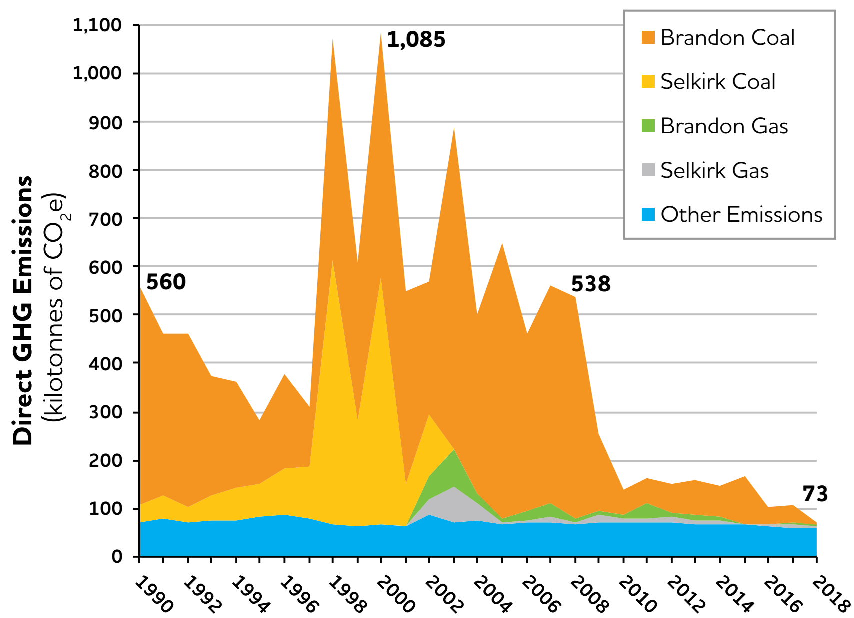
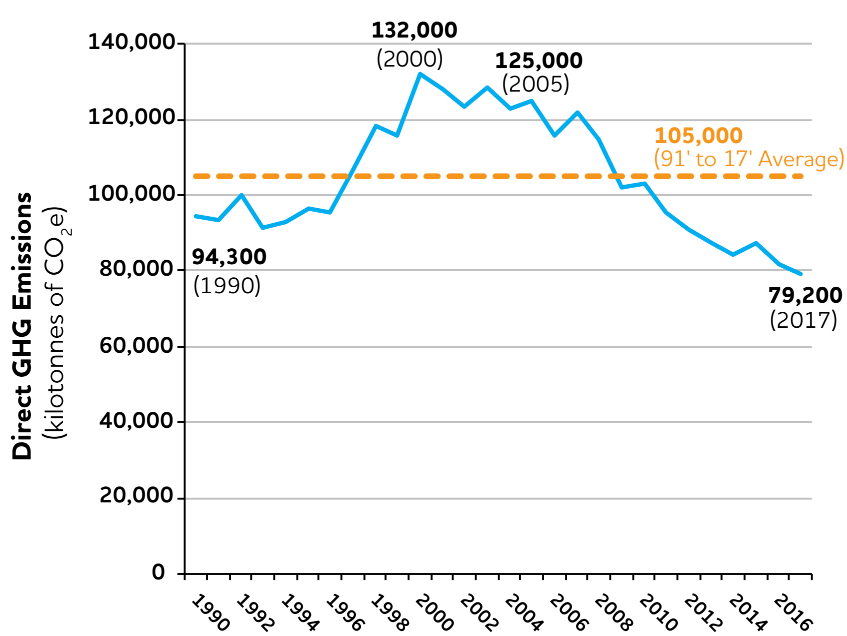


FIGURE 34

Canadian electricity generation emissions (1990–2017) [ECCC, 2019b]

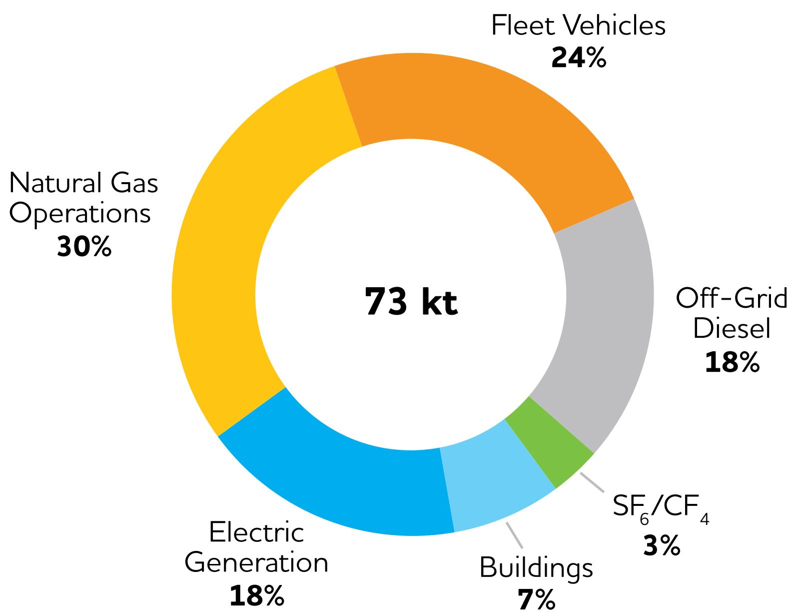


2.2 DIRECT EMISSION SOURCES

Our annual emissions inventory includes several different sources of emissions. For reporting purposes, we categorize them into six distinct sources.

FIGURE 35

Manitoba Hydro's direct greenhouse gas emissions by source (2018) [Manitoba Hydro, 2019]



NATURAL GAS ELECTRIC GENERATION

We burn natural gas in two combustion turbines at Brandon generating station (Units 6 & 7) and two boilers at Selkirk generating station (Units 1 & 2). These units normally run at very low capacity factors, most recently at less than 2% over a full year.

Generation GHG emissions are estimated based on actual fuel consumption, emission factors, and continuous emission monitoring. We are able to keep these emissions low by using our renewable sources of power instead. However, under the most severe drought conditions or long-term system emergencies, GHG emissions from these sources could theoretically surpass one million tonnes of CO_2e.

NATURAL GAS TRANSMISSION & DISTRIBUTION NETWORK

We merged with Centra Gas in 1999 and as a result now distribute natural gas to many Manitobans. This distribution network has several leak sources, most tiny and undetectable, where natural gas is unintentionally released to the atmosphere (a "fugitive" release). From time to time, usually for maintenance, gas needs to be intentionally released (a "vented" emission), and in the winter we heat the network a little with gas heaters to maintain system performance. Emissions can also occur after accidental damage to the system; we strive to avoid these emissions via public information campaigns.

Emissions are estimated based on component counts, company specific calculations, and standard industry practice. We work continually with industry to ensure the best available methods are being developed and applied. We voluntarily report these emissions, along with a cross-Canadian group of transmission and distribution companies, to contribute to an annual industry-wide GHG inventory [ORTECH Environmental, 2019].

FLEET VEHICLES

We have a large fleet of vehicles that consume gasoline, diesel, and propane (overall, mostly diesel). This fleet is needed to maintain our vast system which includes 13,800 km of electrical transmission lines and 75,500 km of distribution lines. We also maintain over 10,000 km of natural gas main pipelines and over 7,000 km of service lines. The fleet is also important for gaining access to the remote areas associated with our hydroelectric generating stations.

Fleet emissions are calculated by categorizing vehicle type, model year, and total fuel consumed and then applying associated emission factors. Even while our fleet has expanded over time as our system has grown, emissions have decreased, mainly due to improved vehicle technology.

OFF-GRID DIESEL GENERATING STATIONS

Diesel-fuelled generating stations provide power to the four remote off-grid northern Manitoba communities of Brochet (Barren Lands First Nation), Lac Brochet (Northlands Denesuline First Nation), Tadoule Lake (Sayisi Dene First Nation), and Shamattawa (Shamattawa First Nation). Diesel generation emissions are calculated based on fuel records and emission factors.

NATURAL GAS USED IN BUILDINGS

Some of our buildings use natural gas for heating. Resulting emissions are calculated using appropriate building natural gas combustion emission factors and consumption data.

Our buildings also consume electricity, which has indirect emission impacts. But these impacts are already captured within the inventory under the electric generation category.

RELEASES OF INSULATING GASES

Sulphur hexafluoride (SF_6) is used as an insulator in electric equipment due to its excellent insulating properties. Carbon tetrafluoride (CF_4) is blended in to ensure the SF_6 doesn't liquefy at cold temperatures. Because of this we directly emit SF_6 and CF_4 through generally unintended releases. Lost gas is normally determined by tracking how much replacement gas is required.

These gases have very high global warming potentials (GWPs) – 22,800 for SF_6 and 7,390 for CF_4. So even though our losses are small they still have a noticeable impact on our emission inventory.

Most of the time GHG emissions are not directly measured, they're estimated. Using an "emissions factor" is standard practice. These factors are developed through direct scientific analysis of actual emissions and then generally applied. For example, we assume our gasoline vehicles emit 2.307 kilograms of CO_2 for every litre they burn based on a scientific study provided to the federal government.

[ECCC, 2019b]

MINOR EMISSIONS

We do have the occasional small release of other GHGs used in fire suppression systems and as refrigerants, normally due to mechanical failure. While these products (halons, hydrofluorocarbons, and chlorofluorocarbons) generally have higher GWPs, they are not included in the inventory as the net impact is negligible due to the very small number and magnitude of releases and these products all comply with the Montreal Protocol for ozone protection. We also release CO_2 directly as part of our operations, such as through the operating of synchronous condensers, but those emissions are relatively negligible as well.

EMISSIONS OUTSIDE OUR ORGANIZATIONAL BOUNDARIES

For reporting purposes, we use an operational control approach, which generally aligns with financial control as well [World Resources Inst., 2004]. Some emissions, which are a consequence of our activities, but occur from sources we don't control (Scope 3 Emissions), fall outside of the scope of our annual inventories. Examples of some major Scope 3 sources include most emissions from our construction projects as well as air travel by employees. Scope 3 emissions are considered when we assess the impact of our major facilities being planned or constructed via life cycle assessment (Section 2.4).

RESERVOIR EMISSIONS

Hydroelectric development can alter natural carbon cycles, primarily through the flooding of organic matter and its resulting decomposition over time. We have directly studied our reservoir emissions and have estimated the impact of recent hydroelectric projects (Section 2.5). Overall, our reservoir monitoring efforts indicate the "reservoir effect" for our mature reservoirs and the recently created Wuskwatim reservoir has subsided and emission rates are similar to those of natural lakes and rivers. The Wuskwatim reservoir was designed to have minimal impact by minimizing flooding.

Our reservoir emissions reporting has been done separately from our annual emissions inventories as even with substantial monitoring effort to develop site-specific GHG emission rates, reservoir inventories have a high degree of uncertainty which comparatively limits their end-use. However, we are keeping current with emerging reservoir GHG inventory methodological advances.

2.3 MANDATORY REPORTING REQUIREMENTS

Both the federal and provincial governments have mandatory requirements to report certain GHG emissions. In compliance with their respective Environmental Act licenses, the provincial government requires that we report GHG emissions associated with electric generation from each of the natural gas generating units at the Selkirk and Brandon generating stations.

Federally, Environment and Climate Change Canada (ECCC) requires reporting on GHG emissions from Canadian facilities through its Facility Greenhouse Gas Emissions Reporting Program (GHGRP). We most recently reported 2018 data for the generating station (Brandon) and for our natural gas transmission and distribution network as both facilities met the current 10,000 tonne CO_2e reporting threshold.

Brandon is a covered facility under the federal Output-Based Pricing System [Canadian Department of Justice, 2019]. Starting in 2020 we will be submitting an Annual Report to ECCC that quantifies both GHG emissions and production data for Brandon. This report will indicate our compensation obligation for GHG emissions above Brandon's limit; it must be accompanied by a third party prepared Verification Report.

It is common to measure and report greenhouse gas (GHG) emissions on an annual basis. But given that many GHGs persist in our atmosphere for decades or even centuries it is very important to understand that such emissions have a cumulative impact on the climate. Globally, we are releasing more GHGs in the atmosphere than can be absorbed by natural systems. This builds up over time. An analogy is that of allowing a steady number of cars onto a bridge, but letting very few cars off on the other side. At some point, the cumulative weight is too much for the bridge. Thus, when developing policies to address GHG emissions, it is important to consider the impact of cumulative emissions, not just annual emissions.

Made-in-Manitoba Climate and Green Plan
[Manitoba Sustainable Development, 2017]

2.4 LIFE CYCLE ASSESSMENTS

Since 2002 we've undertaken detailed life cycle assessments (LCA) of the climate change impact of major facilities being planned or constructed. 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 resource planning process, as well as meeting regulatory requirements such as Environmental Impact Studies.

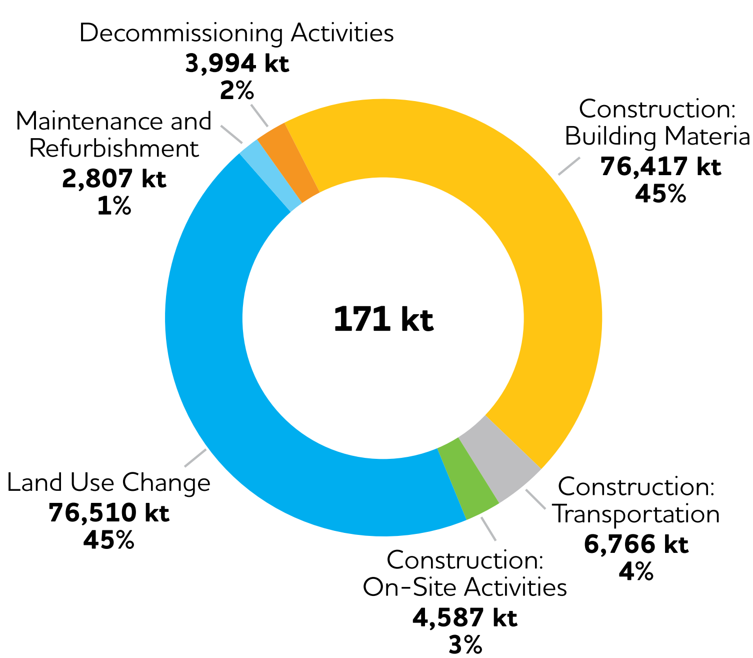
These scientific studies follow the ISO Standard No. 14040 principles and framework [International Organization for Standardization, 2006] utilizing a complete "cradle to grave" analysis of the GHG emissions which includes:

- 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, including fuel used in helicopters);
- land clearing and other land-use change impacts (including reservoir formation);
- operation throughout the life of the facility;
- impacts associated with ultimately decommissioning the project.

FIGURE 36

Manitoba–Minnesota Transmission Project life cycle assessment results
[Jeyakumar and Kilpatrick, 2015]

Greenhouse gas emissions per project stage, excluding generation effects



One component of these LCAs 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]. Assessing the net change in GHG emissions from reservoir creation is complex and site-specific. GHG production is influenced by many factors, including the amount and type of biomass that is flooded, and changes in water quality, land cover, shape and size of the aquatic system, water residence time, and the amount and rate at which carbon is buried within the reservoir. Scientific research and life cycle assessment models indicate that GHG emissions from northern reservoirs can be modest.

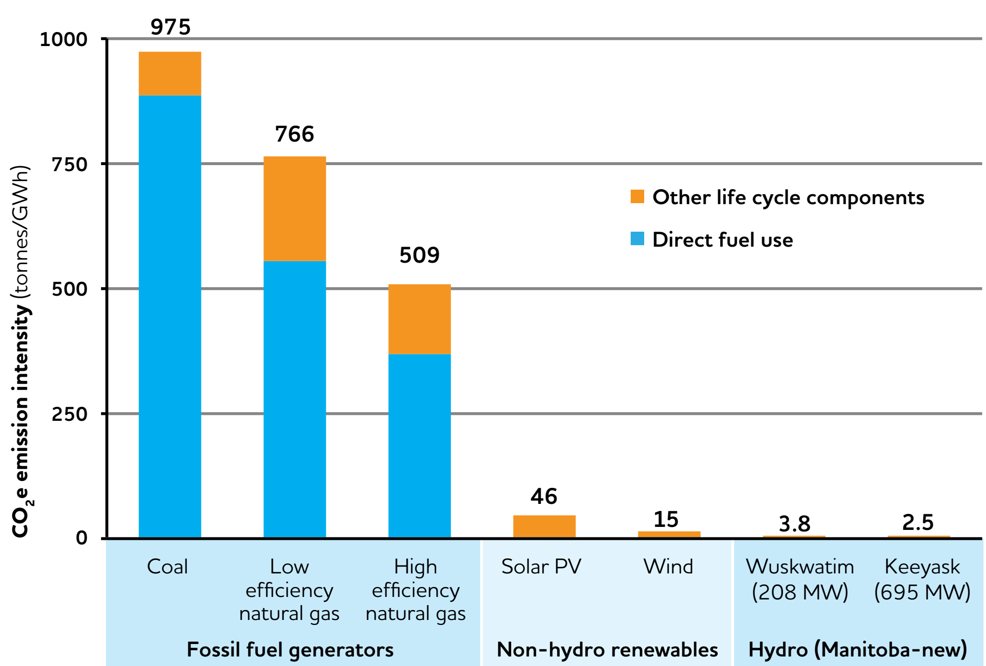
To put their life cycle emission intensities into perspective: an identically sized combined cycle natural gas facility produces more GHG emissions in well less than one full year of operation than the under construction Keeyask hydropower station will over its entire 100 year expected life.

Our most recent LCA was of the Manitoba–Minnesota Transmission Project (MMTP), a new interconnection with the USA. The majority of MMTP life cycle GHG emissions will occur from land use change due to the creation of the right-of-way as well as the manufacture of project materials.

A key conclusion of the MMTP life cycle assessment is that it's very likely the largest climate change impact the MMTP will have will be how its introduction to the electrical grid influences generation both inside and outside Manitoba (i.e. "generation effects"), not GHG emissions from the project itself. Analysis indicates that the MMTP is expected to produce a net reduction in global GHG emissions.

FIGURE 37

Comparison of life cycle greenhouse gas emissions – various generation technologies
[IPCC, 2011; Manitoba Hydro, 2013c; McCulloch and Vadgama, 2003; Switzer, 2012]



2.5 RESERVOIR GHG RESEARCH

Reservoir GHG sampling in the forebay water areas of several of our hydroelectric generating facilities was started in 1999 by a Fisheries and Oceans Canada led collaboration with Manitoba Hydro. Continuous emissions monitoring and point-in-time measurements began in 2004 and concluded in 2014 with the understanding that the reservoir effect has subsided for our mature reservoirs and the newly created Wuskwatim reservoir.

The current focus of our monitoring program, which commenced in 2009, is the under construction Keeyask Generating Project (Keeyask). We partnered with the University of Manitoba in 2017 to research the net impact of Keeyask on reservoir GHG emissions.

The program involves:

- measuring GHG-related parameters, including GHG emissions, before and after reservoir flooding;
- researching dominant site-specific GHG processes to determine why GHGs are occurring at the observed levels, locations and time periods;
- developing a site-specific model to explain and predict long-term GHG emissions and carbon cycling resulting from the Keeyask reservoir.

This research will enable the Keeyask Hydropower Limited Partnership to fulfill the Keeyask Environmental Impact Statement reservoir GHG monitoring commitments and the Keeyask Environment Act License GHG monitoring requirements.

Keeyask is notable amongst Canadian hydroelectric reservoirs as water impounded for the reservoir will flood predominately peat soils underlain by discontinuous permafrost. The peat soils contain centuries of accumulated organic carbon. This research will provide insight into levels of GHG emissions that result from reservoir creation and operation.

The research program is intended to identify and measure the potential reservoir GHG emissions pathways, which include:

- diffusive emissions, which are dissolved GHGs passing from the water surface into the atmosphere;
- methane bubbles that originate in sediments and migrate through the water column;
- emissions from plants (aquatic and terrestrial);
- emissions from terrestrial surfaces; and
- future degassing emissions (as water passes through the hydroelectric generating station turbines and spillway, gases are released because of pressure differences between the water and atmosphere).

During the 2017 to 2019 pre-flooding period, the University of Manitoba team has measured GHG-related parameters within the main Nelson River channel and in a shallow “back bay” area of the future Keeyask Reservoir. Two portable eddy covariance towers have been monitoring CO_2 and CH_4 fluxes associated with the main Nelson River channel and a representative “back bay” during the ice free period. Eddy covariance is capable of measuring all of the GHG pathways mentioned above. In addition, a water sampling program and continuous underwater CH_4 and CO_2 sensors are in place to measure the properties of the river water that underpin GHG emissions.

Measurements will continue after flooding, comparing pre- and post-flood results to determine net GHG emissions.

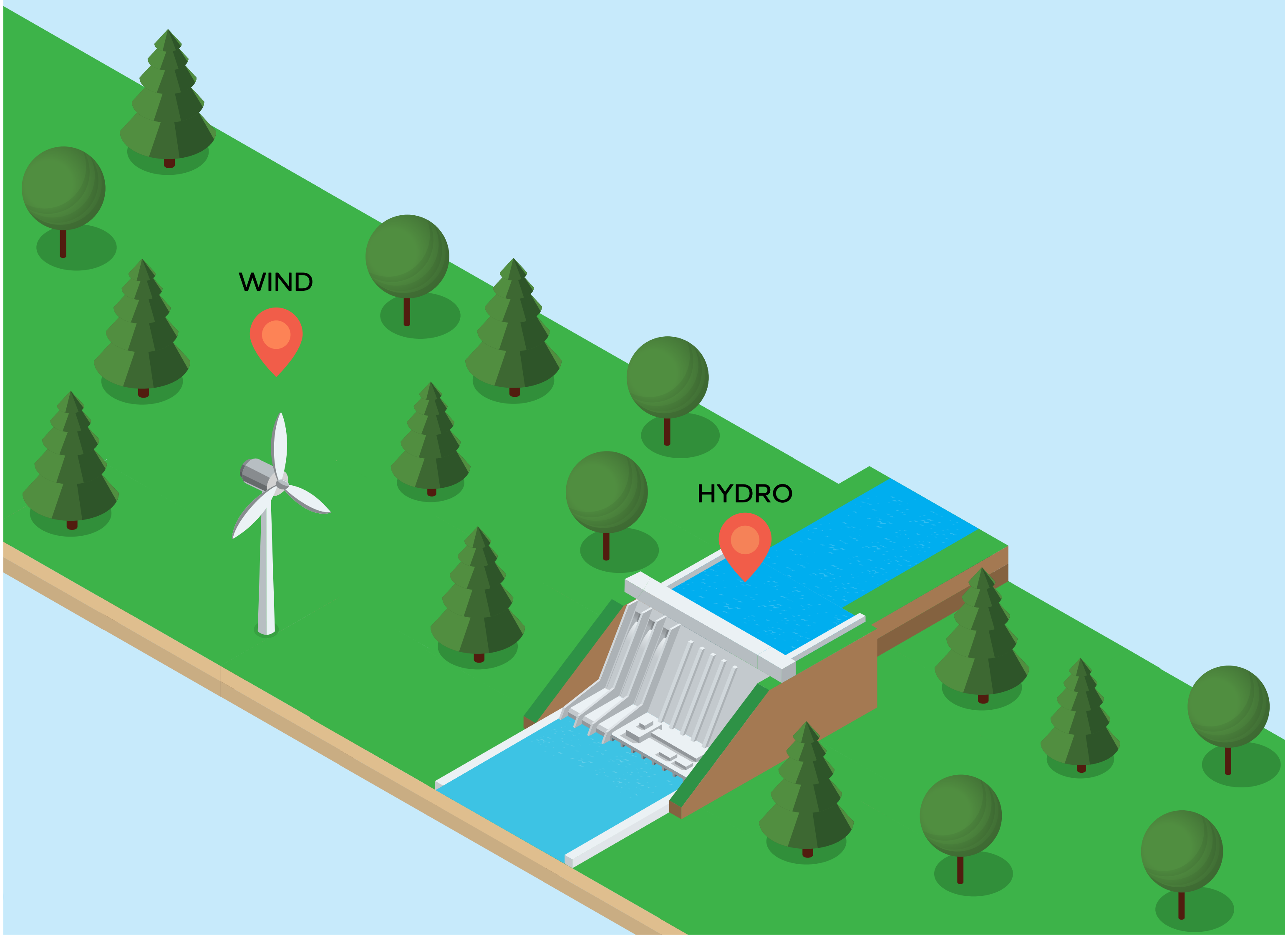
The project will bring clarity to ongoing discussions amongst the hydroelectric industry, scientific community, and climate change policymakers on the effect of hydropower on GHG emissions.

FIGURE 38 **Keeyask reservoir monitoring equipment**

3

REDUCE

Manitoba Hydro has very low electric generation GHG intensity relative to other electrical utilities. Building on this advantageous starting position, we have contributed further and intend to continue contributing to global GHG emission reductions.



3.1 REDUCTIONS IN FOSSIL-FUELED GENERATION

Our main grid is primarily powered by 15 hydroelectric stations, wind power purchases from independent Manitoba wind farms, and two fossil fuel generating stations. Under most conditions the hydroelectric stations and wind purchases can meet Manitoba's electricity needs; the two fossil fuel generating stations provide a source of backup power during short-term emergencies, periods of high demand, and during drought years. They also can enhance system stability and provide voltage support. In the past they've produced revenue for us during periods of high export power prices.

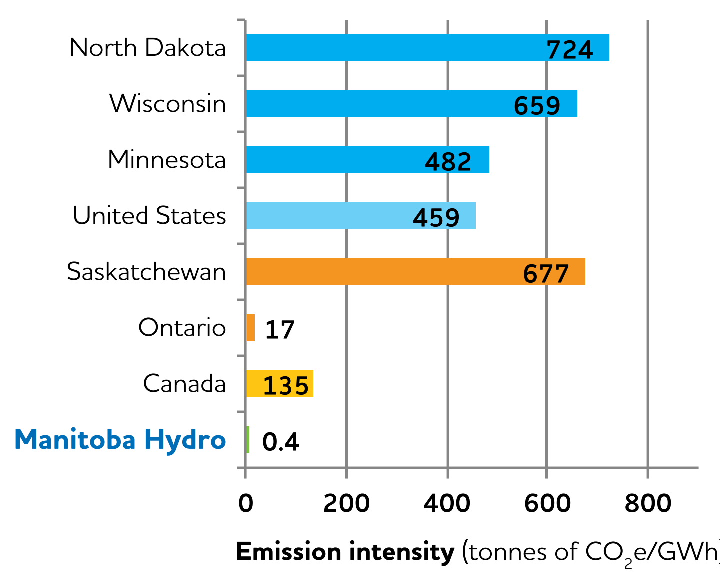
In some past years our electric generation emissions have been over one million tonnes. But, in our most recent inventory (Section 2.2) our electric generation emissions were under 13,000 tonnes, around just 1% of our historical high.

In addition to actions on coal, we have extended the power grid to nine remote northern communities, reducing the number of communities that are served by diesel generation to four. Manitoba Hydro, the Province of Manitoba, and Crown Indigenous Relations and Northern Affairs Canada continue collaborative discussions led by Indigenous Services Canada about future energy options for these communities.

> "Climate change is one of the defining challenges of the 21st century. It is a global problem, and tackling it requires global action. Governments around the world have committed to work together to limit global warming, recognizing that climate-related risks grow with the magnitude of warming and associated changes in climate."
>
> Canada's Changing Climate Report [ECCC, 2019a]

FIGURE 39

GHG emission intensity comparison of electricity generation [ECCC, 2019b; Manitoba Hydro, 2019; United States Energy Information Administration, 2019]



3.2 RENEWABLE GENERATION DEVELOPMENT

Renewable electrical generation facilities have allowed us to operate one of the most environmentally friendly generation systems in the world. We manage about 5,200 MW of hydroelectric generation with the majority of this capacity in northern Manitoba. The 695 MW Keeyask generating station is under construction, with full commercial operation targeted by the end of 2021.

Our most recent completed hydroelectric project was the 208 MW Wuskwatim generating station, located on the Burntwood River and completed in 2012. 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. The Keeyask Hydropower Limited Partnership opted not to develop higher head options as well. The project under construction at Keeyask is the lowest head option that could be constructed at the site.

In 2002 both units at Selkirk generating station were converted from coal to natural gas. Such conversions were rare at the time and the action received an Honourable Mention in the 2002 Canadian Council of Ministers of the Environment Pollution Prevention Awards – Greenhouse Gas Reduction Category.

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

On an ongoing basis we also enhance the generation output of our existing generating facilities and transmission systems. This helps us maximize the production and availability of our renewable electricity. Examples of some these activities include the refurbishment of generation equipment and rerunnering projects. These supply side enhancement projects are often coupled with extended planned outages for major equipment upgrades and, because they are opportunity-based, they are often subject to economic and financial evaluations, similar to other major resource projects.

In addition to hydropower, we have also pursued wind resources in the province. Currently we have 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". We recently contracted a much smaller solar Power Purchase Agreement, around 1 MW, as well.

Customers have been pursuing solar energy for their own needs as well. In April 2016, we launched the Solar Energy Pilot Program to assist customers with the upfront capital cost of installing solar photovoltaic (PV) systems. The 2-year pilot allowed us the opportunity to learn more about how customer-sited solar PV systems would interconnect with our overall system, what processes and systems need to be in place to allow large scale installations, and to provide better understanding of current market pricing and expected customer adoption under these price signals. Participation was beyond expectations with 40 MW of solar capacity to be installed by mid-2020. However, even with pending electric rate increases, the economics for solar are currently not favorable in Manitoba due to low electricity rates and peak hours of production.

On an ongoing basis we also consider a wide array of emerging electricity technologies, such as bio-energy and microturbines, in our generation planning and actively research and support their concept development. This work helps to ensure that our development plans continue to make the most sense from economic, environmental, technical, and social perspectives. Evaluations of these technologies take many forms and may include in-house research, consultants' reports, and literature searches as well as collaborations with academia and industry associations.

> "The majority of Manitobans are served by renewable electricity provided by Manitoba Hydro. Four northern communities that are not connected to the grid, however, rely on diesel generators for their electricity. These generators are sources of carbon emissions, among other pollutants, and are dependent on the delivery of diesel fuel — typically by winter road — an option that is becoming increasingly uncertain as winters shorten and average temperatures increase due to climate change."
>
> Made-in-Manitoba Climate and Green Plan [Manitoba Sustainable Development, 2017]

3.3 DEMAND-SIDE MANAGEMENT

More than 60 incentive-based, customer service, cost-recovery, and rate-based demand-side management (DSM) initiatives and programs have been offered since 1991 by Manitoba Hydro to encourage efficient energy use in the commercial, agricultural, residential, institutional, and industrial customer sectors.

Efficiency Manitoba is Manitoba's newest Crown corporation devoted to energy conservation. Although responsibility for DSM programming will eventually fully transition to the new Crown corporation, we will continue to deliver all legacy DSM programs in the interim. Once fully operational, Efficiency Manitoba will deliver DSM programming with our support.

Future DSM programs will likely continue to demonstrate the customer-focused economic benefits of energy efficiency while also proactively addressing climate change for Manitobans. We will continue to assess DSM resource options independently and in collaboration with Efficiency Manitoba as part of our resource planning process.

Manitoba Hydro's past energy efficiency programming has resulted in total annual energy savings of 3,469 GWh of electricity and 124 million m^3 of natural gas to date. These energy savings are contributing to GHG emissions globally by nearly 2.6 megatonnes of CO_2e per year. The majority (91%) of these GHG emission reductions result from electric DSM program activity through indirect emission reductions from our export sales, and the remaining 9% of emission reductions are direct reductions that occur because of lower natural gas consumption in Manitoba.

Even smaller actions can add up!

We look for opportunities across the board to reduce emissions. Some other corporate actions include:

- building a state-of-the-art energy efficient head office in downtown Winnipeg;
- investigating new ways to electrify our fleet vehicles; and
- engaging our employees through initiatives promoting active transportation and paper use reduction.

3.4 GLOBAL EMISSION REDUCTIONS

We plan our system to meet the electricity needs of Manitobans during the worst drought conditions. Since these conditions are rare, we normally have surplus energy, which is nearly free to produce and very economical to sell to interconnected neighbouring states and provinces. Since 2005 our annual net electricity exports have averaged about 10,000 GWh per year. Since the main alternative to importing from us would be to burn more coal and natural gas, our operations contribute to a significant net reduction in global GHG emissions.

When considering incremental changes to electricity consumption through energy efficiency, or fuel switching applications, we evaluate these decisions based on the global GHG impacts. We have assumed a factor of 750 tonnes CO_2e/GWh since 2006, which reflects a conservative estimate of the incremental GHG emission impacts of changes within the interconnected region. Analysis has indicated that the 750 tonnes CO_2e/GWh factor will likely remain conservative for the next several years. This factor would be even higher if all life cycle impacts were considered.

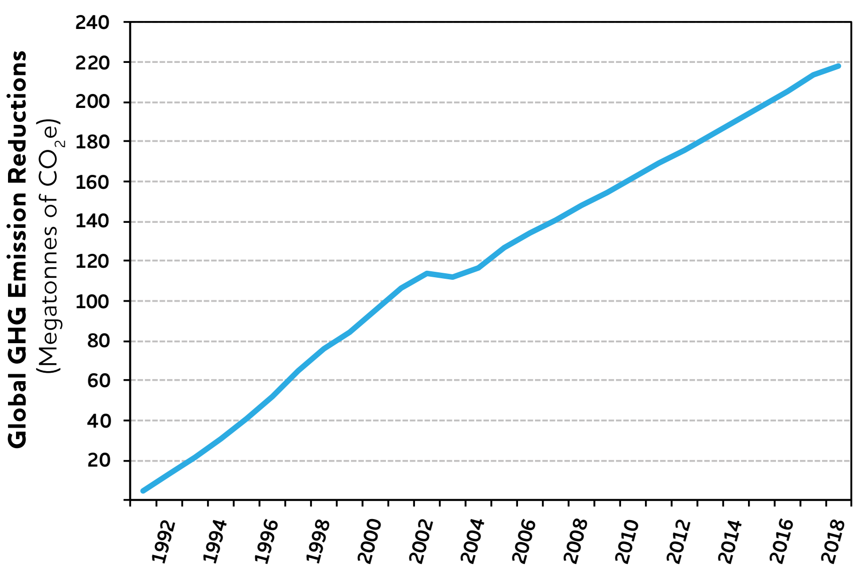
"From the perspective of the earth's atmosphere, it does not matter where GHG emissions or reductions occur."

The GHG Protocol
[World Resources Inst., 2004]

FIGURE **40**

Global implications of Manitoba Hydro operations
[Manitoba Hydro, 2019]

Net cumulative greenhouse emission reductions.



Why "Incremental"?

It is straightforward to estimate the impact of small/incremental changes in electricity use. However, large changes can lead to meaningful changes to the whole system, such as a new wind farm being built or a coal plant being retired. Assessing the GHG impact of these large changes is much more complex.

4

SUPPORT

Scientists agree we need to act with urgency to reduce GHG emissions to limit global warming to less than 2°C. Regulations, legislation, programs, and markets are all policy options that can help to achieve emission reductions. For more than 25 years, we have participated in the development and analysis of municipal, provincial, regional, national, and international climate change policies, advocating for practical policies that are environmentally effective and economically efficient. Well-designed GHG policies that deliver a meaningful price for emissions are the most flexible and cost-effective way to reduce emissions. We actively engage with government, industry, think tanks, research organizations, environmental non-governmental organizations, our customers, and other climate policy stakeholders to understand the implications of various policy proposals and suggest changes to enhance environmental and/or economic outcomes.

100+ YEARS

OF RENEWABLE ENERGY EXPERIENCE

4.1 CANADIAN CLIMATE MITIGATION POLICIES

Recognizing the urgent need to reduce emissions, Canada and 197 other countries signed the Paris Agreement under the United Nations Framework Convention on Climate Change. As part of this agreement, Canada committed to reduce its emissions by at least 30% by 2030 (2005 baseline) and achieve net zero emissions by 2050.

To meet this goal, federal, provincial, and territorial governments came together to develop the Pan-Canadian Framework on Clean Growth and Climate Change (the Framework) that aims to reduce emissions across all sectors of the economy, stimulate clean economic growth, and build resilience to the impacts of climate change. The Framework recognizes that low-emitting electricity is foundational to achieving emission reductions in other sectors like transportation, buildings, and industry through electrification. It also includes a number of policies that directly or indirectly put a price on GHG emissions and improve the economics for non-emitting and renewable resources like hydro, wind, and solar power.

> "A price on carbon pollution creates incentives for individuals, households, and businesses to choose cleaner options."
>
> Output-Based Pricing System [ECCC, 2018a]

The Framework established a benchmark national GHG price in Canada beginning in 2019, allowing for equivalent jurisdictional pricing systems such as Québec's cap-and-trade program. The benchmark applies an escalating regulatory charge on the GHG content of fuel while the Output-Based Pricing System is used to price emissions from large and trade-exposed industries, including electricity generation [Canadian Department of Justice, 2018].

The Framework also proposed a national Clean Fuel Standard that would lower the life cycle emissions intensity of fossil fuels used in transportation, buildings, and industry. To meet the standard, fossil fuel suppliers could lower emissions throughout the extraction, production, transmission, or distribution of the fuel; blend the fuel with lower-emitting fuels like renewable or biofuels; or purchase credits from lower-emitting alternative fuels. This type of standard could add a cost to fossil fuels while creating a market for emission reductions achieved by using alternative fuels like our low-emitting electricity.

The Framework recognizes that pricing GHG emissions may not be enough to drive emission reductions and proposes a number of other complementary actions. These actions include phasing out coal and establishing standards for natural gas-fired electricity generation; funding research into enhanced inter-provincial transmission to increase the use of clean energy in Canada; using incentives, codes and standards to reduce energy use in the built environment; accelerating zero-emission vehicle adoption; and assisting industry as well as the forestry and agricultural sectors to lower emissions and advance innovation. These complementary policies, coupled with policies that add a price on GHG emissions, have the potential to drive electrification. We are actively working with our customers, government, research bodies, and non-governmental environmental organizations to study electrification and how it may impact our resource planning.

As national policies are proposed, designed, and implemented, we support provincial staff, industry associations, and our customers to understand their implications and advocate for practical solutions to achieve emission reductions.

4.2 MANITOBA'S CLIMATE & GREEN PLAN

Manitoba's Climate and Green Plan aims to position Manitoba as the "cleanest, greenest and most climate resilient province." The Plan recognizes the value of our low-emitting electricity and offers multiple strategies to reduce reliance on fossil fuels in favour of lower-emitting alternative energy sources like electricity, renewable fuels, and biofuels. With an expectation that global GHG markets will grow exponentially over the coming years, the Manitoba government plans to develop GHG offset programs and projects such as those that combust landfill or livestock gas to produce electricity or heat, and energy efficiency and renewable electricity generation [Manitoba Sustainable Development, 2017]. We continue to support the Manitoba government as they look to implement their Plan to achieve emissions reductions across the Manitoba economy.

OVER 30 YEARS OF CANADIAN AND INTERNATIONAL CLIMATE CHANGE MILESTONES

1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003

- 1988: IPCC established.
- 1992: Canada ratifies the United Nations Framework Convention on Climate Change (no legally binding targets).
- 1994: Canada produces its first National Report on Climate Change which reports 1990 GHG emission levels.
- 1998: IPCC's Kyoto Protocol Adopted (signed by Canada).
- 1999: Canada starts GHG sampling in Manitoba Hydro forebays.
- 2002: Canada ratifies the Kyoto protocol: accepts legally binding target of 6% below 1990 levels by 2012.

4.3 SUPPORTING CLIMATE POLICY IN WHOLESALE MARKETS

Climate policy continues to be an active issue in our USA wholesale markets. At the federal level, several cap-and-trade, GHG tax, and clean energy standard bills continue to be proposed by both Democrat and Republican lawmakers, though none have been passed into law. While the Trump Administration has withdrawn from the Paris Agreement and unwound regulations intended to curb GHG emissions, local and state governments in Minnesota and Wisconsin are actively discussing climate policy proposals such as ambitious goals to supply all electricity from non-emitting sources by 2050. Aside from local and state governments, investors and large customers are also encouraging utilities to consider climate change in their resource plans and pursue a lower-emitting electricity generation mix.

Our electricity exports can assist wholesale customers in meeting their investors' and customers' needs while responding to and preparing for climate change mitigation policies. As verified through third-party life cycle assessments (Section 2.4), hydropower is virtually GHG-free electricity and can assist in achieving emission reductions and renewable energy goals. The vast majority of our electricity is generated through hydropower which offers unique operational flexibility to complement generation portfolios with increasing intermittent renewable generation such as wind and solar. We regularly work with policymakers in the USA to ensure that policies recognize the value of both cross-border electricity trade and hydropower in affordably achieving climate goals while ensuring reliability.

Current and potential customers in Saskatchewan and northern Canada are considering how electricity from Manitoba can assist them in decarbonizing their electricity supply, limit risk associated with future climate mitigation policies, and ensure customers have access to affordable and reliable electricity. While our current transmission linkages to Canadian provinces and territories are significantly smaller than our USA interties, we are working with provinces, territories, and the federal government to study the potential benefits of increasing transmission linkages and supplying these markets with our primarily renewable electricity.

- 2004: Canada's GHG Reporting Program's first data.
- 2007: Assessment Report 4 released (IPCC).
- 2010: Copenhagen Accord produced (IPCC).
- 2011: Canada withdraws from Kyoto.
- 2015: Canada commits to non-legally binding target of 30% below 2005 levels by 2030.
- 2016: Paris Agreement adopted (IPCC). Pan Canadian Framework created.
- 2018: Canada's GHG Pollution Pricing Act receives Royal Assent.

4.4 RENEWABLE ELECTRICITY ENERGY MARKETS

Climate change and related energy policy development can have a direct impact on the supply and demand for renewable electricity. There is a close relationship between existing and potential GHG and renewable energy policies and markets. About 30 USA states have enacted renewable portfolio standards (RPS) that obligate utility companies to meet mandatory renewable energy .targets; an additional eight USA states have set their own renewable energy goals. The affected RPS 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 electricity source. Qualifying renewable technologies differ by state and program type, and are driven by a variety of motivations. As well, the emergence of clean energy programs has gained popularity over the past few years among corporations globally, setting renewable energy and GHG reduction targets for participating companies by a set year. Many of these programs allow RECs as an eligible means to meet the program's requirements. We have been actively marketing RECs associated with our electricity exports in the USA and Canada since 2008 in both the RPS and voluntary green power markets. As states and provinces pursue deeper GHG reductions in their electricity sectors, RPSs and markets may evolve into GHG-free standards and markets that include additional technologies like CO_2 capture and storage, biomass, nuclear energy, and energy storage.

OVER 25 YEARS OF SUPPORT

Assisted in the design and participated in the Chicago Climate Exchange.

(2003–2010)

Participated in Canada's Climate Change Voluntary Challenge & Registry (1995–2007)

1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006

1993: Centra Gas joins the board of Gas Technology Canada (a precursor to CEPEI).

1998: GHG Emission Reduction Trading Pilot. This was a pilot with the Canadian government.

2001: Participated in the Great Plains Institute Powering the Plains program. Stakeholders collaborated to understand key energy and climate issues and how the region could respond.

4.5 MEMBERSHIPS, WORKING GROUPS, AND RESEARCH & DEVELOPMENT

Section 2.4 shows how we work with various associations to see how climate change may affect our core business. We provide climate change policy support through our affiliations as well. The timeline at the bottom of the page highlights some of our many affiliations going back to the early 1990s.

Also, as an example, we are a member of the Canadian Energy Partnership for Environmental Innovation (CEPEI), which is the environmental technical committee of the Canadian Gas Association whose members are from natural gas transmission, distribution, and storage companies. CEPEI member companies collaborate to develop technical information to meet the increasing demands of regulatory and public emissions reporting, environmental impact assessment, and accountability. Key CEPEI projects have involved the creation and ongoing update of the Methodology Manual, which allows for the estimation of GHG emissions from Canada's natural gas transmission, storage, and distribution systems [Clearstone Engineering Ltd., 2018].

We are also currently a participating member in the Electric Power Research Institute's Understanding Climate Scenarios and Goal Setting Activities (UCSGSA) project. This project helped develop a technical foundation to inform company decision-making and stakeholder discussions regarding climate change scenario strategies and GHG emissions goal setting. By participating we were able to gain a better understanding of how the industry was supporting climate change policy and integrating climate change goals into their resource planning activities.

Reporting GHG Emissions & Intensity to CEA's Sustainable Electricity Program (2008–present)

REC Tracking and Trading (2008–present)

2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019

2007: Became an affiliate member of Ouranos.

2010: Engaged with the Midwest Governors Association on the Midwestern GHG Reduction Accord.

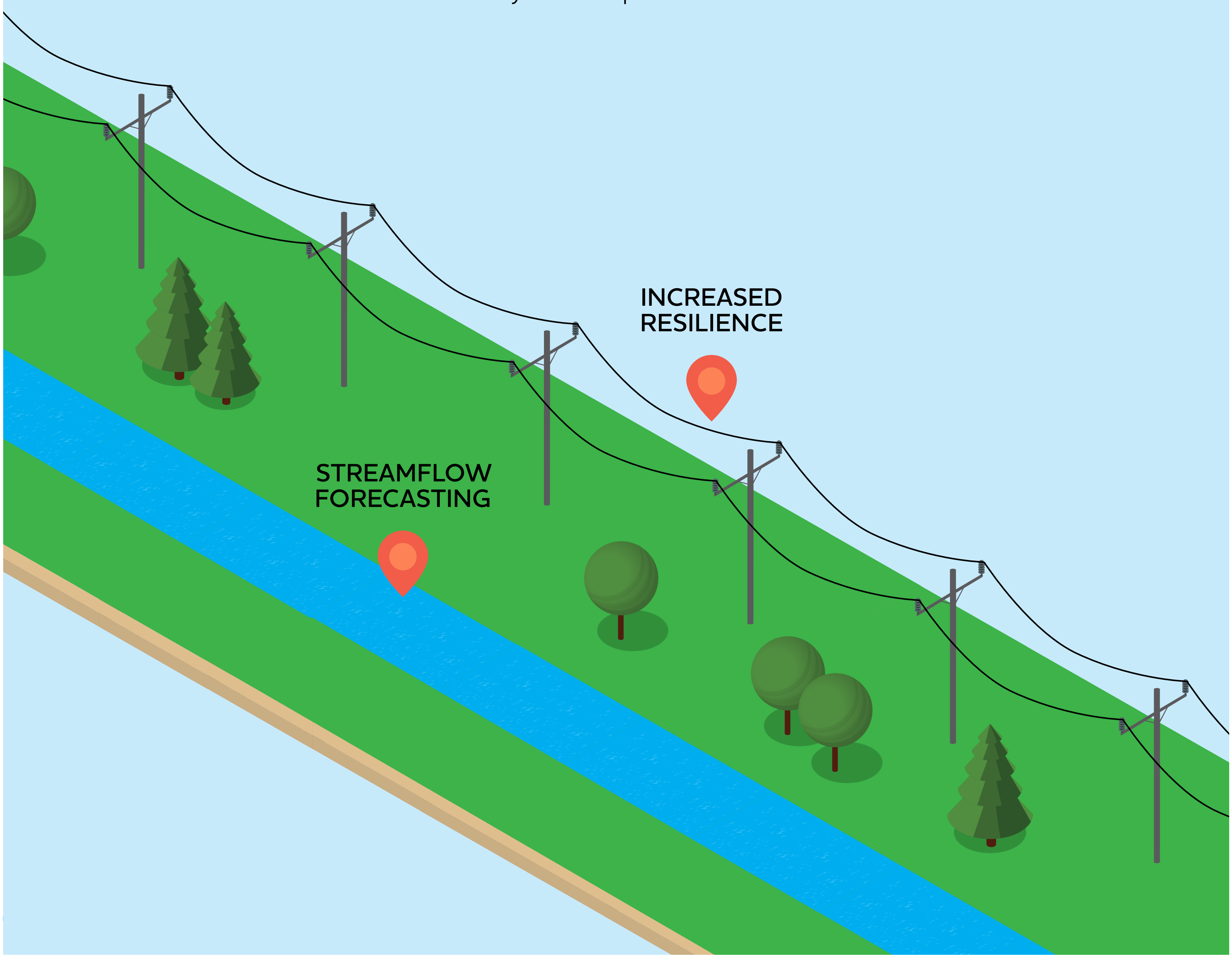
2013: Started sponsoring GHGSat's innovative satellite-based remote sensing technology project.

2017: Became a participating member of EPRI's UCSGSA.

5

ADAPT

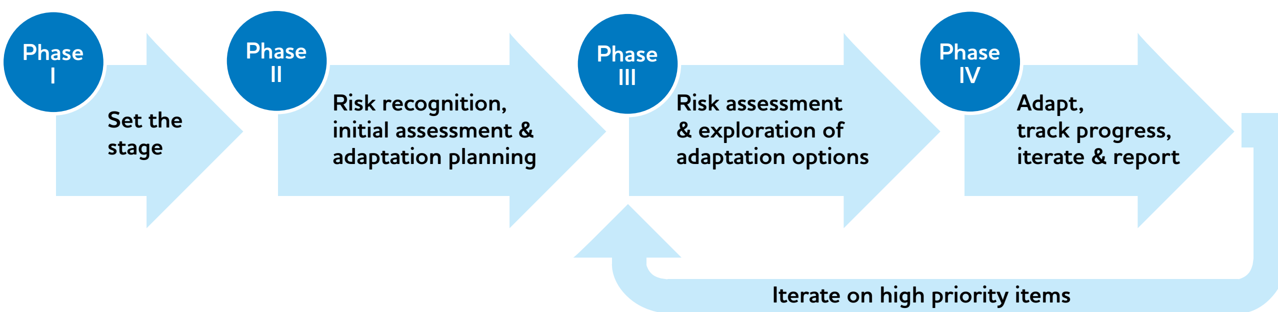
Climate change adaptation refers to the process of taking action to reduce negative impacts as a result of climate change and taking advantage of new opportunities. Climate change adaptation may also be viewed as the reduction, or management, of weather-related risks. Since Manitoba is subject to highly varied intra-annual and inter-annual variances in weather, management of weather-related risks is already common practice.



It is well understood that climate change has the potential to impact hydroelectric utilities like Manitoba Hydro. Impacts may include changes in water supply, energy demand, environmental loads experienced by our transmission and distribution system, and greater stresses on our human resources who work in outside environments. We have a plan to comprehensively address climate change related risks and incorporate adaptation into our business.

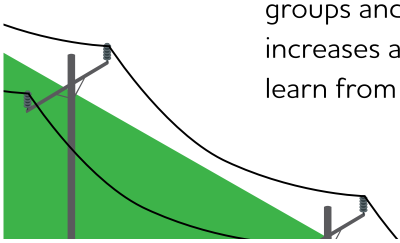
Development of a Climate Change Opportunities, Risks and Adaptation (CCORA) Working Group is underway to help us adapt to climate change. This initiative involves members from across the corporation and aims to identify, screen, and prioritize a comprehensive list of potential climate-related sensitivities facing Manitoba Hydro. For high priority items, specialized studies will be undertaken to better understand the risk or opportunity, explore potential adaptation options and make recommendations. The CCORA Working Group will be divided into sub-groups to help explore specific topics in greater detail and will explore opportunities to integrate with existing business processes such as strategic and financial planning as well as asset management policies and practices.

FIGURE 41 **Climate Change Opportunities, Risks and Adaptation (CCORA) working group phases**



We have been taking adaptation actions prior to the formal development of CCORA. For example, the presence of an internal group to monitor climate science and conduct internal studies is an established and ongoing adaptation action. Past, ongoing, and future research also helps us better understand climate-related sensitivities (e.g., climate change impact on water supply and energy demand). Involvement in working groups and industry groups also increases awareness and helps us learn from what others are doing.

> "Protecting against climate risks requires adaptation actions tailored to expected, specific adverse impacts and to the unique characteristics of the systems at risk."
>
> Canada's Top Climate Change Risks [Council of Canadian Academies, 2019]



INITIATIVES

Our many internal initiatives to manage weather-related risk position us to adapt to future climate changes. A few of these initiatives are identified below.

5.1 RESOURCE PLANNING

In 2013, we used GCM projections of future runoff to explore the economic sensitivity of energy resource development plans to climate change impacts on streamflow. This analysis was highlighted in the Needs For and Alternatives To (NFAT) business case application submitted to Manitoba's Public Utilities Board. See Manitoba Hydro (2013b) and Ouranos (2016) for additional information. We are now working to refine its approach for using climate change in resource planning studies. This refinement includes enhancing the generation of future streamflow scenarios as well as building on previous studies that looked at climate change impacts on energy demand [Manitoba Hydro, 2015b].

It is important to acknowledge that even as our climate change assessment 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, we 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.

5.2 STREAMFLOW FORECASTING

Improving streamflow forecasts enables our system operators to better manage energy resources (e.g., reservoirs), schedule maintenance, and coordinate major construction activities (e.g., Pointe du Bois Spillway Replacement Project and Keeyask Generation Project). We are modernizing our streamflow forecasting process by developing an Operational Physically Based Inflow Forecasting Framework (OPBIFF) for the entire Nelson-Churchill Watershed at key points of interest.

OPBIFF couples weather forecasts from Environment and Climate Change Canada (ECCC) with hydrological models to forecast streamflow conditions 21 to 90 days into the future. While this time frame is relatively short in the context of climate change, it provides a more realistic forecast of streamflow compared to traditional statistical (auto-regressive) forecasting methods. The physically-based approach and extended forecast range (90 days) fosters a longer planning period than previously used. As longer term (e.g., seasonal) numerical weather modelling improves, we are positioned to incorporate longer and more accurate weather forecasts into its operational framework.

Investigating how climate and hydrology of the Nelson-Churchill Watershed has changed and will change in the future is key to understanding and adapting to the potential vulnerability and opportunities of climate change. OPBIFF has led to improvements in watershed modelling tools which benefit the study of longer-term climate change projections. Improvements include:

- enhanced Canadian Precipitation Analysis data [Lespinas et al., 2015; Fortin et al., 2018];
- computational efficiency;
- incorporation of reservoir operations [Tefs et al., submitted]; and
- analysis of precipitation network design [Abbasnezhadi et al., 2019a; Abbasnezhadi et al., 2019b].

5.3 TRANSMISSION & DISTRIBUTION SYSTEM RELIABILITY

Extreme weather, such as wind, icing, and forest fires, can cause disruptions to our electrical transmission and distribution systems. With possible increases in the frequency, duration, and intensity of extreme weather events due to climate change, projects that increase system resilience and reliability provide adaptation benefits.

Approximately 70% of our generated capacity is carried from hydroelectric stations in northern Manitoba to major load centres in southern Manitoba via a High Voltage Direct Current (HVDC) transmission system. Until recently, the HVDC system consisted of Bipoles I & II utilizing a common 900 km-corridor and terminating at the Dorsey converter station northwest of Winnipeg. Extreme weather events in 1996 (microburst winds brought down 19 HVDC towers in southern Manitoba) and 2011 (overland flooding froze and threatened the collapse of 60 towers in northern Manitoba) demonstrated vulnerability of the system. A new HVDC line (Bipole III) was added in July 2018, traversing a corridor separate from Bipoles I & II, and terminating at the new Riel Converter Station southeast of Winnipeg. In addition to providing more transmission capacity from northern to southern Manitoba, Bipole III increases resilience to extreme weather events that may damage the HVDC system. Similarly, the planned Manitoba–Minnesota Transmission Project increases system reliability by providing additional import capacity during droughts and export capacity during higher flow conditions.

We also employ an ice monitoring and mitigation program to help protect our distribution system. An Ice Vision system is employed to detect and monitor ice accumulation at key locations prone to icing. Ice rolling and ice melting techniques are applied to remove ice after major icing events. These systems were not originally envisioned as climate change adaptation measures but position us to manage some specific weather-related risks.

5.4 GREENHOUSE GAS PRICING IMPLICATIONS

Adapting to climate change also includes planning for the impact of climate change policies. GHG pricing is a policy that directly impacts our operations. Canadian GHG pricing policies are impacting the cost of operating our thermal generating stations, operating our fleet, and heating our buildings and natural gas distribution pipelines.

The Greenhouse Gas Pollution Pricing Act currently imposes a $20/tonne CO_2e Fuel Charge on most fuel use in Manitoba and is set to rise to $50/tonne CO_2e in 2022 [Canadian Department of Justice, 2018]. Brandon generating station is a mandatory participant in the Output-Based Pricing System and only pays a GHG price on emissions above a performance standard of 370 tonnes of CO_2e/GWh [Canadian Department of Justice, 2019]. Conversely, our application for Selkirk generation station to be a voluntary participant in the Output-Based Pricing System was denied as ECCC's policy is to not accept participants emitting below 10,000 tonnes of CO_2e annually [ECCC, 2018b]; therefore, all combustion emissions at Selkirk generating station are subject to the full Fuel Charge. Were we to build any new gas-powered units they would have a performance standard of 0 tonnes of CO_2e/GWh from 2030 onward, thereby making all emissions subject to a GHG price [Canadian Department of Justice, 2019]. Our off-grid diesel-fuelled generating stations are completely exempt from the GHG pricing (i.e., the Fuel Charge).

We embed Domestic GHG Price Forecasts in our financial forecasts and resource planning activities. But while current legislation is known, there remains significant uncertainty as to the long-term price of GHG emissions and the details of future systems. The range of potential long-term GHG emission prices, as well as fuel prices in general, is a key consideration in resource planning.

Beyond Renewable Portfolio Standards and Production Tax Credits, which produce indirect GHG pricing signals, there is currently no direct GHG price in our U.S. export market. However, the future implications of GHG policies implemented in our U.S. export regions are embedded in Manitoba Hydro's Export Price Forecast.

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

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WE'RE IN IT TOGETHER

Manitoba Hydro is committed to helping the world reduce emissions and mitigate the effects of climate change. As the climate continues to change, we are adapting our processes to ensure we continue delivering reliable, renewable energy to Manitobans.

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