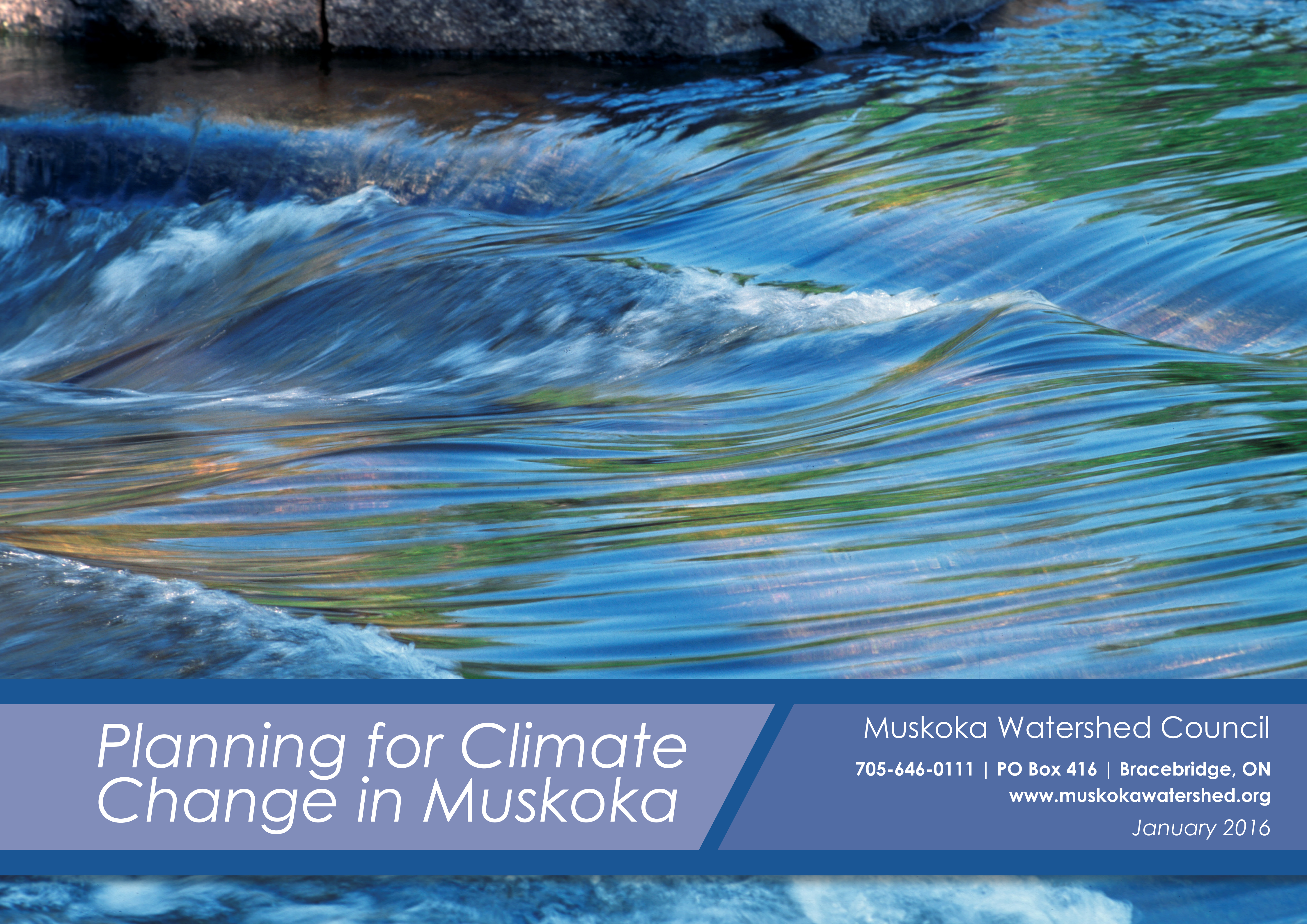

Planning for Climate Change in Muskoka

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Planning for Climate Change in Muskoka

Contents

1. Summary

Climate is now changing more rapidly than it has changed at any previous time in the history of human civilization. If we continue on our current path, with ever rising emissions, we face unprecedented, catastrophic climate change later in this century.

Climate change has been happening for many decades, is occurring in Muskoka as well as in other parts of the world, and is now becoming apparent in people's daily lives. Muskoka cannot prevent climate change, although every one of us, by making various changes in our lives, can participate in the global effort to reduce emissions of greenhouse gases – the primary cause of climate change at the present time. Because of time lags in the Earth's complex climate system, human activities until now have caused changes that are going to reveal themselves over the rest of this century and beyond. Any additional changes in behavior that we introduce (as individuals, or as part of the 2015 Paris Agreement, or future global treaties) in the next few years will only bring measurable climatic improvements later in the century as climate continues to change. They can have little effect on the climate that is already on track to be here by mid-century. These time lags, and the slow pace of climate change, are a major reason why it has been difficult to convince people of the need to act in order to avoid truly catastrophic climate changes in the future.

This report is about the climate that Muskoka is likely to experience at mid-century. That time is sufficiently far away that the climate will be measurably different to what we have today, yet not so far away that it fades into the misty future. If you have children starting kindergarten in 2016, they may have children of their own in school at mid-century. Your grandchildren!

This report examines the likely impacts of that mid-century climate on our lakes and waterways, our beautiful forests, our built infrastructure, our communities, and our way of life. Its recommendations for actions to address some of those impacts deserve careful consideration and prompt action by provincial agencies, district and municipal governments, local businesses, community groups and individual Muskokans. The good news is that climate change in Muskoka, while substantial, is unlikely to create insurmountable problems. The better news is that while there will be a number of negative impacts on our environment and our lives, we have sufficient understanding of the causes and processes involved, plus the relevant skills to plan for and implement adaptive responses that will minimize these impacts. The still better news is that with community-wide commitment to forward planning and timely action we should be able to adapt effectively to the new world that is coming while keeping costs manageable.

We are at the beginning of a journey the like of which has not been seen in human history. Not since the invention of agriculture has climate changed to the extent and at the speed it is expected to change over the remainder of this century. With adequate preparation this will be an intriguing journey as we match our skills and intellect to the new challenges our planet is providing for us.

The good news is that so long as we plan ahead and take adaptive action, the climatic changes likely to come to Muskoka by mid-century are manageable. Our experience will be better, and the expense we will incur in adapting to the new climate will be less, if we begin that planning and those actions now.

While it is not yet possible to precisely define future climates, the growing expertise in climate science makes it possible to set out plausible and likely climatic conditions for future periods, given specific assumptions about how the global economy grows and its pattern of energy use changes. We have used data generated by the Intergovernmental Panel on Climate Change (IPCC CMIP5 Project) to extract information on the mid-century values for temperature and precipitation in Muskoka that are expected if the world follows each of two plausible scenarios for economic growth and greenhouse gas emissions reductions. We have compared these data with equivalent measurements of temperature and precipitation in our current climate. While there will still be warm years and cold ones, wet ones and dry ones, the typical year at mid-century is likely to be 3-4°C warmer each month than at present, and about 10% wetter. As well, the precipitation will likely shift towards the winter/spring season, so that summer and fall will be dryer than at present, while the six months from November to April will be about 17% wetter. The warmer climate is expected to also increase rates of evaporation and transpiration, so that while the amount of precipitation during the May to October period will be little changed from today in a typical year, soils will be dryer, some wetlands will dry up, and flow in streams and rivers will be reduced compared to at present. Drought and a greater risk of fire will impact our forests.

Our evaluation of the data suggests that Muskoka's climate at mid-century is going to be warmer and slightly wetter than at present, and that precipitation may come in fewer but more pronounced storm events. These changes have impacts.

Impacts of these changes on the Muskoka environment could be substantial. The increased precipitation during winter months, and the expectation that much of this will come as rain rather than snow except in colder than usual years, may greatly alter the typical annual pattern we currently experience -- accumulating snowpack, spring thaw, and a summer with sustained but reducing flow through our waterways. Instead, much of the winter precipitation may flow downstream during frequent thaws during that season. The reduced availability of water during summer and fall, and the warmer climate expected, will mean that by mid-century our lakes will be ice-free for longer, will warm up more during the season, will be more productive, but may also be at greater risk of deteriorating water quality. Algal blooms are likely to become a more frequent event, and there are likely to be subtle but important changes to the ecology of our lakes and to the composition of species that live there. While many of these changes will be of little concern for the scenic, recreational or economic value of our waterways, some of these changes may be of major concern generally, or at specific locations.

We recommend increased attention to sound, science-based monitoring of our lakes and other waters, so that we will have the information enabling us to assess how they are changing. We must develop greater understanding of algal blooms, their causes and the factors that determine when and where they are likely to occur; it may become necessary to introduce active measures to reduce the tendency to bloom in some or all of our lakes. It will also be prudent to explore more active management of water flow than has been attempted until now, seeking ways to keep water uphill and available to nourish our waterways during summer and fall, rather than allowing all the winter precipitation to move quickly down to Georgian Bay.

Opportunities for outdoor recreation and enjoyment of our lakes are likely to increase in the warm and sunny summers we anticipate by mid-century. Winter recreational opportunities will be outstanding in some years with plenty of snow, but in most years the snow season is likely to be substantially shortened. Venturing out on ice covered lakes will become more risky.

Our forests will also change in a number of ways under the changing climate. Most of the trees that live in Muskoka are likely to be better suited to locations far to our north by the end of the century, and those still living here will be under climatic stress and likely not faring well. The pace of climate change is so fast that it will likely be necessary to assist suitable southern trees in moving north, by using species suited to a climate that is currently well south of Muskoka in urban planting, landscaping, and in reforestation. The warmer climate and increased atmospheric CO_2 should facilitate plant growth; farmland should be more productive so long as water is available in summer and fall. The generally dryer conditions during the growing season will increase the risk of fire, and some of our forests may well be reshaped by new fire regimes.

Unfortunately, the warmer and seasonally dryer climate we expect will facilitate the arrival of various insect pests and pathogens that will impact our forests. Other new pathogens will bring new human diseases to Muskoka – Lyme and West Nile disease are both already, or will soon be here, but both will become more prevalent as climate warms. Insect-borne diseases such as malaria, dengue fever and chikungunya disease may enter our region later in the century. Potentially more important than these new diseases may be the increased risk of heat-related death for elderly and infirm poor people dealing with prolonged summer heat waves in conditions without adequate temperature control. In general, it is expected that the increases in heat-related deaths will be greater than any reductions in cold-related deaths due to the warmer winters.

Although we were unable to specify the extent of change in severity of weather events, it is widely recognized that a warming climate will result in more extreme episodes of precipitation – whether as blizzards, ice storms or thunder storms. Violent storms, including tornadoes, will likely be more frequent. Flooding, particularly during winter and spring, is likely to be substantially more severe than at present, especially in colder years when a substantial snowpack develops. We need a plan to cope with severe weather events of all types, and to make better information available to the community on where there are lands at risk of flooding. Our stormwater management systems and infrastructure will need review, and probably substantial renewal/expansion. So will our electricity grid, if reliable service is to be maintained. Such infrastructure renewal will be done in a more cost-effective way with appropriate forward planning and staged implementation.

While our report focuses on the likely climate at mid-century, the process of climate change will continue beyond that time. How climate changes later in the century and beyond will depend very much on decisions by humanity on the nature of our future energy sources and the size and energy intensity of our global economy. Muskoka can, and should, do its part in the global effort to reduce emissions of greenhouse gases and increase energy efficiency; the 2015 Paris Agreement on climate change is a spur to collective action. Muskoka should also plan wisely for effective adaptation to the changes now seen as very likely by mid-century, while continuing to monitor and prepare for changes that will become better defined as the century progresses. Our need to adapt to a changing climate does not end at 2050.

Muskoka provides a wonderful environment in which to live, and that environment sustains a vibrant tourism and recreational economy worth approximately $400 million annually (roughly 55% of our total economy). Climate change is going to alter our weather and our environment over the next decades, and these alterations will inevitably change our lifestyles and our economy. The good news, supported by the best available climate science, is that while climate change will bring quite substantial changes by mid-century, it need not make Muskoka a less wonderful place in which to live. In fact, it is likely to make our summers longer and more glorious than ever, and with appropriate forward planning, and modifications to infrastructure and activities, we should be able to adapt effectively at least to mid-century, while retaining most of the environmental values that enrich our lives and sustain our economy. On the other hand, if the international community (including Muskoka) fails to deal adequately with the need to reduce emissions, we and the rest of the planet are in for a very rough ride later in the century.

This report provides an in-depth look at the changes likely to come, and at the likely effects on our environment, our infrastructure and our lives. It closes with 15 specific recommendations for action by government, by business or community groups, and/or by individual residents (pages 43 to 46). We encourage all to read these recommendations, explore the arguments behind them, and join in the effort to adapt to the climate that is coming. With effective adaptation effort over the next several decades, we can keep Muskoka that special jewel at Ontario's heart.

2. Introduction

Climatic changes likely to come to Muskoka by mid-century are manageable if we plan ahead and take adaptive action. Our experience will be better, and the expense we will incur in adapting to the new climate will be less, if we begin that planning and those actions now.

The climate on this planet is not static; it has changed many times in the past for a variety of reasons, and will undoubtedly continue to change in the future. Relatively speaking though, climate has been surprisingly stable since the end of the Pleistocene ice ages (~12,000 years ago) until quite recently[1]. Now the tremendous changes wrought by humanity since the start of the industrial revolution are causing it to change more rapidly than humans have ever experienced.

Climate is changing in Muskoka just as it is changing elsewhere, and we are powerless to alter the trajectory by taking local action. Instead, we must adapt to the changes coming, while supporting the global actions that need to take place if we are to avert truly serious changes in climate later in this century. To adapt effectively, we must plan ahead and act proactively.

Why another report on climate change from the Muskoka Watershed Council?

MWC first reported on climate change in 2010. That document, ***Climate Change and Adaptation in Muskoka***, remains relevant and is available on our website. However, it is our view that understanding of the details of climate change and its environmental consequences has progressed rapidly during the last five years, and more evidence is available that climate is already changing. There is also increasing awareness of climate change by the public, and we believe that now is the time to begin serious discussion about the need for local adaptation to its consequences.

We intend this report to re-invigorate the need for long-term adaptation planning by individuals, businesses, community groups and local governments. We recommend that efforts be coordinated, because together, we will be better able to take the necessary steps. Muskoka Watershed Council believes that a significant long-term response to climate change will be needed if the Muskoka community is to be well prepared for the changes likely to arrive by mid-century. By planning ahead, we will be best able to protect the intrinsic values of our natural environment, while fostering a more diversified economy that is still grounded in tourism and recreation. By encouraging such an approach, MWC hopes to ensure long-term benefits for the health of our watershed.

Our approach in this report

Climate[2] is typically defined by the long term averages of daily or more frequent measurements of temperature and precipitation (rain plus snow). These are important measurements, carried out in Canada by Environment Canada, through a comprehensive nation-wide network of monitoring stations. These measurements are used for short-term weather forecast computer modeling; they are also the Canadian input used in long-term global climate models. This distinction between weather and climate is an important one. Weather is what we experience day-to-day; it is the heat we feel in the summer and snow we shovel in the winter. Weather can change rapidly from one hour to the next and is measured by thermometers and rain gauges. Climate is the long-term average of weather, and the UN's World Meteorological Organization has defined a *climate normal* to be the average of weather recorded over a period of 30 years. When talking about

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[1] *The Medieval Climate Anomaly (MCA, 950 to 1250 AD) was a time of warm climate over northern Europe and the Atlantic with temperatures comparable to those of the mid-20th century (cooler than today). The Little Ice Age (1400 to 1700 AD) was the coolest period in the northern hemisphere over the past 1,500 years, experiencing temperatures averaging about 0.4°C lower than the MCA in the northern hemisphere and about 0.24°C over the entire planet (Mann et al., 2009).*

[2] *Italics are used in this report to highlight terms that are defined in the Glossary.*

climate in this report, we are referring to averages of daily temperature and monthly precipitation over three decades.

In this report we have opted to focus attention on the climate likely to be here by mid-century. That is quite soon to detect climatic change, but it is also about as far into the future as most people are capable of planning for. Because climate is changing very rapidly compared to past planetary history, although still slowly in human terms, it is sufficiently far into the future that the changes that will occur are likely to make the climate measurably different than today. The choice of mid-century is a compromise: we could have talked about more extreme change by picking a later date, but at the risk of not engaging readers in the necessity to begin acting to prepare for what is coming, and to mitigate its impacts where possible.

Given our resources, we have also chosen to focus on the impacts of the climate expected in a typical year at mid-century, rather than on the impacts of the warmer, or wetter than usual years, or on the impacts of the particular extreme weather events that will make up any of those mid-century years. Global climate models are enormously sophisticated and deal with a myriad of factors and processes that modulate the interactions of land masses, oceans and atmosphere to generate climate. But they model climate, not weather, and the steps required to move from a model of a future climate to a risk analysis based on frequency, intensity and periodicity of storm events are many and themselves also complex. It is changed weather, rather than changed climate, that will likely have the most significant impacts on our built infrastructure. Changed weather will also have important impacts on our environment. We draw attention to these facts at appropriate points, but attend primarily to the effects of the changed climate, reasoning that the periodicities and severity of future weather are likely to be similar to, or more pronounced than weather today.

We are using the best source of climate science data available to infer the likely climate in Muskoka at mid-century. We recognize that all projections of climate are imprecise, but that combining multiple projections provides increased confidence in the average trends described. At the same time, we understand that the actual climate that eventually arrives in Muskoka at mid-century is unlikely to be precisely the climate we set out in these pages. Reality is far too complicated for that. As an analogy, consider the ‘simple’ task of predicting the number of ‘heads’ if a coin is tossed 10 times. Intuitively, we’d expect 5 heads and 5 tails. Indeed, if we tossed the coin 10 times, then again, and repeated sets of 10 tosses until we had 100 or 1000 such sets, the average result would be 5 heads, or very close to that. But if we tossed the coin 10 times on one occasion, we could get 10 heads, 0 heads, or any number in between. Climate is determined in a far more complex (and less random) way than is the result of 10 coin tosses. We have proceeded using the best description of our likely mid-century climate we could assemble. It is sufficiently changed from today that there are impacts on our environment and our lives that deserve serious consideration and adaptive or mitigating action[3]. We discuss these impacts and their implications, and make recommendations based on that assessment. This approach is one used in a number of other communities around the world. We believe it provides an effective basis for moving forward on planning and action here in Muskoka.

Why is climate changing?

Analysis of gas bubbles in glacial ice cores is one of several techniques that provide data on the composition of our atmosphere in the past. These bubbles tell us that our atmosphere used to contain far less CO_2 than it does today. Before the start of the industrial revolution our global economy ran mostly on horse power, water power and wind power. With James Watt’s invention of the first practical steam engine in 1765 our use of coal expanded rapidly, to be joined later by use of oil and gas. These three ‘fossil’ fuels now provide most of the energy needs of the global economy, but by burning them we release CO_2 into the atmosphere (along with small amounts of other gases).

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[3] *Adaptation is the process of modifying procedures or structures to resist new stresses due to the changed climate; mitigation is the process of taking other actions that will reduce those stresses partially or entirely.*

The concentration of CO_2 in the planet's atmosphere was about 280 ppm prior to industrialization; it stood at 315 ppm in March 1958 when direct measurement at Mauna Loa commenced, has now risen to over 400 ppm, and continues to increase sharply (Figure 1). While its concentration has been higher than this in many earlier geological periods, it is now higher than at any time in the last 25 million years, and is rising at a more rapid rate than at any time in the last 65 million years (Royer 2006, Zeebe 2012).

CO_2 is known as a *greenhouse gas* (GHG), because along with other GHGs such as methane and nitrous oxide, it is transparent to light energy but less so to heat energy (much like glass in a greenhouse). Light energy arriving from the sun is converted to heat energy when it is absorbed by surfaces on the planet. That heat radiates back into space at a rate that depends on the composition of our atmosphere. Higher concentrations of GHGs cause the atmosphere to impede the radiation of heat, keeping the planet warmer.

Our burning of coal, oil, and gas releases carbon that has been buried deep within the planet for millions of years. That carbon is combined with oxygen to form CO_2 which enters the atmosphere. While a substantial fraction of this 'new' CO_2 promptly moves from the atmosphere to the ocean (as dissolved CO_2), or is incorporated in new plant tissues during photosynthesis, about one third of it remains in the atmosphere. This increase of atmospheric CO_2 is the main way in which we have been inadvertently modifying the climate. By progressively increasing the abundance of CO_2 and (to a lesser extent) other GHGs such as methane in our atmosphere, we are causing the planet to warm up, and long-term measurements of temperature reveal the extent of the change so far.

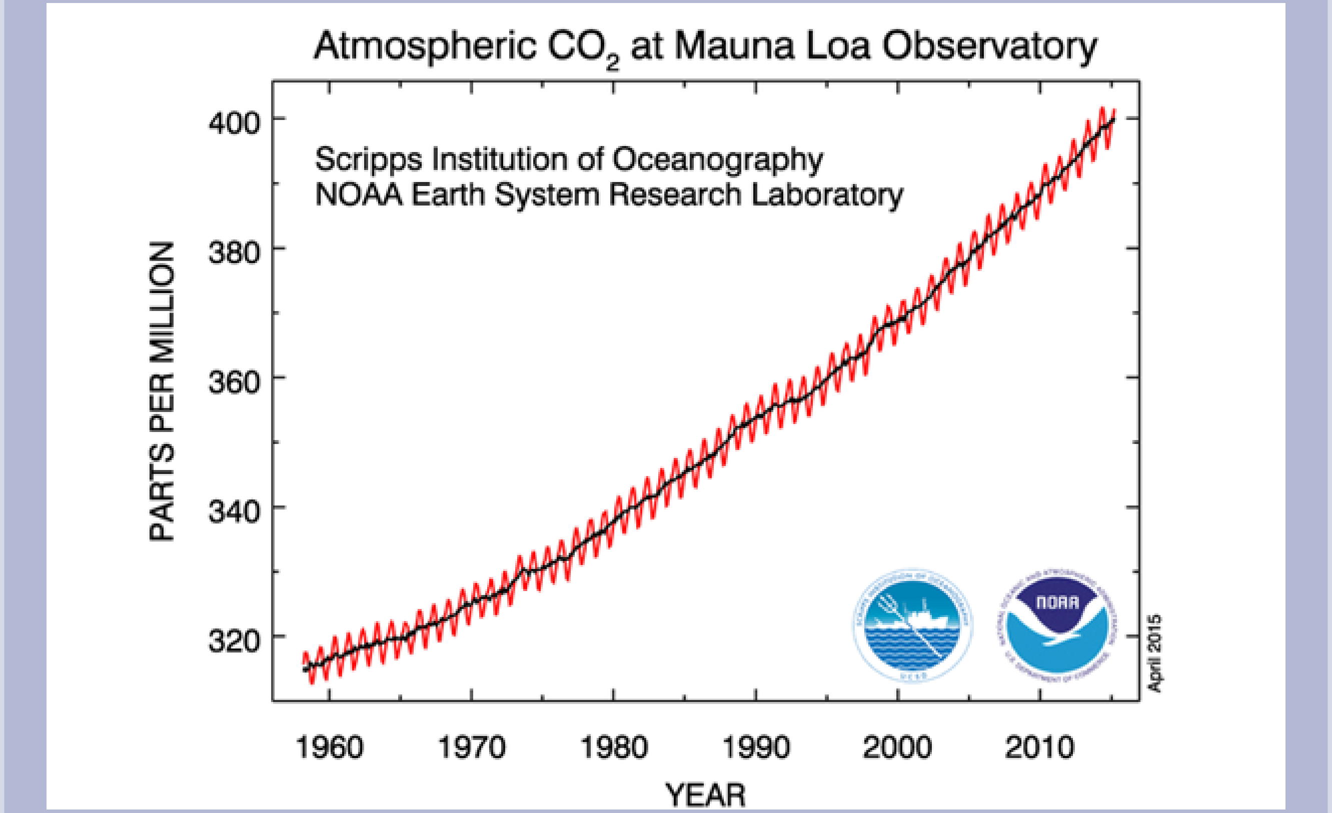


Figure 1. The plot of direct measurements of CO_2 concentration in the atmosphere by instruments at the summit of Mauna Loa, Hawaii, from 1958 to the present. Shown is the annual trend (black) and the monthly trend (red). This is the longest set of direct, continuous measurements of CO_2 concentration in existence. Graph courtesy of NOAA Earth Systems Research Laboratory (Source: U.S. National Oceanic and Atmospheric Administration's Earth Systems Research Laboratory, Global Monitoring Division website: http://www.esrl.noaa.gov/gmd/ccgg/trends/).

If it were not for the greenhouse gases in our atmosphere, our planet's average temperature would be <0°C, all water would be ice, and life as we know it would not exist.

The full story is a bit more complex. More light energy arrives in the tropics than in polar regions. The geographic differences in amount of resulting heat energy are a primary factor driving major wind systems and ocean currents. A warmer atmosphere is more energetic, leading to stronger winds and more severe storms; it can also hold greater quantities of water vapor, altering the water cycle and leading to more pronounced rain events and droughts. There are also natural changes in the orbit of the planet around the sun, cycling on timeframes ranging from 10 to 100,000 years, and in solar activity, that together modulate the amount of light energy delivered per second. However, these changes cause variations in climate that are far smaller than those now being caused by the accumulation of GHGs due primarily to our rapidly growing, fossil-fuel-powered economy and the CO_2 emissions it produces.

Climate is now changing more rapidly than it has changed at any previous time in the history of human civilization, primarily because of our emissions of greenhouse gases, and the changes are taking us to climates that are 'new' in human experience. As IPCC (2013) tells us, "Since the 1950s, many of the observed changes are unprecedented."

The causes of climate change are well understood, and we can alter the future trend by substantially reducing our emissions of GHGs. However, this demands a sustained international effort and all major emitter nations, including Canada, must participate for it to succeed. In addition, there are long latencies within the planetary climate system as well as within our global economy that mean that we cannot change the composition of the atmosphere overnight. Global cooperation will be necessary over the long-term to reduce GHG emissions, and the sooner a real effort commences the easier (and less costly) it will be to avert truly dangerous climate change. No matter how effectively the parties to the UN Framework Convention on Climate Change come together to act (and little progress has been made over the last 20 years), we cannot avoid significant climate change impacts on our lives here in Muskoka during this century. Thus there is a need for both local adaptation planning and the global effort to reduce GHG emissions.

This report focuses attention on the likely climate in Muskoka at mid-century, and the adaptive actions that need to be planned and implemented if we are to ease the stresses coming to our environment, to our economy, and to our lifestyles.

How has local climate changed in recent decades?

We've all heard tales of how cold Muskoka winters used to be back in our grandparents' time; some people say our 2014-2015 winter was reminiscent of those past winters. Beyond such stories, fondly or less fondly remembered, there are reliable weather data that reveal how climate has been changing here.

Weather is the day-to-day variation in temperature, rainfall, wind speed, and so on; climate is the average of weather conditions over spans of 30 years. By averaging over 30 years, climate scientists smooth out the day-to-day fluctuations of weather in order to characterize 'typical' conditions and to detect any long-term trends at a location.

As shown in Figure 2, averaged across the entire planet, temperature has been rising, and the planet is now about 0.8°C warmer than it was around 1900 (Riebeek 2010). The entire planet has not warmed evenly at all locations; temperature records from a Ministry of Environment and Climate Change (MOECC) weather station at Harp Lake, east of Huntsville, ON, reveal a somewhat greater increase of 1.2°C since 1978, and a slight reduction in total annual precipitation (Figure 3).

Across the Muskoka River watershed, about half the precipitation arriving flows through the system to Georgian Bay, while the other half returns to the atmosphere via evaporation and transpiration. Data from the Harp Lake station also enable a glimpse at the fate of water arriving as rain or snow in that small portion of the Muskoka River watershed, and how this has varied over past years. Figure 4 shows statistically non-significant trends since 1978, revealing that, for Harp Lake, run-off marginally exceeds evaporation in most years. That difference may be narrowing as evaporation increases with rising temperatures. The occasional particularly dry year now provides a glimpse of what is likely to become more typical in the future.

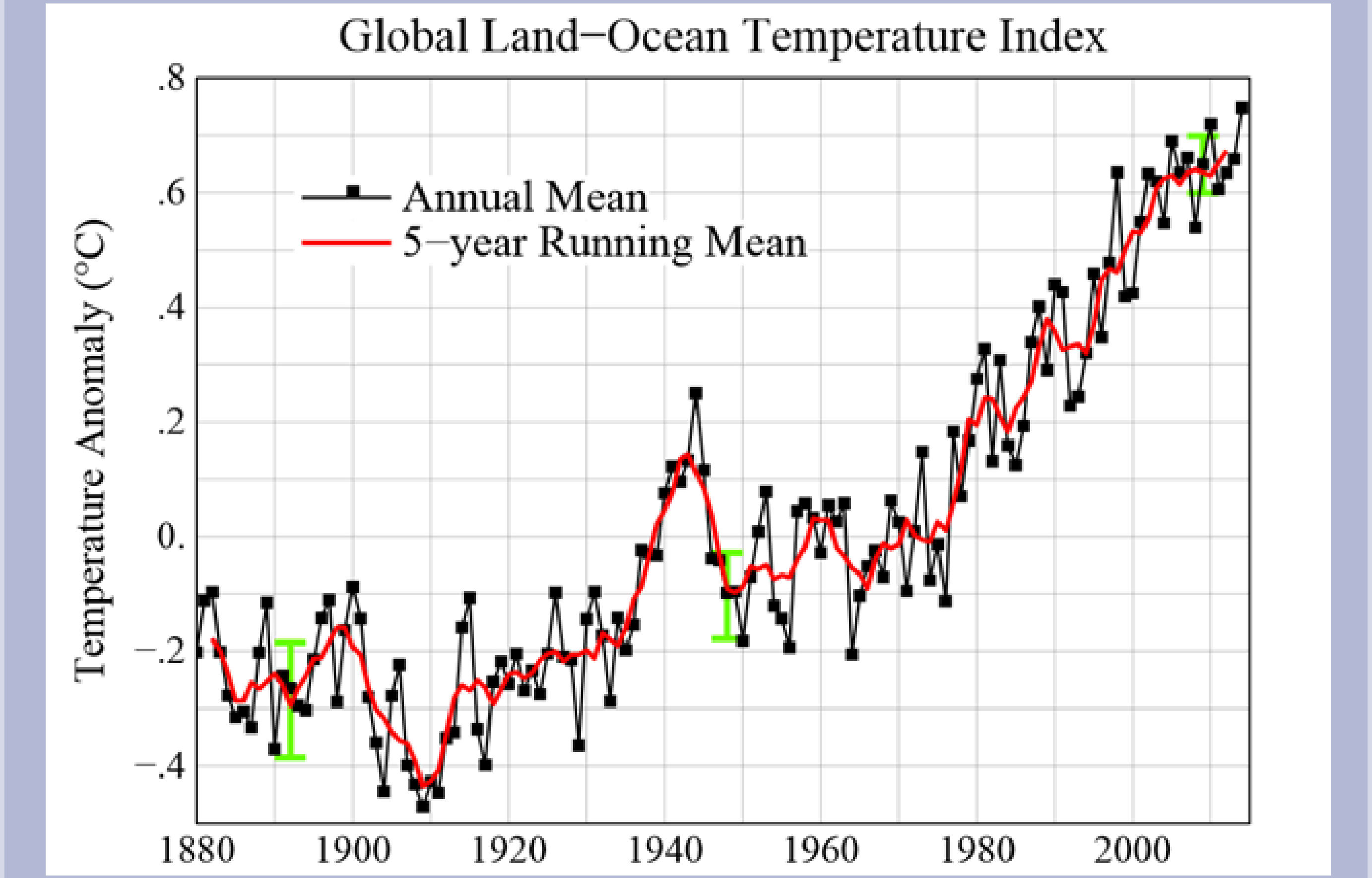


Figure 2. Despite ups and downs from year to year, global average surface temperature is rising. By the beginning of the 21st century, Earth's average surface temperature was roughly 0.5°C above the long-term (1951-1980) average, and 0.8°C above the average for the end of the 19th century. This graph depicts the annual mean temperature anomaly (the departure from the long-term average during each year – the black line), and a five-year running average of the annual anomaly (the red line). Also shown are estimates of uncertainty in the data (green bars). Figure courtesy NASA Goddard Institute for Space Studies website (Source: U.S. National Aeronautics and Space Administration's Goddard Institute for Space Studies website: http://data.giss.nasa.gov/gistemp/graphs_v3/).

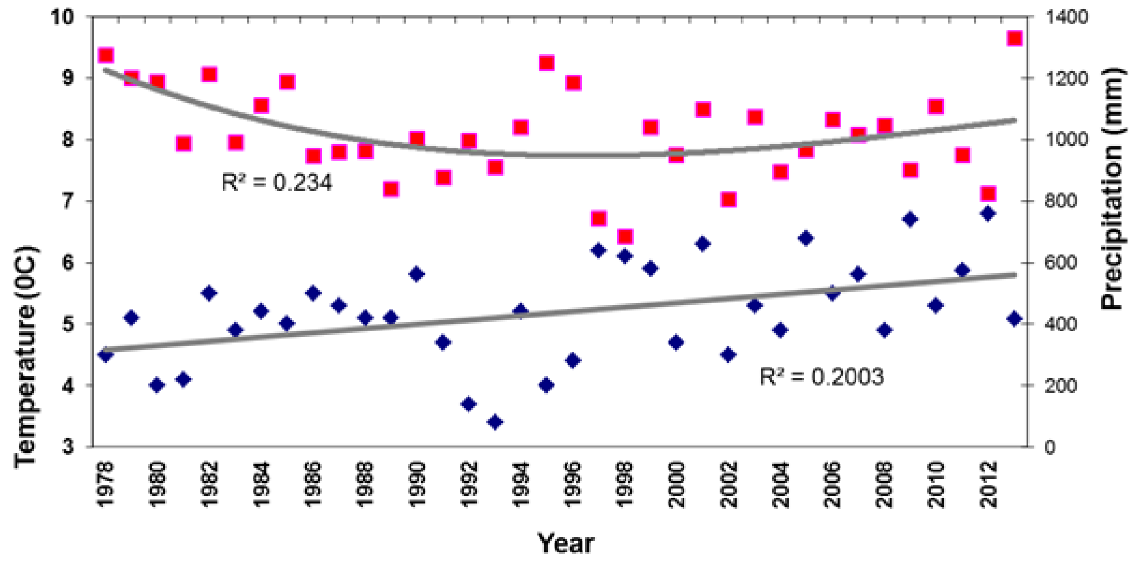
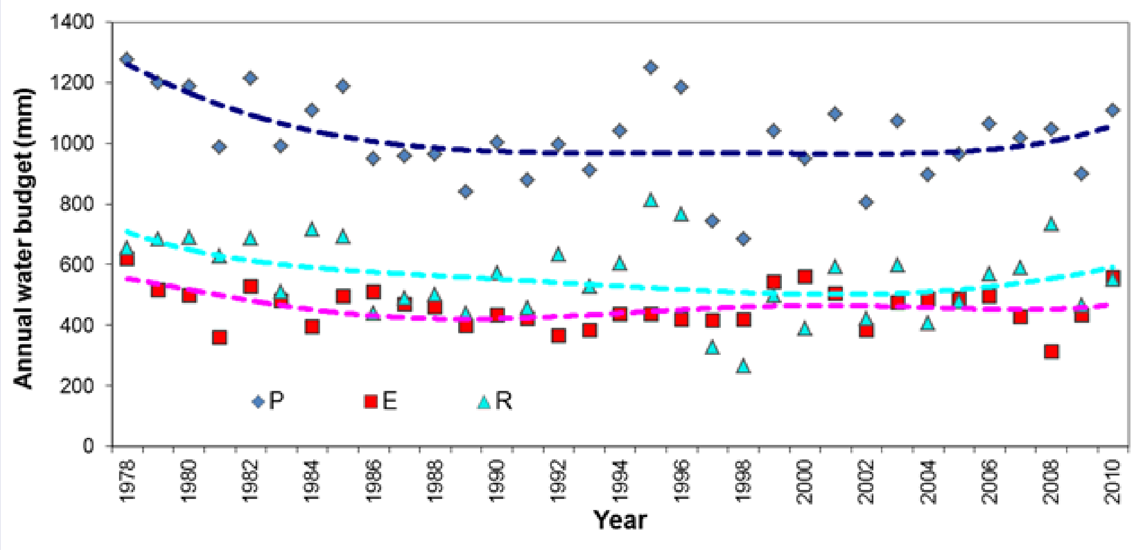


Figure 3. Graphs showing annual mean temperature (blue diamonds) and annual total precipitation (red squares) at the Harp Lake weather station, from 1978 to 2013. While there is considerable variation from year to year in both graphs, there is a consistent, statistically significant, increasing trend in temperature over this time period. The precipitation record reveals a statistically non-significant decline, which may now be reversing. Figure uses MOECC, Dorset Environmental Science Centre data.

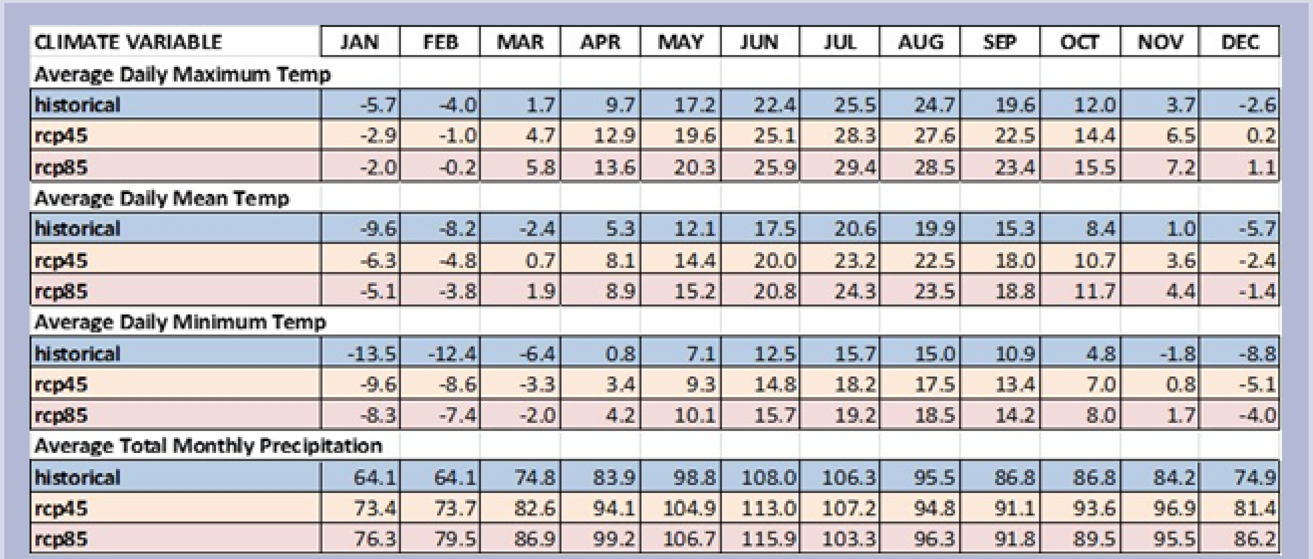
Figure 4. Graph showing the annual water balance of the Harp Lake catchment during 1978 to 2010: P = annual precipitation (blue diamonds), E = annual evaporation from the catchment (red squares), and R = annual runoff (aqua triangles). Overall trends are not statistically significant. Evaporation has varied less than precipitation during this time, increasing slightly since 1990 (due to increased temperature). Runoff has varied somewhat more, largely in synchrony with precipitation, and tends to account for slightly more than 50% of total precipitation. Figure uses MOECC, Dorset Environmental Science Centre data.



3. Muskoka at Mid-Century 1: Climate

Creating future scenarios

The Earth's climate system is inherently complex and dynamic. We cannot know precisely what our climate will be like in several decades' time. That depends on many factors, including the degree to which countries act to reduce emissions of greenhouse gases. However, climate scientists now have considerable understanding of what determines climate, and major effort over the past two decades has improved the overall accuracy of *global climate models* (GCM), and their ability to project climate for particular geographic regions (such as central Ontario). As explained in **Box A**, we have made use of the output from a suite of GCMs for climate at a location in Muskoka as an appropriate projection of our likely mid-century climate. Two alternative projections of this climate which make different assumptions about future human policy on GHG emissions are displayed in Table 1. These projections are discussed on pages 15-16; they describe the mid-century climate that we use in the remainder of this report.



CLIMATE VARIABLE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Average Daily Maximum Temp												
historical	-5.7	-4.0	1.7	9.7	17.2	22.4	25.5	24.7	19.6	12.0	3.7	-2.6
rcp45	-2.9	-1.0	4.7	12.9	19.6	25.1	28.3	27.6	22.5	14.4	6.5	0.2
rcp85	-2.0	-0.2	5.8	13.6	20.3	25.9	29.4	28.5	23.4	15.5	7.2	1.1
Average Daily Mean Temp												
historical	-9.6	-8.2	-2.4	5.3	12.1	17.5	20.6	19.9	15.3	8.4	1.0	-5.7
rcp45	-6.3	-4.8	0.7	8.1	14.4	20.0	23.2	22.5	18.0	10.7	3.6	-2.4
rcp85	-5.1	-3.8	1.9	8.9	15.2	20.8	24.3	23.5	18.8	11.7	4.4	-1.4
Average Daily Minimum Temp												
historical	-13.5	-12.4	-6.4	0.8	7.1	12.5	15.7	15.0	10.9	4.8	-1.8	-8.8
rcp45	-9.6	-8.6	-3.3	3.4	9.3	14.8	18.2	17.5	13.4	7.0	0.8	-5.1
rcp85	-8.3	-7.4	-2.0	4.2	10.1	15.7	19.2	18.5	14.2	8.0	1.7	-4.0
Average Total Monthly Precipitation												
historical	64.1	64.1	74.8	83.9	98.8	108.0	106.3	95.5	86.8	86.8	84.2	74.9
rcp45	73.4	73.7	82.6	94.1	104.9	113.0	107.2	94.8	91.1	93.6	96.9	81.4
rcp85	76.3	79.5	86.9	99.2	106.7	115.9	103.3	96.3	91.8	89.5	95.5	86.2

Table 1. Projections of four components of the climate for Muskoka at mid-century, based on the IPCC CMIP5 data set. The average daily maximum temperature, average daily temperature, and average nightly minimum temperature are listed (all in degrees Celsius), together with the total precipitation (in mm of rain or melted snow) received for each month of the year. Current climatic values for these components are shown (historical), and compared with values derived for mid-century under two different emissions scenarios (named RCP4.5 and RCP8.5). Details in Box A.

IPCC has created a set of *emissions scenarios* which describe possible changes in human behavior with respect to GHG emissions during this century. In evaluating Muskoka's likely future climate, we have assumed that the world will follow IPCC's *RCP8.5 scenario*, a pattern of fuel use that requires fewer, less substantial alterations to past policy. This is the scenario we have been tracking most closely over the past decade. By taking this approach, Muskoka Watershed Council is not suggesting that continuing current policies is a sufficient response to the global threat that is climate change. It is our opinion that Canada and other countries should all work to achieve the deepest and most rapid cuts in GHG emissions possible, but we also recognize that this is NOT what is happening at present. A precautionary approach requires that we focus on the most likely rather than on a preferred policy scenario. We will briefly note differences in the anticipated Muskoka climate if a more aggressive scenario of CO_2 emissions reductions is adopted (e.g. RCP4.5), keeping average global temperature to a maximum 2°C increase by 2100. (Note that under conditions achieving an average global increase of 2°, the increase in Muskoka will still be greater than 2°C.)

Box A: Use of Global Climate Models (GCMs)

Climate scientists are now able to build scenarios of what climate might be like in the future, given assumptions regarding human economic activity and efforts to mitigate climate change. They do this by using GCMs. Highly complex models of the atmosphere, land and oceans, GCMs are built to respond according to known processes and relationships. Their behavior has been validated by showing that they are able to reproduce past trends in such things as temperature very well, and precipitation somewhat less well. Much of the understanding of likely future climate change has been developed by running multiple GCMs which differ in the details with which they represent the many complex causal pathways governing the interactions of atmosphere, ocean and land. When many different models agree closely in their predictions, those predictions are seen as more reliable, and scenarios based on them are more likely.

In preparing this report, we decided to use an extensive set of global climate data that has been assembled by the Intergovernmental Panel on Climate Change (IPCC) under its *Coupled Model Intercomparison Project*. Built by a collaboration of 26 climate research centers worldwide, this CMIP5 data set brings together projections of climate out to 2100 under specific scenarios of how humanity will respond to the need to mitigate emissions of CO_2. The CMIP5 data set is 3.3 Petabytes (about 60 million 4-drawer filing cabinets filled with text) in size, and includes over 800 projections of the global climate, generated by 61 different GCMs running under four specific GHG mitigation scenarios.

These four scenarios, termed *Representative Concentration Pathways*, or RCPs are:

- RCP8.5, a scenario (often termed 'business-as-usual') in which we continue to use fossil fuels as the primary source of energy for our economy,
- RCP6.0, a scenario in which we reduce use of fossil fuels to some degree,
- RCP4.5, one in which the global community makes a sufficient change to its fuel sources that we limit warming of global mean temperature to 2°C by 2100, and
- RCP2.6, a scenario in which we work even harder to reduce use of fossil fuels quickly. Many climate scientists view RCP2.6 as no longer achievable given slow progress until now.

The change in global climate over the last several years has been tracking, or slightly exceeding, the warming trend exhibited by the RCP8.5 scenario.

We used the years 1971-2000 to define the present climate, and the years 2041-2070 for the mid-century climate. For each of these periods, 19 CMIP5 models were used to sample the data for a central location in the Muskoka watershed (45° 5' N, 79° 18' W, a location close to High Falls in Bracebridge). Two scenarios were used, the optimistic RCP4.5 and business as usual RCP8.5 scenarios. The CMIP5 data were accessed from a climate data archive at the Water Systems Analysis Group, University of New Hampshire. For each CMIP5 model, daily minimum and maximum temperatures were taken directly from the daily time-step climate data and mean temperature was averaged from these two values. All temperature values were averaged for each month of the year in each 30-year period. Precipitation was obtained from monthly time-step climate data and averaged for each month over each 30-year period.

Changes in temperature and precipitation anticipated by 2050

Climate models cannot provide a precise picture of the future weather – climate is not weather. Instead, climate projections are descriptions of the 'typical' year during that mid-century period. Nor do different climate models agree precisely on what the future climate should be. Therefore climate scientists treat the broad family of model runs (we used output from 19 different models) as a range of possible futures and by averaging across these models they can build robust measures of expected future climate. It is these measures, averaged across 19 global climate models, as expected monthly averages for Muskoka over 30-year periods, which are shown in Table 1.

Our evaluation of the data suggests that Muskoka's climate at mid-century is going to be warmer and slightly wetter than at present, and that precipitation may come in fewer but more pronounced storm events.

While there will still be warm years and cool ones, wet years and dry ones, the climate that we expect to see in Muskoka by mid-century will be a little warmer than the present climate throughout the year. It will also be noticeably wetter in winter and spring, but likely no wetter than at present in summer and fall. Because of the warmer temperatures, summers will seem dryer and soils will be dryer than they are at present.

The extent of likely warming, about 3-4°C in average daily temperatures each month, may seem slight, but is substantial. For comparison, during the last glacial maximum of the Pleistocene, global temperatures were only about 4.5°C colder than they are at present (Hansen et al., 2013); that was sufficient to build glaciers kilometers thick above Muskoka.

In addition, while the warming occurs throughout the year, Table 1 shows more warming of nighttime than of daytime temperatures, and more warming of winter than of summer temperatures. This slight asymmetry and the overall 'position' of our climate on the temperature scale mean that the typical year at mid-century will have about half the number of really cold winter nights (-20°C), about four times the number of winter nights that remain above freezing, half again as many winter days in which maximum temperature breaks through 0°C (an increase from 36 to 56 such days per year), and seven times as many days (increase from 4 to 27 days) in which the maximum temperature exceeds 30°C (see Box B for more details)! These changes are all ones that will have considerable impact on our lives, and on our environment.

Modern climate models are less effective in modelling precipitation than temperature. We have reasonable confidence in the projections of total amount of precipitation, but far less certainty in how much of this will be rain and how much snow, or in the pattern in terms of amount per storm event, or number of days between precipitation events. Climate scientists mostly anticipate mid-century climates will be ones in which rain arrives in fewer, more intense storms, and periods between rain events are longer than at present.

The mid-century projections for Muskoka reveal about a 10% increase in the total amount of precipitation in a typical year. Nearly all of this increase is likely to occur in late fall to early spring (November through April) for a 17% increase in the total for those 6 months (524 mm compared to 446 mm at present). The expected typical precipitation for the remaining six months will be just 3.6% greater than at present, increasing 21 mm from 582 mm in the current climate. This pattern of increased precipitation in late fall to early spring is consistent with earlier studies at a Great Lakes Basin scale (Kutzbach et al., 2005).

The projected increase in precipitation during November to April at mid-century is largely driven by Muskoka's geographic location east of Georgian Bay. The warmer climate will likely decrease ice coverage on the Great Lakes, and increase evaporation from Georgian Bay and Lake Huron well into winter months, providing greater quantities of moisture to be delivered to Muskoka as rain or snow squalls (Jasechko et al., 2014).

Just as with the changes in temperature, these changes in precipitation have important ramifications for our environment and for our lives. The increased winter precipitation may lead to very snowy winters, but much of it will likely come as rain because of the warmer climate, and much of the snow may melt during winter rather than contribute to a large snowpack. The best description at present, given the considerable variation in weather from year to year, appears to be that winters will sometimes be very snowy but in many years precipitation will arrive mainly as rain, sleet, and ice storms, and that the extent and duration of snowpack will vary substantially. The very slight increase in summer precipitation in a typical mid-century year appears likely to be insufficient to counteract the drying effect of the warmer temperatures. Evaporation and transpiration will both be increased, and the land is likely to be noticeably dryer particularly in early fall (see more detailed analysis on page 21-24).

Environmental consequences of these climatic changes

Changes in our climate will not just lead to changes in the weather. Through day-to-day weather, climate has a wide range of impacts on our environment and on our lives, and the climate we expect to be here by mid-century will have different effects than our present climate. In Sections 4 and 5, we examine the likely consequences for our lakes, rivers, streams and wetlands, and for our forests. In Section 6 we turn to an examination of that climate's impact on our lives, our economy, and our lifestyles.

There are aspects of these anticipated climate effects, such as effects on lakes of changes in prevailing temperature, which are relatively well understood and can be described with some precision. Other aspects, such as the effects of the anticipated shift in precipitation towards fewer but more intense storm events, are more difficult to specify. There are also flow-on and interactive effects of changed climate. For example, the warmer climate will lead to longer growing seasons, but also to a general increase in evapotranspiration, which in turn modifies the hydrologic cycle, and the quantity of water available to flow through out watersheds towards Georgian Bay.

More detail on our mid-century climate

This more detailed section can be skipped by those readers seeking an overview. Section 4, dealing with impacts on aquatic systems, begins on page 19.

The extent of climate change by mid-century will depend to only a modest degree on how the world community deals with CO_2 emissions due to use of fossil fuels between now and then; the effects of any new policies on CO_2 emissions will mostly be experienced later in the century. As can be seen in Table 1, temperature values for months at mid-century under the RCP8.5 scenario are projected to be about 1°C warmer than those under RCP4.5, a difference which is well within the expected year-to-year variation in temperature. Differences in precipitation are similarly small. For mid-century, the climate we are likely to experience is very largely already set by actions taken, or not taken, with respect to emissions.

Figure 5 displays the change in temperature anticipated by mid-century, using the more likely RCP8.5 values of Table 1. The expected change is more-or-less symmetrical through the year. Monthly mean values for daily maximum temperatures increase between 3.1° and 4.1°C each month while monthly mean values for nightly minimum temperatures increase between 3.0° and 5.2°C each month compared to the present climate. Increases in both minima and maxima tend to be greater in winter than in summer months. One result of these temperature changes is that July and August daily maximum temperatures average close to 30°C (29.4° and 28.5°C respectively), meaning that we will experience many +30°C days each summer. Conversely, maximum daily temperatures will tend to be at or above freezing for all months of the year except January, when the daily maxima will average -2°C.

The change in precipitation is substantial (Figure 6), but confined mostly to the November to April period. In each of these months the total precipitation is likely to increase by from 11.3 to 15.4 mm, increases which represent overall a 17% increase in precipitation during those six months. By contrast, precipitation is likely to increase just 3.6% in the other half of the year, and in the average year is expected to be 3 mm less than it currently is during July. Thus, while our climate is projected to be wetter on average, our summer and fall are likely to receive little more precipitation than now. In the warmer climate, however, there will be more evapotranspiration (evaporation from soil or water surfaces plus transpiration by plants), and therefore our summer/fall environment will be dryer than at present.

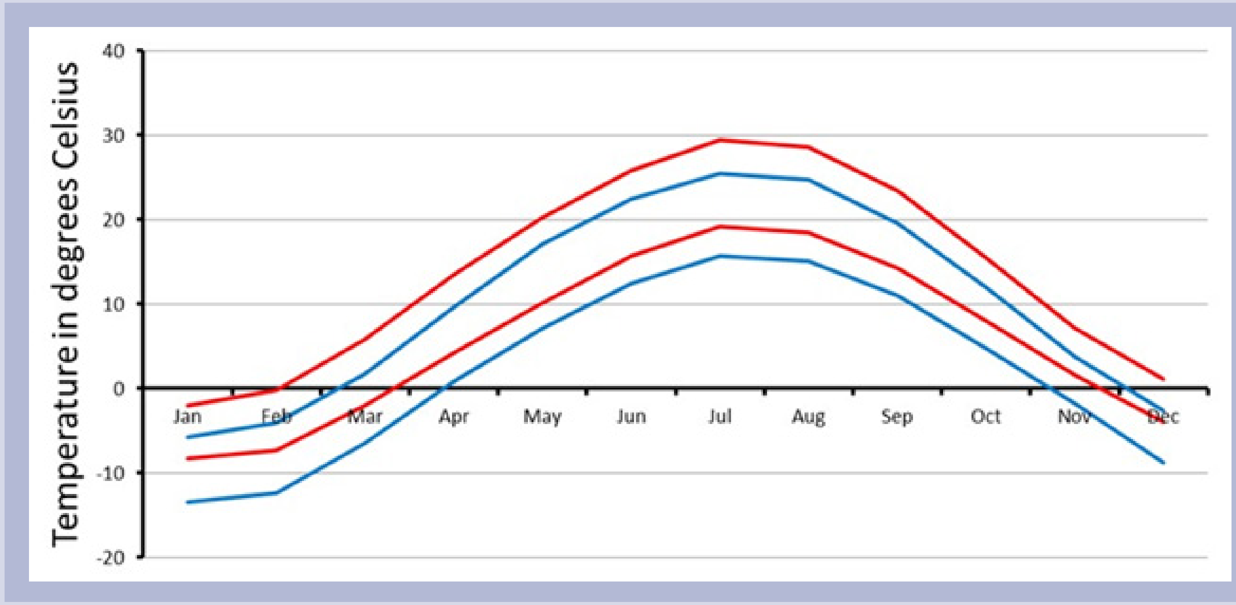


Figure 5. Graph comparing Muskoka's mean daily temperature each month for a typical year during the present (1971-2000) climate (daily high and low temperature as blue lines) and that of a typical year during the mid-century (2041-2070) climate (daily high and low as red lines), assuming we track the RCP8.5 scenario.

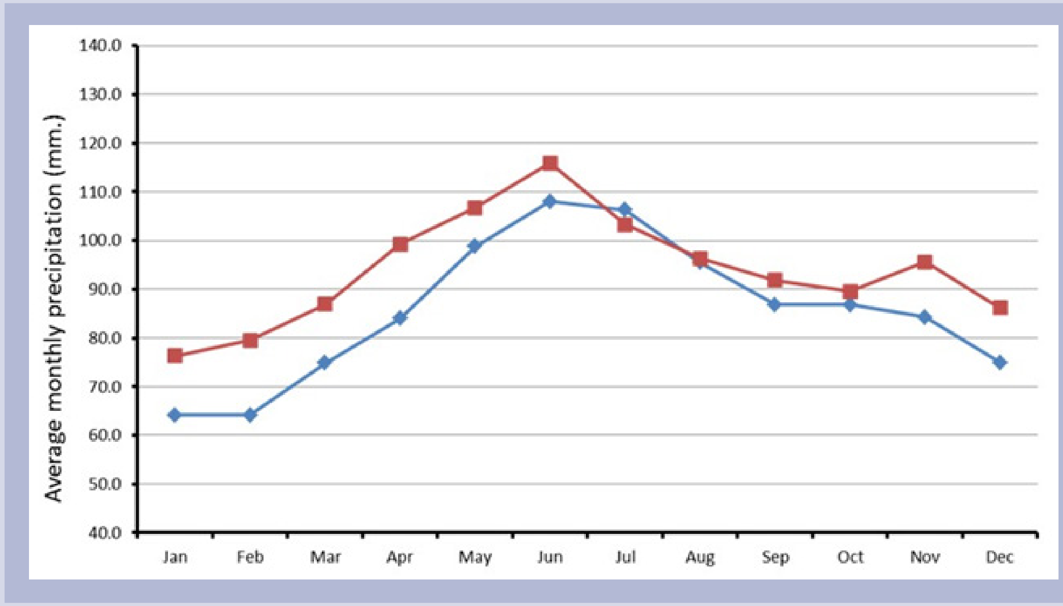


Figure 6. Mean monthly precipitation in Muskoka for each month in a typical year under the current climate (1971-2000), as the blue line with diamond symbols, compared with the mean monthly precipitation for each month in a typical year during the mid-century climate (2041-2070), as the red line with squares, assuming we track the RCP8.5 scenario. Total annual precipitation in the typical year at present is 1,028 mm rain or rain equivalent. At mid-century it is projected to be 1,127 mm.

If global agreements are reached that lead to substantive reductions in CO_2 emissions, and the world tracks to the RCP4.5 scenario, the change to Muskoka's climate is likely to be somewhat less than if less effective global responses continue. Monthly mean values (Table 1) projected for mid-century in Muskoka will be 2.4° to 3.1°C warmer than at present for daily maxima, and 2.2° to 3.9°C warmer than at present for nightly minima. These changes are approximately 1°C less extreme in all cases than those under RCP8.5. Precipitation is still projected to increase primarily during the November to April period (12.5% higher vs. 17%), and show little if any change in July and August; however the total increase in annual precipitation (8%) is little different than the 10% overall increase expected under RCP8.5 scenario.

Box B: How many heat waves? How many cold days?

If maximum daily temperatures, averaged over each month, are likely to be 3° to 4°C warmer at mid-century than at present, to what extent will this increase the frequency of heat waves? Are those of us who know you don't really need air conditioning in Muskoka in for a shock? Average maximum daily temperatures for July and August are projected to be in the high 20s (Table 1) suggesting that shock might be coming!

Conversely, if average daily maximum temperatures in all months except January are going to be above 0°C, it looks like we will have to deal with far more freeze/thaw cycles than at present. But can we get a better idea of the extent of this change in winter climate? To get a better answer to both these questions, we did a simple manipulation of some real temperature data for Muskoka. We took the daily temperature record from the Environment Canada weather monitoring station at the Muskoka Airport in Gravenhurst (Station # 6115525) for the period 1 January 1971 to 31 December 2000, and adjusted every measurement by the projected increase by mid-century for that month of the year, assuming we will track RCP8.5. We then looked at summer heatwaves and winter days with maxima exceeding 0°C. The results are clear. At present, the average year includes 3.6 days in which the maximum temperature exceeds 30°C, and 35.8 days during January, February and March in which the maximum temperature exceeds 0°C. In the mid-century climate projected under RCP8.5, we expect 27.2 summer days over 30°C and 55.8 winter days with temperatures breaking through 0°C.

Put simply, we expect that instead of three to four days of +30°C weather in the typical summer, we will be experiencing four weeks of such temperatures at mid-century. And while the typical winter (January through March) now includes just over a month's worth of days with temperatures above freezing, by mid-century we expect double that. Or, putting it yet another way, by mid-century we expect winters to include only 33 days in which the temperature does not break above zero.

If we look instead at nighttime minimum temperatures, our analysis suggests that while we currently experience 28 nights that are colder than -20°C in a typical year, we are likely to experience about half that number (12.8) of cold nights at mid-century. Conversely, while typical winters currently include 4.2 nights in which temperature remains above 0°C, by mid-century the typical winter will likely include more than four times that number (18.8) of warm nights.

4. Muskoka at Mid-Century 2:
Our lakes, rivers, streams and wetlands

Background

In the Muskoka River watershed, lakes, rivers, streams and wetlands create a network through which surface water flows as it travels across the landscape (Figure 7). Groundwater, water within the soils, connects to this network of surface water, sometimes adding water to the surface flow and sometimes taking water from it. The ultimate source of the water is precipitation whether falling as rain or snow, and the ultimate destinations are Georgian Bay or transfer via evapotranspiration back to the atmosphere.

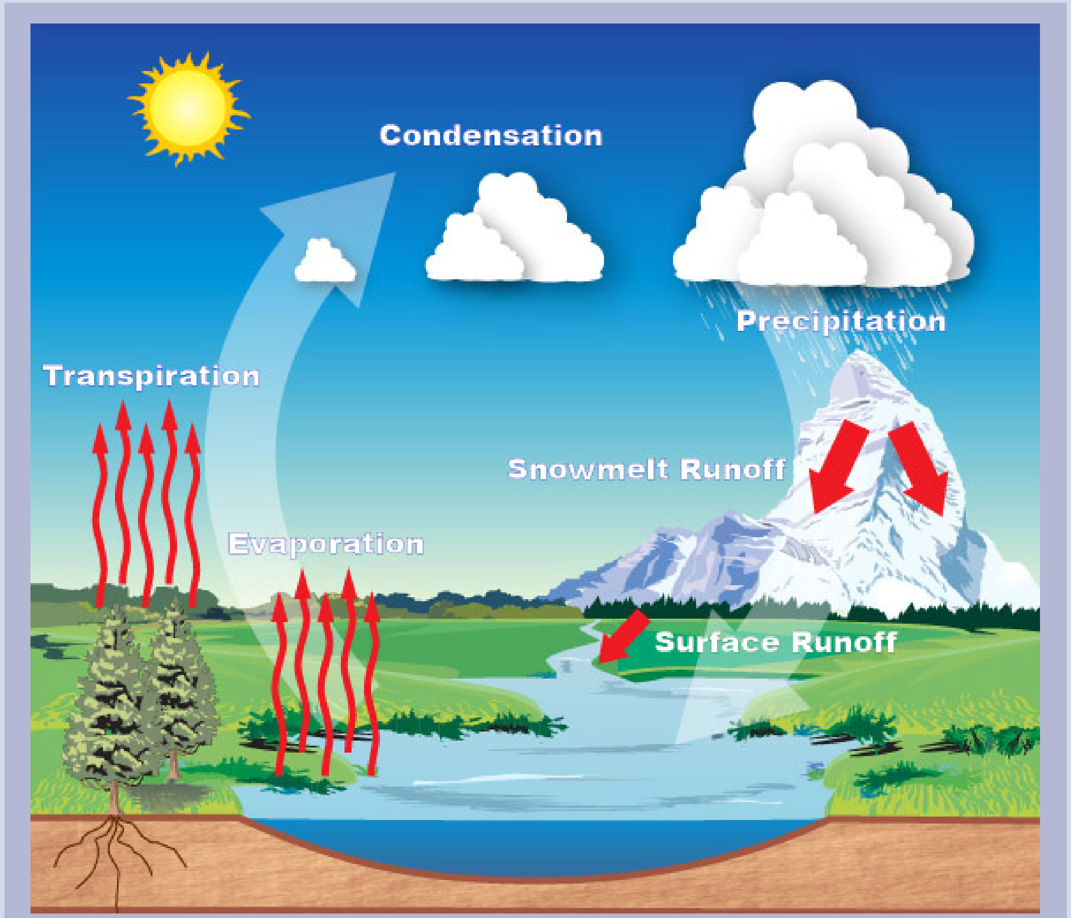


Figure 7. Diagram of the hydrological cycle. One effect of a warming climate is that the cycle moves more quickly, with more evaporation and transpiration and more precipitation. Figure courtesy Jetstream Online School for Weather, US National Weather Service, NOAA (Source: Jetstream website: http://www.srh.noaa.gov/jetstream/atmos/hydro.htm)

The physical and chemical characteristics of our surface waters are determined by several factors. Precipitation arrives with a certain chemical composition characteristic of the region and air quality. The composition of soils and underlying rock alter water chemistry as the water moves across the landscape to a surface water body as well as in the lake basins and river beds over which surface waters travel. Climate influences the physical and chemical characteristics of surface waters directly. The annual temperature regime helps determine the timing of ice-out, and the rate at which a particular body of water warms in spring. Wind regime, water color, and size, shape and bathymetry (depth profile) of the water body also affect rate of warming, and whether a lake becomes stably stratified during summer and fall, or remains only weakly stratified and subject to being frequently remixed during wind events. Extent of forested land, and degree of shading of water bodies also contribute to the rate at which surface waters warm and the temperatures reached in late summer. Climate also determines the quantity of water in the system directly through the rate of precipitation, and less directly through air temperature which influences both the amount of water vapor carried in the atmosphere, and the rates of evaporation and transpiration. Rates of evaporation and transpiration determine the fraction of water delivered to the watershed that returns to the atmosphere instead of flowing out to Georgian Bay.

How our lakes warm during the season, and whether they develop stable thermal stratification through summer and fall, have important consequences for concentrations of dissolved oxygen, and nutrients such as phosphates both in the warmer surface waters and the (usually) cooler deep waters. The quantity of water flowing through a water body may also have effects on temperature and concentrations of oxygen, nutrients, and other chemicals.

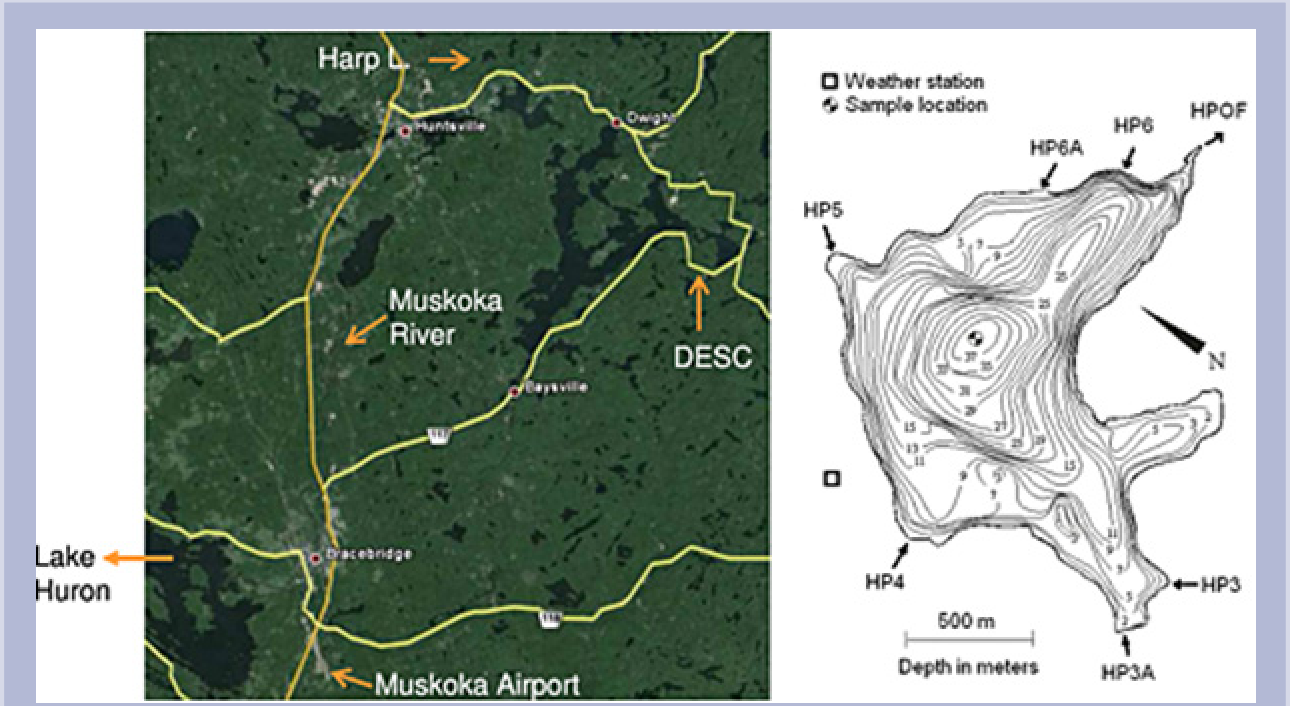


Figure 8. Harp Lake (45.18 N. Lat, 79.13 W. Long) is a small lake supplied by six inlet streams that drain its surrounding catchment (watershed). It is one of the Dorset Environmental Science Centre's eight intensively monitored lakes, and has been subject to detailed monitoring since the mid 1970s. Locations of weirs on six inlet streams (HP3, 3A, 5, 6, 6A), and the single lake outlet (HPOF) are shown. Figure from Yao et al., 2014, with left-hand image from Google.

Lake stratification

A lake becomes warmed as air temperature rises in the spring. As surface waters warm, they become less dense than the colder water below. This separates the lake's water into two layers – an upper warm one, often nearly as warm as the air, and a lower cold one with temperatures that can still be as low as 4°C in mid-summer. The lake has become *stratified*. The transition between these two layers, the *thermocline* can be less than 1 m in thickness, with a steep trend in temperature. Those who swim, or store beer in a minnow trap in Canadian lakes, know the thermocline, even without knowing the technical name for it!

Mixing between the upper *epilimnion* and the deeper *hypolimnion* is prevented until the lake begins to cool in the fall. As epilimnetic temperatures cool, and the density of the epilimnion approaches that of the hypolimion, a slight wind can mix the two layers together. This process, called *turnover*, mixes slightly warmer, nutrient-poor epilimnion water with the still cool, nutrient-rich, hypolimnion water beneath. The process of lake stratification starts again in the spring.

A recent study has confirmed that surface waters of lakes around the world are warming due to climate change (O'Reilly et al. 2015). The changes in climate that are projected to occur by mid-century will have impacts on the quantity, and the physical and chemical characteristics of surface waters in Muskoka. These impacts will vary with the particular characteristics of each water body and its surrounding terrestrial systems, as well as with regions within the watershed, because neither temperature nor precipitation is uniform across the Muskoka River watershed. We currently lack the data to provide detailed descriptions of likely impacts on surface waters for each location within the watershed. Yet, the question remains: how significant will the impacts of the new climate be on our lakes and waterways?

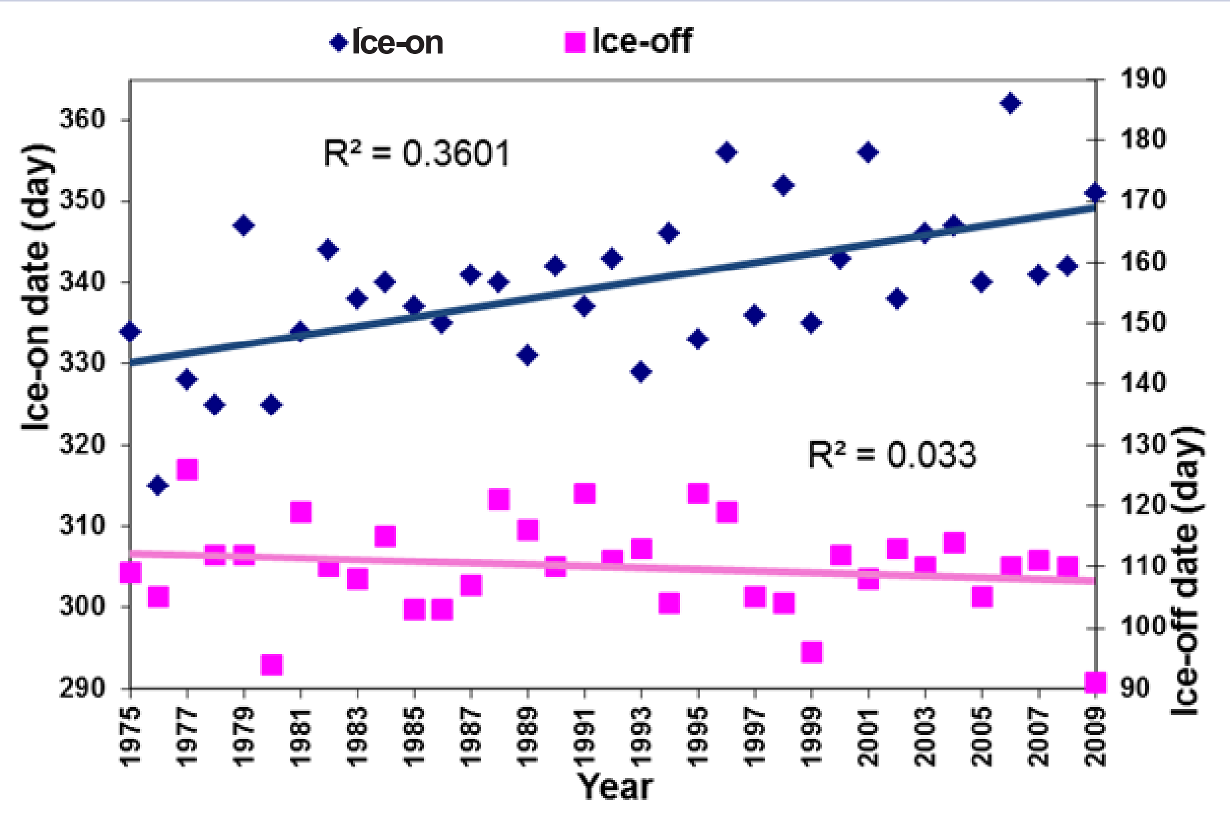


Figure 9. Dates of ice-on and ice-off at Harp Lake from 1975 to 2009. The date of first ice freeze up (ice-on) is plotted (blue diamonds, left-hand axis) as the Julian day for each year. The date the lake opened in spring (ice-off) is plotted (pink squares, right-hand axis) also as the Julian day each year. (Julian day is day number where 1 January = day 1 and 31 December = day 365.) The trend towards a later freeze-up in the fall is statistically significant, while the slight advance in ice-off date is non-significant. Figure based on Dorset Environmental Science Centre data.

Harp Lake as a model watershed – likely hydrological and water quality changes

In this section, we look at Harp Lake in detail, exploring likely consequences for that lake of the anticipated mid-century climate. For the great majority of lakes within the Muskoka River watershed, we do not have the depth of information we have for Harp Lake, and cannot carry out equivalent evaluations. Still, with caution, we will use the results for Harp Lake to infer likely consequences of the new climate for the rest of the region. *For those readers who would prefer to go straight to our expectations for aquatic habitats across the region, skip forward to the Summary section on page 24.*

Harp Lake is a small headwater lake (71.38 hectare lake in a 470.7 hectare watershed) east of Huntsville, which has been closely monitored by the Ministry of Environment and Climate Change's Dorset Environmental Science Centre (DESC) since 1976. It is one of very few lakes in the watershed for which a detailed record of hydrology and water chemistry is available. Figures 3 and 4 provide information on current climate and hydrology at Harp Lake. Figure 9 provides current ice phenology, and Figure 10 shows number of days with and without ice cover in the recent past for Harp and other monitored lakes in this part of Muskoka. Over the past three decades, the climate at Harp Lake has become significantly warmer, and the duration of the open-water season has correspondingly increased

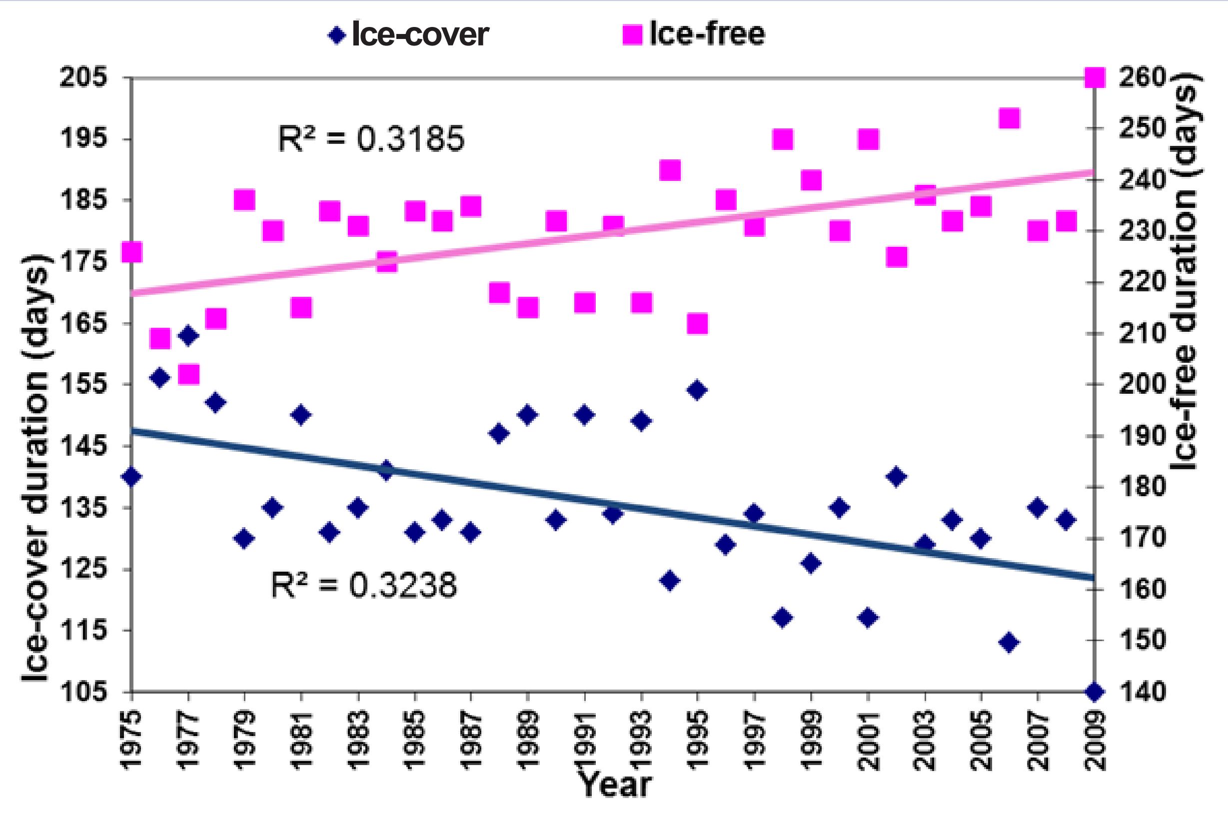


Figure 10. Duration of open-water and ice-covered seasons at Harp Lake from 1975 to 2009. The number of days each year that the lake is ice-covered (blue diamonds, left-hand axis) has reduced significantly over the 34-year period, while the duration of the open water season (pink squares, right-hand axis) has correspondingly expanded (also significantly). Figure based on Dorset Environmental Science Centre data.

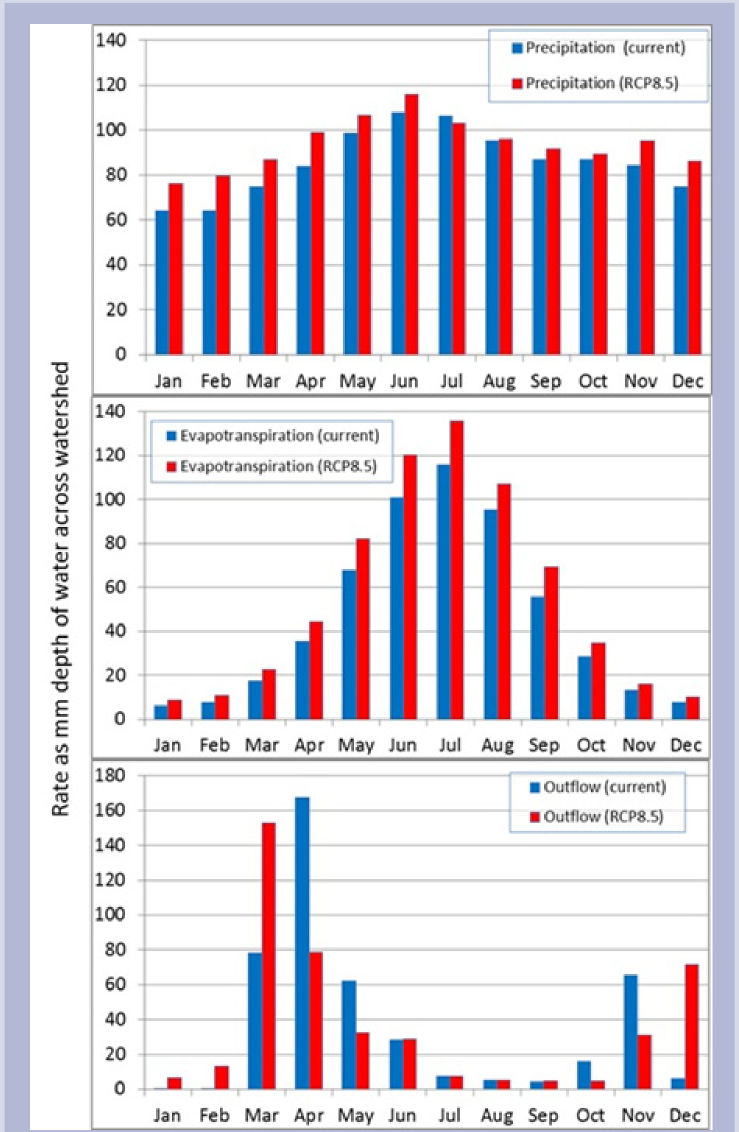


Figure 11. Seasonal pattern of precipitation, evapotranspiration, and outflow from the Harp Lake catchment during typical years under the present climate and that expected at mid-century under the RCP8.5 scenario. Quantities of all three are expressed as depth (mm) of equivalent volumes of water across the area of the watershed. Figure based on Dorset Environmental Science Centre data and output from the USGS hydrological model. Details in text.

(Yao et al., 2013). That increase in duration has occurred primarily because ice cover is now forming almost three weeks later in the season than it did in 1975. Reductions in duration of ice cover have been reported across the Province (Minns et al., 2014).

The hydrology of the Harp Lake catchment is assessed using six continuous recording gauges on inlet streams and a lake level gauge near the outfall (Figure 8). By combining data from the inlet flow gauges, local precipitation and temperature, and using a USGS monthly water balance model, Yao et al., (2009) showed it was possible to estimate the pattern of outflow, extent of snowpack, and proportion of precipitation returned to the atmosphere via evapotranspiration. The model generated a good approximation of historical outflow measurements since 1975, and so it was used to project likely changes at mid-century under the RCP8.5 climate scenario.

In a typical year at present, the outflow from Harp Lake sends downstream just 43% of all precipitation arriving in its catchment; evapotranspiration accounts for 54%. At mid-century, we expect the annual outflow to be marginally reduced in absolute volume, despite a 10% greater amount of precipitation. The increase in evapotranspiration due to the warmer climate exceeds the increase in precipitation.

The model suggests that under RCP8.5 at Harp Lake, the ***seasonal pattern*** of outflow will be substantially changed from that seen now (Figure 11), although the ***total annual outflow*** changes only slightly. Total annual outflow in a typical year at present is 2.07 million m3 (equivalent to 441 mm of water across the 470.7 ha catchment), while in an RCP8.5 mid-century year we project an outflow of 2.05 million m^3 (436 mm of water across the catchment). Apparently, the expected increase in annual temperature leads to an increase in evapotranspiration sufficient to consume the expected 10% increase in total annual precipitation, and outflow from the lake does not increase. While evapotranspiration uses 54% of annual precipitation at present, it will likely use 59% in an RCP8.5 mid-century year at Harp Lake.

Compared to a typical year at present, the ***seasonal pattern*** of outflow is one in which there will be much more outflow in December, somewhat more in January and February, and the spring thaw will occur in March rather than April. Outflow during these four months will be almost three times higher than at present, and will account for more than half the outflow for the year. In June through September, outflow will be about the same as at present, but in April-May and October-November it will be substantially less than at present. Total outflow for the eight months, April through November, will be 46% less than in a typical year at present.

We cannot know at present whether the flow regime of Harp Lake is typical for the entire Muskoka River watershed. However, if it is, the expected 10% increase in annual precipitation by mid-century may result in no real increase (even a slight reduction) in water moving through the watershed to Georgian Bay. Instead, that extra water will be returned directly to the atmosphere via evaporation and transpiration. However, the shift in timing of precipitation and outflow towards the winter months will mean that the flow of water through the system will become more strongly seasonal than at present with summer and fall becoming times of little water movement, while winter or spring floods may well become more severe on average than at present.

Harp Lake can also provide insight into possible changes in lake water quality under the anticipated new climate. A central question concerns whether the anticipated warming will be sufficient to materially alter the summer surface water temperature in our lakes. Recently, Yao et al., (2014) fed Harp Lake data for 1978 to 1993 into the General Lake Model, a hydrothermal and water quality model developed by University of Western Australia scientists working with the Global Lake Ecological Observatory Network (Kratz et al., 2006, Hipsey et al. 2014). It generated a pattern of surface water temperature over 16 years that fits remarkably well to the real data (Figure 12).

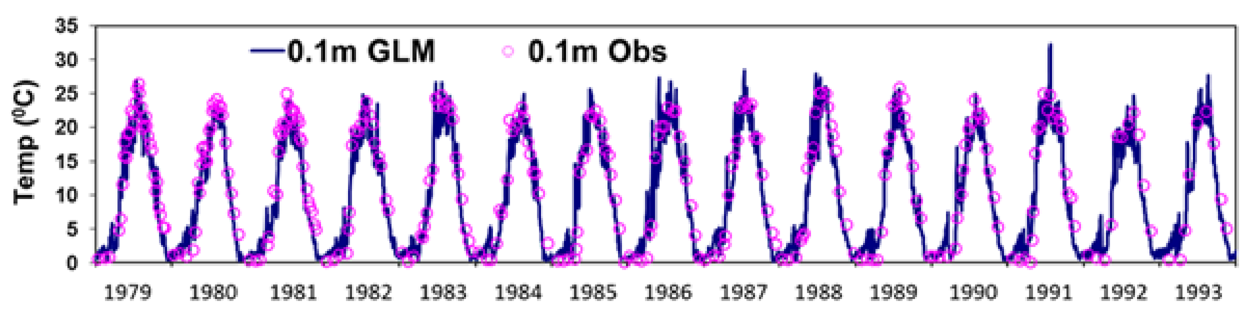


Figure 12. The surface water temperature (at 0.1m depth) recorded from Harp Lake is shown for 1979 to 1993 as the pink circles. Superimposed is the surface water temperature estimated from the General Lake Model parameterized for Harp Lake. The model clearly does a very good job of modeling the observed temperature data. Figure modified from Yao et al., 2014.

Satisfied that the model could mimic real data on water temperature, we then used air temperatures drawn from the IPCC CMIP5 data set to examine the direct effect of warmer air temperature on lake water temperature. Specifically, we left all aspects of the General Lake Model unaltered except for air temperature. We took 16 years (1978 to 1993) of daily air temperatures from the IPCC CMIP5 data set and input these to the General Lake Model to generate equivalent lake surface temperatures. We then repeated with 16 years of mid-century air temperatures from the CMIP5 data set to generate equivalent mid-century lake surface temperatures. We then compared the two sets of lake surface temperature, looking for the number of days on which surface waters were particularly warm. The results are in Table 2.

For a lake with the characteristics of Harp Lake, the air temperatures expected at mid-century under the RCP8.5 scenario are sufficient to warm lake waters to a greater degree than at present. Specifically, while surface water temperatures exceeded 27°C on fewer than one day per year during 1978 to 1993, there are likely to be more than five days per year with surface waters this warm under the mid-century climate. For a lake resembling Harp Lake, but with darker waters, the change is even greater, from about 1 day per year at present to about 11 days per year at mid-century. In Box C, we discuss implications of warmer lake waters for aquatic organisms inhabiting our lakes.

There are many other aspects of the Harp Lake system for which projections into mid-century remain far more speculative, or simply beyond our current capabilities. For example, while our modeling of outflow and evapotranspiration also yielded an estimate of snowpack that was on average 37% less than at present, we anticipate there will be very substantial variation in this from year to year. In some colder years at mid-century, the heightened winter precipitation will lead to a deeper snowpack and very strong spring flows, while in other warmer winters most precipitation will dissipate during winter months and result in a negligible snowpack and little spring flow. Nor can we project with any certainty the extent to which the ice-free season will grow or stratification of that lake will be strengthened during summer, nor whether there will be measurable impacts on deep-water anoxia or shallow water nutrient concentrations. All we can say at present is that each of these characteristics may change.

Summary description of the effects of the expected mid-century climate on aquatic environments across the Muskoka River watershed

Our evaluation of Harp Lake has provided an indication of some of the ways in which that lake is likely to respond to the climate we anticipate at mid-century.

Other lakes within the watershed will behave differently to Harp Lake, depending on their own location, size, depth contour, openness to prevailing winds, and so on. Surface waters of lakes with darker water will warm to a greater extent, compared to the present, than those of clear water lakes, and

CASE 1	CLEAR WATER (secchi depth 3-5m, Kw=0.5)			
Temperature	**Number of days exceeding specified temperature (at 0.1m depth)**			
	Total days in 16 years		**Mean number of days per year**	
	1978-1993	2048-2063	1978-1993	2048-2063
> 27°C	7	87	0.44	5.44
>28°C	4	30	0.25	1.88
>29°C	2	9	0.13	0.56

CASE 2	TEA-STAINED WATER (secchi depth 1-2m, Kw=1.5)			
Temperature	**Number of days exceeding specified temperature (at 0.1m depth)**			
	Total days in 16 years		**Mean number of days per year**	
	1978-1993	2048-2063	1978-1993	2048-2063
> 27°C	16	179	1.0	11.2
>28°C	8	73	0.5	4.56
>29°C	4	18	0.25	1.13

Table 2. The difference in frequency of warm water days at Harp Lake during 1978 to 1993 and at mid-century. Case 1 uses water clarity typical of Harp Lake at present; Case 2 models for a lake similar to Harp Lake except that its waters are more pigmented. Secchi depth and Kw, the light attenuation coefficient, are alternate measures of water clarity.

the other effects of climate are likely to be more pronounced on small, shallow lakes than on large, deep ones. While the shift of precipitation towards winter and spring months and the enhanced evapotranspiration that we expect by mid-century seems likely to reduce water flows across the watershed in late summer and fall, we are not yet in a position to predict the extent of this "autumnal drying", nor how it will vary across the watershed. However, if Harp Lake is typical, it may be that the expected 10% increase in precipitation across the watershed will be entirely compensated, or even exceeded, by the enhanced evapotranspiration caused by the warmer climate. If this is the case, there will be a very noticeably reduced flow of water towards Georgian Bay, and a general drying during summer and fall, given that both precipitation and outflow will be more concentrated in winter months. Nor can we predict, with any certainty, the pattern or extent of the flow during the spring thaw, nor how this varies among locations. However, with a substantially greater outflow during winter and spring, winter and spring floods are likely to become both more frequent and more severe.

Effects of the changed climate on the biology of lakes in the Muskoka River watershed

Our exploration of likely impacts of the anticipated mid-century climate on the hydrol-ogy and chemistry of Harp Lake suggests that there will be some impacts on the biology of lakes in Muskoka. How biological processes will be modified, how serious these changes will be for the 'functioning' of lake ecosystems, and what the impacts of such changes will be on our use and enjoyment of these lakes cannot be specified with any certainty, even for Harp Lake. We have confidence, however, in the accuracy of the following conclusions:

- The warming climate will cause noticeable changes in the thermal regimes in some Muskoka lakes, making their surface waters warmer in summer than at present, and the extent of this warming may prove lethal to some planktonic species, such as *Daphnia*. We thus anticipate some reordering of the zooplankton communities in those lakes that are sensitive to warming. This reordering may lead via their grazing to a restructuring of the phytoplankton community, to altered (likely lowered) productivity, and in turn to a change in capacity of those lakes to support fish. *(See Box C for additional information)*

- The warming climate may increase stress on cold water fish species such as lake trout, and may also render some lakes that now harbor species such as lake trout unable to continue to support them. Affected lakes will be those that currently have a relatively small deep-water refuge which becomes further reduced and anoxic under the warmed climate. Large deep lakes will not be so affected.
- The warming climate will increase the open-water season on all water bodies in the watershed, and this will shift some seasonal cycles in various algal or animal species earlier in the year. The longer 'growing season' in lakes, coupled with the warmer surface waters will definitely alter the cycling of algal populations, and is expected to increase the frequency with which algae produce nuisance algal blooms.
- The change in seasonal pattern and amount of precipitation, and the increase in evapotranspiration are expected to combine to produce little net change in the amount of water being transported through the system to Georgian Bay. Seasonality of flow will likely be more pronounced, resulting in more extreme winter and spring floods and more periods of summer or fall drought. Maintaining flow in rivers and streams, and keeping water in wetlands may become more difficult, and such changes could have real impacts on certain animal species including some fishes. (The expectation regarding net change in flow to Georgian Bay is dependent on whether the overall watershed behaves similarly to the Harp Lake catchment in its increase in evapotranspiration; a hydrological model of the entire watershed is needed.)
- Seasonal drying out of wetlands seems far more likely than at present (Chu 2015), and this will have important ramifications for their species composition and their ecological functions in the hydrological system: purifying water, modulating fluctuations in flow and nutrient cycling, and recharging groundwater.
- Snowpack (and resultant spring floods) is expected to be more variable from year to year than at present, and these variations will mean that biological activity timed to the spring freshet will be variably successful from year to year. In English, this means that there will be gloriously bug-free springs and horrendous, 'eaten alive' springs when black flies and mosquitos flourish.

The plankton of lakes includes numerous species of single-celled and colonial algae as well as the minute crustaceans such as *Daphnia* and other animal species. The algae form the base of the lake food web and are essential if the lake is to have zooplankton, fish, water-birds and so on. The productivity of a lake, frequently measured in terms of the number of fish it produces, depends first on the primary production due to photosynthesis by healthy algal populations. (Along the way, the photosynthesis by these planktonic algae also generates a significant portion of the oxygen in the air we breathe.) Muskokan waters must have algae to be healthy.

The impacts of the mid-century climate on algal populations may be particularly concerning to the people of Muskoka. The quality of our waters is a major factor driving our tourism and recreation-based economy, and algal blooms could affect our economy directly, even if they do not result in conditions with medical risks.

An algal bloom is nothing more than a particularly successful algal population! Under favorable conditions, algal cells can divide rapidly causing the population to increase rapidly in size. Of course, millions of these algal cells are being eaten by *Daphnia* and other zooplankton, which are in turn eaten by fish. Under typical conditions, each algal species has a certain pattern of abundance in a lake; some are early species that build up to their largest populations early in the summer, only to wane as conditions change and become less favorable to them and more favorable to other late-blooming species. Occasionally, under particularly favorable conditions (warm temperatures, abundant oxygen and nutri-

Box C: The impacts of warming on some zooplankton species

About 60 trillion zooplankton live in Lake Muskoka. They play major roles in filtering the water in our lakes, in consuming algae that would otherwise bloom far more frequently than they do, and in providing food for many of our fish species. They are largely unseen, but very important. The changing climate will likely influence these creatures, perhaps in ways that will reduce the environmental value of our lakes.

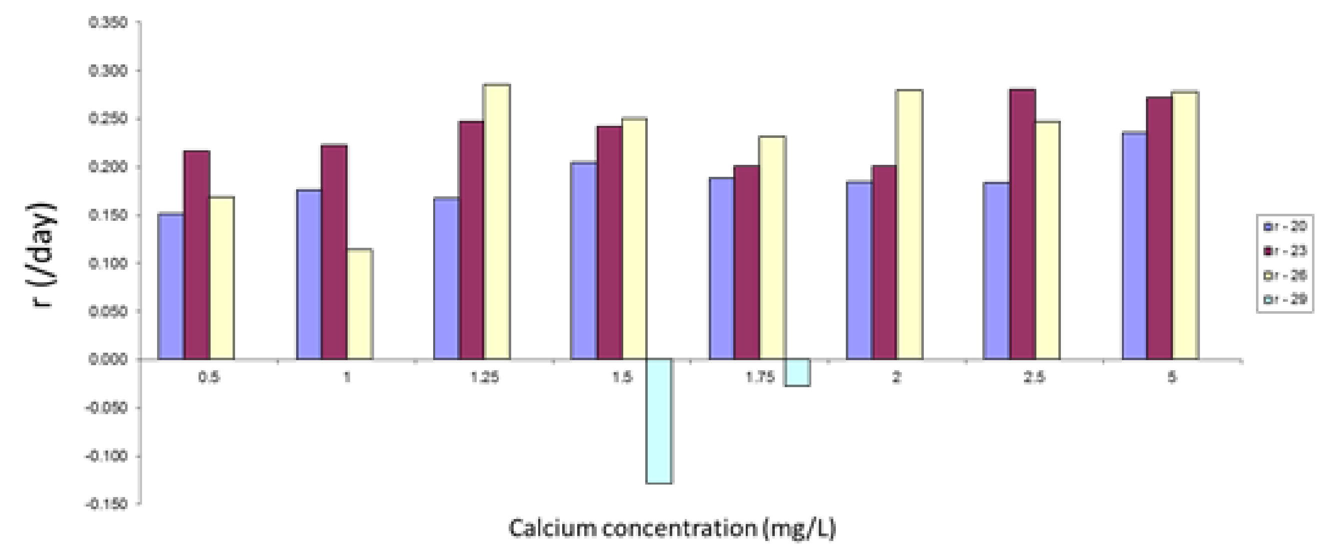


Figure 13. Results of a laboratory experiment in which the rate of increase in abundance (r) of populations of the zooplankter, *Daphnia mendotae* was measured under four different water temperatures and eight different concentrations of calcium. A 29°C temperature kills off populations under any calcium concentration. Unpublished data, D Linley and N Yan, 2009.

Our analysis of the anticipated mid-century climate's likely physical and chemical effects on Harp Lake showed that surface waters in this lake would become warmer, exceeding 28°C on two days in an average summer. It currently experiences a temperature that high for one day about one year out of four. Laboratory experiments have shown temperatures this warm to be damaging for some species (Figure 13). However, the situation is substantially more complicated than that because a species' tolerance of high temperature is modified by other environmental factors such as availability of food, or calcium concentration in the water. Populations of *Daphnia mendotae* grow more slowly in low-calcium water. Where calcium is sufficient they grow better at 26°C than at 20°C or 23°C, but die off where temperature reaches 29°C. Other species have slightly different temperature thresholds, and factors other than calcium can modify responses to temperature.

If our ability to predict impacts of climate change on zooplankton are weak, we have even less ability to predict any flow-on effects from changes in their lives to larger animals such as lake trout and bass, or on the general 'health' of the lake ecosystem. What does appear clear is that the extent of climate change we anticipate for mid-century is substantial enough that, in some lakes, some species of zooplankton are likely to be affected in ways that could alter the dynamics of the lake ecosystem. We need enhanced, continuous monitoring of our lakes if we are to be able to detect deleterious changes quickly, and perhaps act to minimize damage.

ents), certain algal species will become so abundant that they will form a scum on, or just below, the surface of the lake. These scums and algal blooms consist of millions of algal cells packed close together, some still alive, and some dying. They can give rise to noxious odor or taste, and sometimes can release toxins. They also reduce water clarity and can result in severe reduction in amount of dissolved oxygen, or even in anoxia in the waters below, because they use oxygen for respiration while alive and also after death as they decay. Blooms seldom last more than a few days, occasionally a couple of weeks. Eventually, conditions change and that species of algae is no longer reproducing fast enough to maintain the very high population density that constitutes a bloom.

While an algal bloom is a 'normal' event caused by a period of favorable growing conditions, visible blooms have historically been quite rare in lakes in Muskoka. The low nutrient levels typical of lakes on the Canadian shield, and relatively cool temperatures mean that conditions sufficiently good to generate a visible bloom occur only occasionally. Because of their rarity, we have become far more sensitive to the presence of modest algal blooms in sheltered areas of our lakes than would be the case in many other parts of the world where blooms are a regular annual event. Noxious blooms appear to be quite rare on our lakes, and toxic blue-green algal blooms have been confirmed (by Elisa tests) only three times (in two lakes) since 2001.

The new climate anticipated for mid-century is going to produce longer growing seasons and warmer temperatures in the surface waters of our lakes. Both factors increase the likelihood of visible algal blooms. Some of our lakes are relatively more nutrient-rich, and the changed climate may also increase the availability of nutrients in some lakes due to alterations in the way in which the lake develops a stable temperature profile each summer. (A longer period of stability leads to greater loss of oxygen from deeper waters.) As anoxia develops, phosphate is released from lake sediments to the overlying water, in a process called *internal loading* which can stimulate algal blooms. Other factors, such as strength of winds or amount of summer precipitation may also be important in determining whether a particular year is favorable for a particular algal species to bloom.

In recent years, researchers from Dorset Environmental Science Centre and Trent University have examined factors causing algal blooms in some Muskoka lakes (Persaud et al. 2014). Their results show that while higher phosphorus (and perhaps iron) concentrations are commonly a predisposition for the occurrence of noxious, blue-green algal blooms, meteorological and hydrological conditions play a key role in the development of these blooms, and the transition of blooms into unsightly surface scums (as occurred in Three Mile Lake in 2005). Importantly, their research predicts that algal blooms and scums will likely be more common by mid-century, as climate change creates conditions favorable for their occurrence (as described above).

It is clear that the changes taking place will have numerous effects on the biology of our lakes and other waterways. It is also clear that we need more detailed information than is currently available to be able to track, and perhaps project the extent of these changes from place to place. More detailed monitoring of our aquatic ecosystems will be required if we want to understand and anticipate such changes.

5. Muskoka at Mid-Century 3:
Our forests

Overview

Climate change affects Muskoka's terrestrial environments as well as its aquatic ones. In this section, we focus on our forests, because forest is the native ecological type that is typical of the great majority of our land surfaces. Grasslands and other low, herbaceous flora do occur naturally in some parts of our region where soils are thin to sparse such as in parts of the Georgian Bay lowlands and in the Torrance Barrens. They have been encouraged artificially for many hundreds of years in many other parts of our region, first through controlled burning by aboriginal communities to maintain habitats favorable to certain game (e.g. deer) and edible plants, and over the past two centuries by land-clearing and farming operations undertaken by European settlers. Such open land tends to revert slowly towards forest if management ceases.

The effects of climate change on our forests are many. Some of these effects are already apparent although many will not become apparent until much later in the century. Trees are often long-lived organisms that, once established, can persist through stressful times. The climate effects are both direct and indirect, through effects of the changing climate on other species or processes that then affect the forests. To understand these effects, perhaps the most important thing to remember is that it is the rapid pace of change in climate, as well as the extent of the change, which is causing changes in our forests.

A forest does not respond to stresses as a unified whole; each species responds in its own particular way, and since all forest species do not respond identically, a forest under climate stress will change in composition as the more susceptible species show far greater change than those less affected. Some species may benefit from the changing climate and become more common than they are at present, while others become rare or disappear entirely.

Just as in the aquatic environments, changes in annual patterns of temperature and precipitation are both important factors. Additionally, the increase in atmospheric concentration of CO_2 may influence forests directly, because rates of photosynthesis (and tree growth) might be increased (Pretzsch et al., 2014). As in aquatic environments all direct and indirect climate factors act together, so determining how, or if, a forest is going to change as climate changes can be a challenging question.

A typical Muskoka forest contains a mix of tree species more or less well adapted to the climatic conditions of the last several centuries. Growth of trees, stimulated by adequate precipitation and warmth during the growing season, is balanced by decline and loss of trees due to a range of disturbances including insect outbreak, disease, drought, windfall, and fire, as well as harvest. A healthy forest is a patchwork of sites in different stages of growth and decline (***successional stages***) due to the patchy pattern of action of all these disturbances, and some patchiness in favorability to growth. Well managed forests are recognized as a valuable tool for reducing CO_2 concentrations in the atmosphere by sequestering it in timber, rootstocks and the soil.

Climate change alters the frequency or severity of disturbances such as drought, fire, windfall, insect outbreaks and disease, while also pushing the forest into a climatic regime that will favor growth to a different degree (either enhancing or impeding it) for each tree species. An additional complicating factor in Muskoka is the on-going reduction in availability of calcium in our thin, poor, easily exhausted soils. This can be exacerbated by forest management practices that remove all tree material from a site at harvest, exporting calcium in the wood and by-products. While calcium decline is not a part of climate change, that it is happening now adds an additional possible impediment to our forests remaining in good condition. This decline in soil calcium is also leading to reduced calcium in our lakes (Yao et al. 2015).

At present, it seems clear that the warmer climate we expect, and the shifted seasonal pattern of precipitation that will leave summer and fall scarcely wetter than at present, will lead to greater evapotranspiration, creating dryer soils more prone to drought. These negative changes may swamp possible positive effects on tree growth due to a longer, warmer growing season and higher CO_2 concentrations.

Warmer weather and dryer soils also increase the likelihood of wildfire. Forests respond to the fire regime in different ways. White pine and oaks are fire dependent and likely to be favored in drier sites if fire becomes more frequent. Less arid locations, favoring maples, beech and basswood, may not see any increase in fire risk (Terrier et al., 2013), and could become important natural barriers to fire. Fire also increases the cost of firefighting and the risk of property damage in a community that includes numerous homes scattered close to, or within the forest, and unoccupied for substantial periods of the year. If climate change brings more intense storms, as appears likely, we can anticipate increased wind damage, at least initially, and a gradual change of forests to more wind-resistant patterns of growth. Finally, the changing climate will alter the geographic ranges of plants, their insect pests and pathogens. Our forests will change in composition as a result; the extent and rate of change is not yet clear.

To sum up, we can anticipate that Muskoka will still be forested at the end of this century, but that the forests may be quite different in species composition, in productivity (amount of wood production per year), in age and size distribution of trees, and in health as indicated by prevalence of disease and of insect outbreaks. As windfall and fire become more prevalent, the patchy nature of our forests may become coarser – fewer, larger patches of species or age classes of trees, and larger gaps not yet regrown.

Shifting growth zones

One useful approach to model likely forest effects is to examine the impact of climate change on key forest species. The plant growth zones so familiar to gardeners and horticulturists are a simplified form of what are called climate envelopes that can be developed for individual species or for particular locations. Here we diagram changes in the climate for Ecoregion 5E which encompasses all of Muskoka and some surrounding area, and then for some selected species important in our forests.

Researchers based at the Ontario Forest Research Institute, a Ministry of Natural Resources and Forestry (MNRF) facility in Sault Ste. Marie, produced a research document in 2010, titled "***Current and projected future climate conditions for ecoregions and selected natural heritage areas in Ontario***" or ***Climate Change Research Report CCRR-16***, available on-line or on CD. In researching this report, they prepared maps of each of Ontario's ecoregions, depicting the current climate, and the climate at mid- and end-century under two different IPCC scenarios, A2 and B2 (these scenarios were developed in 2000 and have been superseded; A2 is approximately equivalent to RCP8.5, and B2 is approximately equivalent to RCP6.0), and using three different global climate models (GCMs). We have selected maps derived using Environment Canada's GCM, CGCM2[1].

The upper map in Figure 14 shows Ecoregion 5E, including Muskoka, depicting its core (most typical) climate, and the full range of climate within it at the present time (1971-2000). Areas outside 5E that currently share the same climate are also shown. The two lower maps display the locations in Ontario that are projected to have the current ecoregion 5E climate during 2041-2070 under the A2, and under the B2 scenario. In both cases, the present-day climate scarcely exists anywhere within ecoregion 5E by mid-century except for tiny regions northwest of Bancroft. Extensive regions have this climate, but they are north and west of ecoregion 5E, and the difference between these two maps is slight

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[1] *These maps can be downloaded at http://www.ontario.ca/environment-and-energy/climate-change-ecoregions*

indicating the lack of substantial difference in impact by mid-century between these two climate scenarios.

This is a rapid alteration in climate, and trees adapted to the present-day Muskoka climate can be expected to be under considerable and growing climate stress. Growth rates will be reduced, reproductive success lowered, and susceptibility to disease and insect pests will be heightened. Ideally they should all move north, but trees don’t pick up their roots and walk except in the pages of Shakespeare and Tolkien. Tree species do shift their ranges when climate changes, but their ability to move depends entirely on the dispersive capabilities of their seeds. During the early Holocene, as the Pleistocene ice sheet melted back, tree species moved at rates varying between 0.1 and 2 km per year as the North American climate warmed, but the change shown in Figure 14 is on the order of 6 km per year. Some tree species may be able to adapt to the changed climate (many of our trees do extend further south at present), but it looks as if our forests are going to be ‘sorting out’ their responses to the changing climate for many decades to come.

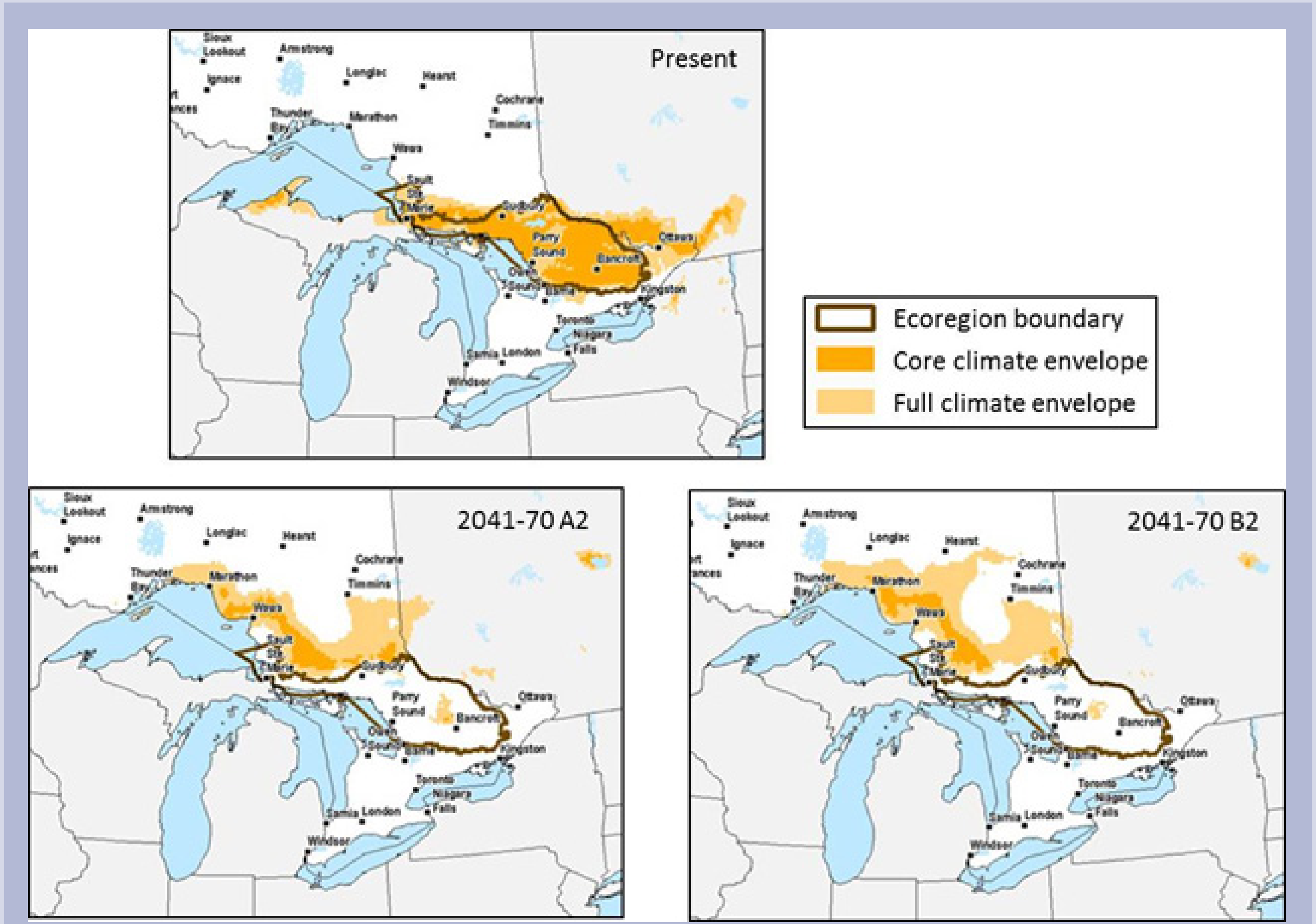

Figure 14. Map of Ontario showing Ecoregion 5E, and depicting all areas within Ontario that possess the climate typical of 5E during 1971-2000. The upper map shows the characteristic 5E climate is largely restricted to that ecoregion except for areas to the east along the Ottawa and St. Lawrence rivers at present. The lower maps are alternative mid-century representations. Both show the climate typical of 5E at present will be almost entirely absent from that region by 2041-2070, but is present in a number of regions to the north. Similarities between the two projections confirm the slight effect of different climate scenarios that early in the future. Forests adapted to the present climate in Ecoregion 5E will be stressed by a changed climate by mid-century. Details in text. Images courtesy of Ontario Forest Research Institute, Ministry of Natural Resources and Forestry.

Direct effects of climate change on distribution of tree species

The situation for Muskoka can be further clarified by looking at the climatic tolerances of several of our primary forest species. The Ontario Forest Research Institute has made maps for selected species available on a Natural Resources Canada website[2]. Here we have used their species range maps based on the maximum entropy (MaxEnt) procedure (which uses climate conditions at sites where the species is known to occur to infer sites where they could occur), a combined set of four GCMs to project climate, and the RCP8.5 emissions scenario. In this way, it is possible to build maps of sites likely to be climatically suitable for a species at a future time. The maps show climatic suitability ranging from low (dark blue) to high (light green). We look in turn at the white pine, *Pinus strobus*, the sugar maple, *Acer saccharum*, and the white spruce, *Picea glauca*. All three are common trees in Muskoka at present.

White pine (Figure 15) is broadly distributed in eastern North America, extending as far south as northern Georgia, and as far north as the southern tip of James Bay. It was the dominant tree species in Muskoka at European colonization, and has been extensively logged. By mid-century, most of its potential range south of the Great Lakes will no longer be suitable for it, while climatic conditions suitable to it could extend to southern Hudson's Bay. By the end of the century, Muskoka will have a marginal climate for this tree, and its potential range will extend further into northern Quebec.

Sugar maple (Figure 16) is also a broadly distributed tree common in Muskoka. Its current potential range extends from the Gulf of Mexico to the most northerly portion of Lake Superior. Climates suitable for it are expected to move substantially northward during this century. According to these projections several portions of southern Ontario become unsuitable for it by the end of the century.

Finally, Figure 17 compares the present distribution of white spruce to that potentially possible at mid- or late-century. This species potentially now occurs throughout Ontario and well south along the Appalachian range, but a suitable climate will only occur well north of Muskoka by mid-century and north of most of James Bay by the end of the century.

These maps are based on consideration of just six climatic variables: mean annual temperature, maximum temperature of warmest month, minimum temperature of coldest month, annual precipitation, total precipitation of warmest month and total precipitation of coldest month. A more detailed analysis of climate could yield more complex maps and more nuanced information on the effects of climate on these species. Still, comparing Figures 15, 16 and 17, it is clear that while potentially suitable climates are likely to develop in the north and disappear in the south, the changing climate will affect different tree species in different ways and to different degrees. The maps do not indicate that these species will establish abundant northern populations over the century (they cannot move that quickly), and they do not reveal what will happen to populations of these species in Muskoka as the century proceeds except to suggest they are likely to be considerably stressed. For example, while Figures 15 and 16 show white pine and sugar maple persisting in Muskoka, it is generally recognized that both species will be significantly stressed and could be far less abundant here by the end of the century. As climate changes, trees characteristic of locations south of Muskoka will be able to colonize this region, but again, they will arrive only slowly. In many cases, the Great Lakes will form an additional barrier to northern dispersal. With all tree species responding to the changing climate, but in species-specific ways, the composition of our forests, both in terms of species present, and in terms of relative abundance of species, is going to change. If we want to maintain high quality forests on our land, it will likely be necessary to anticipate the changes forced by the changing climate, and facilitate the arrival of species more suited to the new climate. This active management of dispersal is termed 'assisted migration', and could become an important factor in ensuring continued integrity and resilience of our forested land at critical, high priority locations.

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[2] *Natural Resources Canada site http://planthardiness.gc.ca*

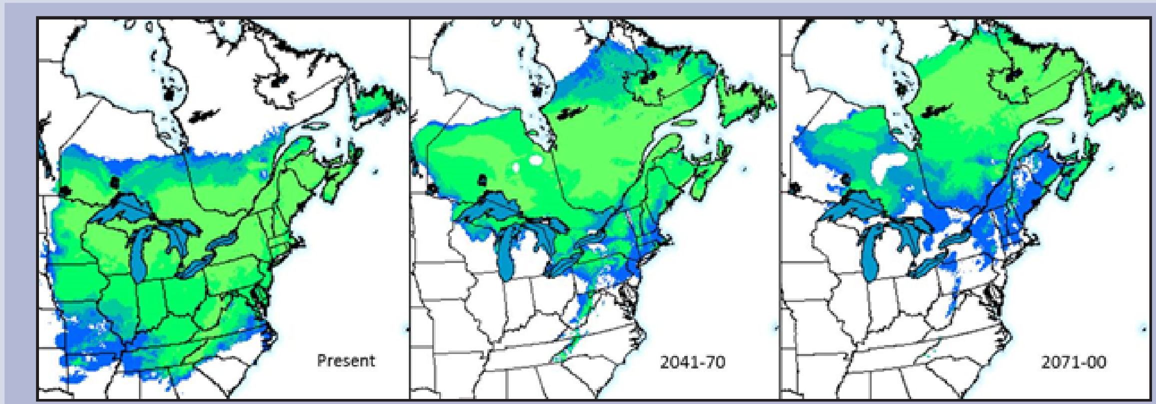

Figure 15. The present distribution of the eastern white pine, *Pinus strobus*, at left, is compared to the potential distribution at mid-century (centre) and at late-century (right), based on the expected shift in climate. Climatic favorability for this species increases from darkest blue to lightest green on each map (more details in text). (Source: http://planthardiness.gc.ca)

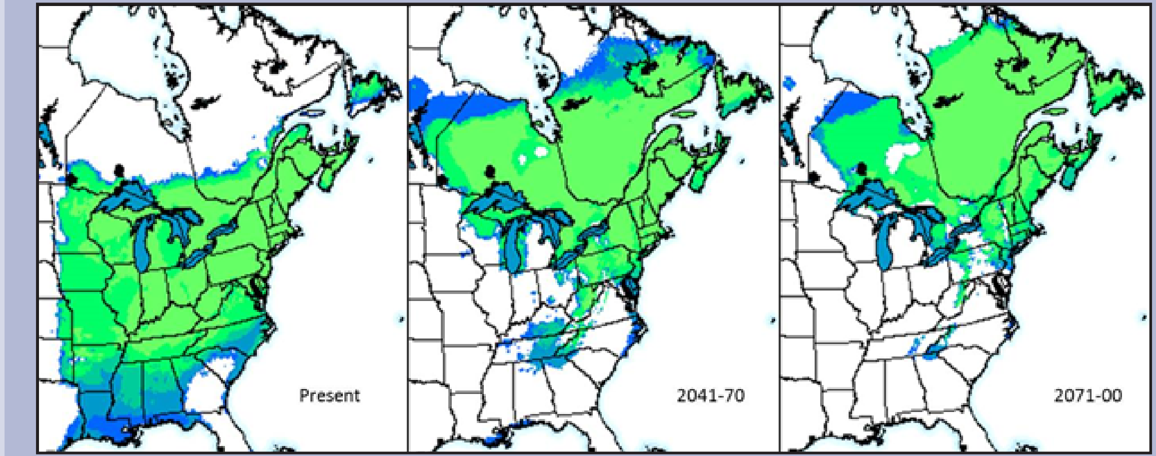

Figure 16. The present distribution of sugar maple, *Acer saccharum*, (left) is compared to that potentially possible at mid-century (centre), and at late-century (right) based on the anticipated changes in climate (occurrence/abundance scaled as in Figure 15). More details in text. (Source: http://planthardiness.gc.ca)

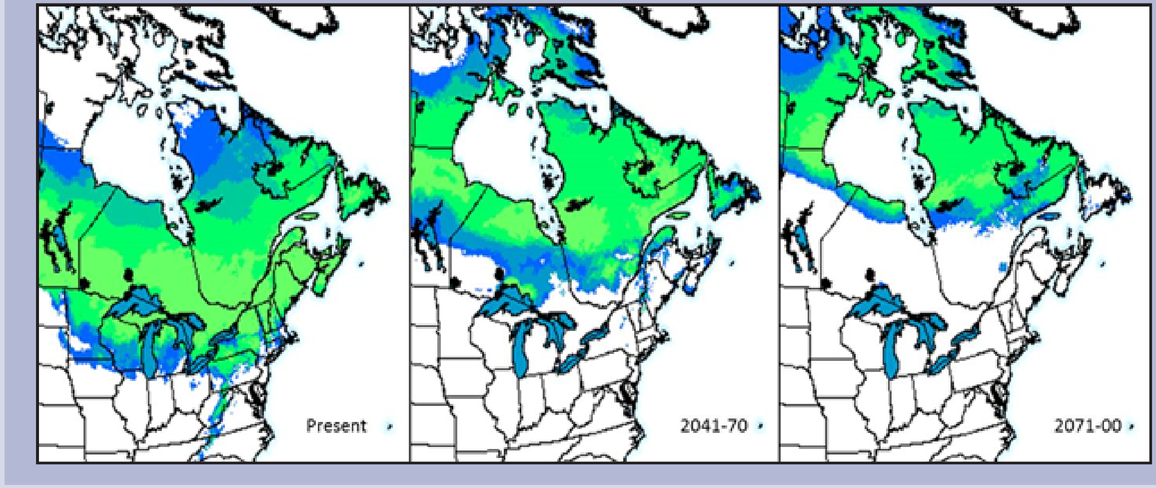

Figure 17. The present distribution of white spruce, *Picea glauca*, (left) is compared to that potentially possible at mid-century (centre), and at late-century (right) based on the anticipated changes in climate (occurrence/abundance scaled as in Figure 15). More details in text. (Source: http://planthardiness.gc.ca.)

While assisted migration is a simple concept, available resources will limit its application. The problem of how to sustain our forests during this century is daunting, given the uncertainty regarding pace and extent of climate change, and extent of climatic sensitivity and ability to adapt among tree species. Indeed, as is argued (Joyce and Rehfeldt, 2013) in a detailed analysis for white pine, the pace of anticipated climate change is such that what likely will happen is not an orderly northward movement of species, but a progressive thinning out and loss of trees on the southern edges of their current range, with relatively little expansion on the northern edges, and with assisted migration helping only in the few select locations where resources and will are sufficient to put a substantial planting program in place. The consequence for any particular region, such as Muskoka, will be a progressive thinning out of forests, with fewer trees of currently dominant species, and insufficient numbers of newly-arrived southern species to take their place. The value of our forests, under these circumstances, will be reduced in terms of wood production, 'leaf-viewing' tourism, and in provision of ecosystem services such as carbon sequestration, water management and local climate amelioration.

Other direct effects of climate: frequency of fire

During summer 2015, wildfires in northern Saskatchewan were some of the worst on record. They coincided with serious fire seasons in much of western North America from Alaska to California. In previous years, there has been similarly widespread fire in Australia, and with climate change leading to warming and drying in many regions of the world, wildfire is likely to be on the rise.

Analyses by scientists from the Canadian Forest Service have shown that projected climate change will increase both number of fires and the annual area burned across much of Canada; however the eastern temperate zone (extending from southern Manitoba through southern Ontario) was expected to be one of the least severely altered homogeneous fire regime (HFR) zones in the country (Boulanger et al., 2014). The future situation in many parts of boreal Canada is likely to be substantially more serious than here in Muskoka.

In a finer-scaled study restricted to eastern Canada (Boulanger et al., 2013), they specified fire risk as follows for the region including Muskoka. Over the period 1961-1990, this region had recorded an average of 0.01 fires per 100,000 hectare burning 0.03% of available area per year. With the caveat that making projections of climate impacts on what are relatively small risks is a task containing considerable uncertainties, they projected this rate of fire activity to increase to 0.06 and 0.12 fires per 100,000 hectare, burning 0.19% and 0.65% of available area at mid- and late-century respectively. While the overall risk remains low, that represents about a 6-fold increase in fire risk by mid-century, and we would be wise to build sufficient fire-fighting capacity.

Apart from the risk to life and property, wildfire shapes the forest, favoring more fire-resistant, or fire-adapted species, such as jack pine (*Pinus banksiana*) and trembling aspen (*Populus tremuloides*) over other species. Thus, we can anticipate that the effects of climate on forests will be both to shift geographic distributions of tree species, and winnow out some otherwise well-adapted, but fire-sensitive species in favor of species that are better adapted to frequent wildfire.

Indirect climate impacts on the forests: insects and diseases.

As well as affecting the trees, climate change can be expected to affect insect pests and plant pathogens. A changed climate can make a region suitable for species that have previously not been able to live there, or have lived there but only intermittently. These include species that typically live further south at present, and species that have invaded from elsewhere, assisted by our travel and shipping activities. Many species regularly arrive as stowaways, but fail to survive in our climate; changing the climate can permit some of them to survive.

In western Canada, the mountain pine beetle, *Dendroctonus ponderosae*, had long been restricted to south-western British Columbia where its activities led to damage and death of trees through its introduction to trees of a commensal fungus. It was prevented from moving further north and east by the cold winter climate; however the warming climate in the 1990s and 2000s led to massive outbreaks of this insect, and during the 2000s, some insects were successful in crossing the Rockies. It is now well established in eastern British Columbia and Alberta, and has been recorded north of 60ºN. It is very likely to move east across Canada's boreal forest in coming years[1].

While the mountain pine beetle may never get to Muskoka, a number of other insects have done so recently or will later this century. The following are some of the more important ones. The beech scale insect, *Cryptococcus fagisuga*, is a tiny insect introduced to Nova Scotia from Europe in the 1890s. It has long been present in southern Ontario, and milder climates have now permitted it to extend north into Muskoka. This insect attacks the bark of beech trees and feeds on the sap. While the insect damage is rarely serious, by creating lesions in the bark it opens the tree to invasion by the beech bark fungus, Neonectria faginata, which travels with it. The fungus disrupts the physiology of the tree leading to crown dieback, death of branches and eventual death of the tree. Beech scale tends to attack larger trees first, and this problem is now of increasing seriousness in Muskoka[2].

The hemlock wooly adelgid, *Adelges tsugae*, was introduced to western North America from Asia in 1924, and first occurred in eastern North America in the 1950s. Until recently it has been kept south of Muskoka by our cold winters. With the warming climate it has now been sighted in Muskoka, and is expected to become more prevalent. This is another insect pest that feeds on the sap of trees. In this case feeding takes place at the base of needles and leads to early needle drop and defoliation, and, over several years, to tree death[3].

Finally, the emerald ash borer, *Agrilus planipennis*, is another Asian invader. This insect was first detected in the Detroit/Windsor area in 2002. It has expanded its range east and north, at least partly through movement of infected firewood. Infestation by this beetle, which feeds during the larval stage under the bark, also leads to tree death in several years. While this appears to be a cold-tolerant species, quite capable of living in Muskoka, its northward movement may be delayed by a colder climate which extends the normally annual life cycle to two years. Thus its invasion, now under way, will be facilitated as climate warms (Hodge et al., 2015)[4].

In summary, there is an abundance of native and introduced insect pests that can kill our trees. The warming climate is likely to facilitate an increased rate of damage by some of these, and probably by all of them. Unfortunately there do not appear to be any tree pathogens that are impeded by warmer climate.

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[1] Information from Natural Resources Canada website: http://www.nrcan.gc.ca/forests/fire-insects-disturbances/top-insects/13397

[2] Information from Bioforest Inc. report to Township of the Archipelago 2012, available at http://www.bioforest.ca/documents/assets/uploads/files/en/forest_health_update_fall_2012.pdf

[3] Information from Pennsylvania DNCR fact-sheet, Forest Health Fact Sheet Hemlock Woolly Adelgid, available at http://www.dcnr.state.pa.us/cs/groups/public/documents/document/dcnr_007179.pdf

[4] Hodge et al., 2015 available in pdf at: http://www.ccfm.org/pdf/Emerald%20ash%20borer%20-%20risk%20analysis%20-%20NFPS%20-%20EN%20-%20FINAL.pdf

6. Muskoka at Mid-Century 4:

Our lives

There are still people who argue that a global temperature increase of a couple of degrees is trivial, and will not impact their lives at all. The climatic changes projected in Section 3 for mid-century in Muskoka will not limit our lives directly, and may even be welcomed. (A recent report in Nature (Burke et al., 2015) suggests the Canadian economy will benefit overall from a slightly warmer climate.) Milder winters, a longer growing season, and warmer, dryer summers might seem ideal for people who value Muskoka primarily for the outdoor recreational possibilities it offers them. On the other hand, the changes projected are substantial relative to any time in human history, and they will have impacts. Furthermore, they are expected to be accompanied by a greater frequency and severity of storm events of various types. In this section, we examine impacts on lifestyle, public health, and built infrastructure.

Lifestyle and recreation

Over 50% of the Muskoka population is seasonal, here for recreation and relaxation. That may change over the decades as knowledge industries and telecommuting offer new employment opportunities, but recreational activities will remain important. In Muskoka it is difficult to imagine recreation without a major component of outdoor activities that take advantage of our natural environment. The good news is that the climate changes projected are likely to enhance opportunities for active on-water recreation, extending the season both in spring and fall. The trend to increasing use of seasonal homes will continue, increasing the economic benefit of the presence of seasonal residents in the region. Amateur gardeners will enjoy a wide range of new southern varieties that tolerate growing in the new Muskoka climate, and maintaining a vegetable garden that yields produce before the first frosts will be a much simpler prospect than in the past. On the other hand, the seasons for skiing and snowmobiling will be shortened, and while snowpack will be considerable in some years, other years may be largely snow-free. Travel across ice roads on the lakes, for construction activities as well as for recreation, and ice-fishing may see substantially shortened seasons. Outdoor skating rinks may become a distant memory.

The good news is that Muskoka's mid-century climate will bring benefits, as well as difficulties for our lives. The bad news is that the difficulties will be real, and they will require that we modify how we live our lives.

The more variable weather we anticipate will challenge winter road transport, and the greater risk of fire, flood or drought increase the cost of home or cottage insurance. While we have necessarily focused on the climate for a typical mid-century year, there are always atypical years – wetter, colder, dryer, hotter than usual. These are the ones that result in risky, damaging weather events. The 2013 spring was such a time, when heavy rain happened to coincide with the peak of the spring thaw. We still are talking about whose fault it was that there was severe flooding that year! Our analysis suggests that in the future, spring flooding will be even more seriously disruptive in some years, but not in all. Lack of water in late summer and fall is also likely to be more of a problem than now, and in dryer than usual years that will cause difficulties. Summer/fall drought will impact the tourist value of iconic waterfalls, and reduce stream flow, but will also raise problems for home-owners dependent on wells for domestic water supply. Our pattern of rural and recreational property development, with homes scattered through forested land, may pose difficulties for management of fire risk. Farmers with a dependable water supply for irrigation will be able to take advantage of the extended growing season, warmer weather and enhanced CO_2 concentrations, while those lacking a dependable supply may find farming a poorer prospect than it is at present. None of these issues are insurmountable, but they require that we modify how we operate our lives.

Impacts on public health

The anticipated mid-century climate is likely to have some significant impacts on public health due to the new opportunities for insect- or tick-mediated pathogens that until now have been unable to tolerate our climate. Among these are Lyme disease, West Nile disease, and malaria. In addition, the projected increase in extremely warm days will increase smog occurrences, the medical consequences of poor air quality, and the rate of heat-related deaths.

Lyme disease is caused by an infection of the bacteria, *Borrelia burgdorferi*, which in turn is transmitted when a person is bitten by an infected blacklegged or deer tick, *Ixodes scapularis*. This tick is an indiscriminant feeder on deer and a number of other animals, and can be dispersed when on migratory birds. At present, known cases of Lyme disease in Ontario are mostly restricted to sites just north of Lakes Erie and Ontario and the St. Lawrence River, including the Ottawa area; however the tick is spreading and with climate change the expectation is that its rate of movement north is going to increase. In 2012, P.A. Leighton and others published a modeling study which suggested the tick would arrive in Muskoka by as early as 2017-18; however, the tick appears to be already here. Public Health Ontario reported one confirmed case of Lyme disease in each of 2011-2013 and four cases in 2014 within the Simcoe Muskoka District Health Unit, but some of these cases may have been contracted elsewhere. They confirmed the tick present in Muskoka in all those years[1]. Lyme disease is readily treated with antibiotics if detected early, but the tick's bite is not painful and symptoms of fever, muscle and joint pain, which develop days after being bitten, can be missed. Not treated early, Lyme disease can be debilitating.

West Nile disease is a virus-caused illness following the bite of an infected mosquito. About 80% of people bitten by infected mosquitoes show no symptoms. In others, fever, headache, joint pain and nausea are usual symptoms, while about 1% experience severe neurological disease. The mosquitos that carry West Nile Virus in Ontario mostly belong to the *Culex pipiens/restuans* complex of closely related species. *Aedes vexans* has also been confirmed as a carrier in Ontario, and *Ochlerotatus japonicus*, another potential carrier, was first detected in Ontario in 2001. Mosquito abundance and activity are enhanced by warmer weather, and climate change is expected to further the spread of existing species and the arrival of new species in our region. *C. pipiens/restuans* was reported in Muskoka in 2012, but not in 2013 or 2014, and between 1 and 3 confirmed cases of West Nile disease occurred in the Simcoe Muskoka District Health Unit in each of 2011-2014 (most of these in vicinity of Barrie)[2]. Again, because of the delay in onset of symptoms, some of these cases could have been infected outside the region.

Other diseases that may appear in future as climate warms include malaria and dengue fever. The Asian tiger mosquito, *Aedes albopictus*, which potentially carries dengue fever and chikungunya disease, has been detected in Ontario in 2005 and 2012[3]. It is not yet considered established, but could become so as the climate warms. Given the likely continued importance of outdoor recreation in Muskoka, and the prevalence of water bodies (mosquitoes) and native fauna (ticks), the likelihood is high that mosquito and tick-borne diseases will become more prevalent as climate warms during this century.

The direct effect of warmer weather on human health will come as heat stress and heat-related death, and from deteriorating air quality and smog which will enhance respiratory diseases such as allergies and asthma. The incidence of respiratory allergies and asthma has been increasing in Ontario.

Another health risk that is likely to grow arises from contact with, or consumption of water from a lake experiencing a toxic blue-green algal bloom. As discussed on pages 25-28, our projected mid-century climate is likely

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[1] *Public Health Ontario Vector-borne Disease Summary Reports for 2011 through 2014, available at https://www.publichealthontario.ca/en/ServicesAndTools/SurveillanceServices/Pages/Vector-Borne-Disease-Surveillance-Reports.aspx*

[2] *Ibid*

[3] *Ibid*

to favor the development of algal blooms on susceptible lakes in Muskoka, and while only three of the small number of blooms reported in recent years have been confirmed to be toxic (by Elisa tests for microcystin), several species of blue green algae that potentially release toxins when they bloom are present in the region. Given the number of waterfront residences that still use surface waters, filtered in various ways, as the domestic supply, there is a growing health risk due to this factor. That the community is so sensitized to any occurrence of algal blooms, and that blooms can be noxious, whether or not they are toxic, keeps this risk modest, but it is real. Our urban centres that use surface waters for the domestic supply have quality controls in place that should prevent health risk; however the forced shut-down of a water supply for several days or weeks poses some inconvenience and added costs.

While Muskoka will remain overall a healthy environment, and while a slightly reduced risk of cold-related illness or death will accompany climate warming, it is clear that the anticipated mid-century climate will bring new health risks to living here.

Impacts of the changing climate on our built infrastructure

Our built infrastructure includes roads, bridges, and other paved surfaces; electricity, phone and other communications networks; swales, drainage ditches, lagoons, canals, culverts, stormwater and domestic sewerage systems; potable water supply systems; dams and other river water control systems; hydro, wind, solar and other power generation facilities; commercial and residential buildings; and all other built structures on the landscape. Some infrastructure is privately owned; much is owned by various tiers of government. To what extent will the anticipated climate change to mid-century affect our infrastructure?

The projected shift in seasonal pattern of precipitation towards the winter months, the overall increase in amount of precipitation, and the expected increase in frequency of severe weather events will have major impacts on winter road maintenance, and provision for drainage of stormwater. With an increase in an average year of 17% more precipitation during the November to April period, we must plan for a significant increase in cost of winter road maintenance. What is now classified as the 100-year flood event is likely to become far more frequent, and we will have to expand our water management capacity to cope.

Road maintenance will also be materially affected by the projected warming of our winters, with many days hovering around the freezing point. At present, the District of Muskoka spends approximately $4.7 million per year on its winter road maintenance, while the six Area Municipalities combine spend approximately $6 million. The province of Ontario, which is responsible for the maintenance of 400-level highways within Muskoka, spends an approximate and additional $1.5 million in an average year (based on 2014 Ministry of Transportation estimates). The shifted temperature regime is going to make control of ice on the roads a greater challenge. The spring-time repairs due to frost heaving will also increase, and there seems little reason to expect that the cost for snow removal will fall even though the average year will see less snow and more winter rain. While new technologies, or a greater tolerance for less safe winter driving conditions may appear, the extent of the alterations to current practice is likely to represent a very significant added burden to be covered by tax revenue.

The inherent variability of weather, bringing us both cold and mild winters, will mean that at mid-century there will be many years with exceptional snowfall and accumulated snowpack compared to typical conditions at present. The capacity to manage this snow and keep roads passable will require a substantially greater investment in machinery and operators than at present. This is true especially in our urban centers where snow removed from roads must often be transported to dump sites rather than piled at the curb. While we can anticipate that these exceptional snowfall years will be balanced by an equivalent increase in years in which there is a lot of winter rain and little snow to plow, it will still be necessary to invest more in equipment and staff so that the capacity to manage the heavy snowfalls is always available.

Coincidentally, the likely increase in use of salt to control ice build-up on our roads is going to have to be undertaken in as environmentally sustainable a way as possible in order to avoid further declines in the quality of our aquatic ecosystems due to salt pollution. While Muskoka municipalities and their contractors have worked hard to put in place salt management procedures that are environmentally sustainable, there is going to be a need for further improvements in order to limit the environmental effects of salt. There is also a pressing need for new environmental research to determine safe levels of salt pollution for Canadian Shield soils and lakes; current Canadian standards for lakes, based on better buffered water bodies than occur in Muskoka, are certainly environmentally unsafe here (Brown and Yan 2015).

Management of water flow, whether resulting from an intense summer storm, a mid-winter thaw, or a spring flood following a high snowpack year, will require infrastructure designed to handle water in quantities significantly greater than at present. Some existing ditching and culverts may need to be augmented or replaced, and new construction potentially designed to higher capacities. At present, the District's Public Works and Engineering Department is reviewing Muskoka Watershed Council's climate change paper to determine what the impact this will have on current engineering design practices related to the road systems. This is a challenge that all transportation jurisdictions are faced with. Large culvert replacements are assessed for capacity using industry-standardized approaches for design storms for Muskoka. This may also require increased funding in order to accommodate additional repairs and replacements and designing to higher capacities.

While the Muskoka River Water Management Plan was never intended to be, primarily, a flood-control plan, the increased seasonality of precipitation will increase the risk of severe spring floods, and the continued development of waterfront land increases the economic cost of flooding. Further, property owners who have become used to the idea that the water level in a lake is 'not supposed to fluctuate' more than a few centimeters in the course of the warm weather season are unlikely to be complacent when water levels are seen to fluctuate over a wider range.

The warmer summers with increased evapotranspiration mean a dryer ecosystem through summer and fall. Drought years will result in much reduced river flow, drying up of formerly permanent streams and wetlands, and overall reduced water movement through the system. As well as having major environmental consequences, these changes potentially reduce the tourism and recreational amenity of the landscape, affecting economic activity, property values, and livelihoods. It is also possible that people relying on well water for domestic use or for agriculture will experience more cases of wells drying up than at present. Technology to create summer rains during drought years is not feasible, and forest managers will have little opportunity other than to facilitate adaptation of the forest to a dryer climate by selecting for drought-tolerant species. The quality and functioning of our aquatic ecosystems could be sustained by managing water flow through the system, holding more of it back for late summer and fall than is presently done. That would require major investment in infrastructure and management design.

Municipal governments can justify spending to enhance infrastructure and substantially revise the water management plan in order to manage floods. Such spending would provide aquatic ecosystems with additional benefits that might be less easily sold to the community if costed directly. An alternative approach would be to leave major water management infrastructure unaltered, but develop and promulgate scientifically-sound, risk-averse information on the extent of flood plains and the expected pattern of flooding. Property owners could then use this information in making decisions on how they develop their own property. Either way there is need for new mapping to delineate flood plains appropriate to the changed hydrological regime; however, leaving water management infrastructure unchanged commits us to substantial alteration in the nature of our lakes, rivers and wetlands.

The anticipated higher frequency of intense weather events increases the frequency of lightning-caused fire, windfall, and damage to electricity and communication grids. While phone service is becoming increasingly wireless, internet service is growing in importance and in the use of wired connections for other than casual use. In a world characterized as the *web of things*, the need for wired internet is likely to grow. The cost of maintaining a wired grid for electricity and communication services is going to grow in heavily treed locations such as Muskoka, unless the grid is separated from trees to a greater degree than at present (resisted by property owners) or is progressively moved underground where it is far better protected. There will be many changes to electricity service in coming decades, driven by the increased decentralization of sources, the growing diversification of generation equipment, and a major evolution in the pattern of grid management and integration. These will require modifications to the grid in Muskoka, and it will be appropriate to improve the resilience of supply in the face of fire, windstorms, and ice storms in the process.

Finally, while warmer winters mean reduced heating costs, the warmer summers anticipated for mid-century will lead to a greater perceived need for air conditioning in all buildings. The Muskoka climate will remain one where intelligent passive solar design and effective insulation of buildings can obviate the need for air conditioning, but unless there is a major shift in attitudes, active air conditioning will likely remain the preferred way to manage summer indoor climate. Since most buildings are now air conditioned, the warmer climate will increase operating costs and electricity demand, rather than call for major new investments in infrastructure. Those individuals whose houses currently operate without the need for air conditioning, may find this becomes more challenging, and some will choose to install that capacity.

7. Planning for actions to ameliorate impacts of the changing climate

In previous sections we have looked at the climate that is most likely to be present in Muskoka at mid-century, examined how it will differ from the one we have now, and considered the consequences of that new climate for our aquatic and forested ecosystems. It is clear that climate is already changing, and that the changes that will have occurred by mid-century are substantial. In this section we set out recommendations for actions that will mitigate some effects of that new climate, while allowing us to adapt our lives to others.

By examining in some detail how these climatic changes are likely to impact our aquatic and terrestrial ecosystems, we have revealed consequences that are far more profound than a simple reporting of the ~3°C average increase in temperature through the year might suggest. Muskoka is entering a new world.

This new world we are entering is not an impossible one in which to live. It has some potential pluses for a community so strongly dependent economically on tourism and outdoor recreation, and our buildings will readily cope with the altered patterns of temperature and precipitation. We could take the easy approach and do nothing to prepare except wait and watch. That is the least expensive approach initially, though certainly likely to be the most expensive in the long term. But it is also the least responsible approach because climate is already changing and we have high certainty that a climate much like that delineated in Section 3 is going to be here in 35 years. We also have high certainty that this changing climate is going to cause a number of other changes that are problematic. Some of these are environmental changes that risk reducing the amenities that we expect, and on which much of our economy depends. Others are changes that increase the risk of property damage and loss of life during severe weather events. Most, but not all, of these less desirable changes can be ameliorated to some degree by forward planning. Muskoka will still have a changed climate – we cannot stop that by local action – but the environment and our infrastructure will have been adjusted by us to cope more effectively with the new demands of the altered climate.

Muskoka will not remain unchanged, exactly the way it is now. But if we plan for and implement policies and infrastructure to accommodate the changing climate, Muskoka will be a better place, a place possessing more of the attributes we value, than it will be if we sat passively, waiting and watching, while climate change alters the place we belong to.

Muskoka Watershed Council strongly endorses a proactive program of planning and implementation to prepare for the climate that we can be reasonably confident will be here by mid-century. We identify a need to manage water flow more effectively in order to retain the character and the ecological attributes that create important economic value in our environment. There is likely also a need to assist the transition of our forests towards a more heat- and drought-tolerant composition. There may also be a need to manage more effectively to retain the ecological processes that protect our water quality. Beyond these environmental management needs, we see a need to bolster our infrastructure to make it able to withstand the stresses brought by a changing climate, and to revise/expand our capacity to manage winter roads. We also recognize the need for more comprehensive data monitoring the state of our environment, and new research to better evaluate such things as the effects of road salt pollution, the consequences of wetlands loss, and the processes leading to algal blooms and other forms of water quality loss.

The very broad range of impacts of climate change on our environment, our infrastructure, and our lives makes it likely that there will be a considerable diversity of adaptive responses communities should take. Some responses to climate change, as well as actions taken simply because we are an innovative species, will lead to additional issues to be addressed. The marked changes that can be anticipated in how electricity is delivered to consumers in a world of distributed power generation, for example, will provide opportunities to also make power grids more resilient to severe weather, an issue of considerable importance in Muskoka even today. In developing our set of recommendations arising from this report, we have attempted to include those we now see as most clearly needed to sustain our environment, our infrastructure and our lifestyles. We recognize that many other actions will also be being taken. To the extent possible, it will be helpful to integrate these actions with those listed below.

We acknowledge that some of our recommendations will be costly to adopt. However, there is also a cost of doing nothing to plan for climate change impacts, and not only from an environmental perspective. In 2011, the National Round Table on the Environment and the Economy published ***Paying the Price***, a detailed look at the economics of climate change for Canada[1]. The authors point out that climate change will have economic costs of several types for Canada. These include costs of coping with impacts of the changed climate, costs of adapting to, or mitigating local impacts of, the changed climate, making its impacts less severe, and costs of reducing greenhouse gas emissions in order to mitigate the climate change that will otherwise occur. They estimate a total cost for Canada of around $5 billion per year by 2020, escalating to between $21 and $43 billion by mid-century. Some of this will be borne by individuals, some by governments and some by particular economic sectors. They make very clear, however, that ignoring climate change costs now will cost us far more later, stating, "The highest costs result from a refusal to acknowledge these costs and adjust through adaptation. In particular, long-lived decisions such as those that are made about coastal development, infrastructure, and forest management should consider the expected impacts of climate change and take steps to account for these costs through adaptation strategies."

They also caution that the costs of forward planning and adaptation are often readily identified, leading to adaptation strategies being rejected as too costly. They note that when the cost of not adapting is accounted for, adaptation often results in a net economic benefit (as it did in several detailed analyses included in the report). Finally, there is the likelihood that infrastructure adaptation undertaken over time in the course of routine repair and maintenance can be very cost-effective.

The recommendations contained in our 2010 report remain appropriate, as does the rest of that document, and several are repeated or extended here. Others are new given that we now have a clearer picture of the local effects of climate change. The following 15 recommendations provide for a set of actions by individuals, by community groups, by the business community, and by government to prepare our Muskoka for our changing climate. They include four types of action. First are actions to build new scientific understanding of the Muskoka environment in order to have the information needed for sound environmental management in challenging times. Second are actions designed to ameliorate some substantive impacts of changing climate on our aquatic and terrestrial systems. Third are actions to strengthen our infrastructure, and fourth are actions to ensure that this overall plan is implemented. Muskoka Watershed Council (MWC) will work to encourage and facilitate wide adoption of these recommendations across our community. We will also work to inspire our community to support all efforts, at local, provincial, national and international levels to reduce emissions of greenhouse gases and in other ways wrestle anthropogenic climate change to a halt. Our planet, and our children will thank us.

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[1] *Available for free download from https://www.fcm.ca/Documents/reports/PCP/paying_the_price_EN.pdf*

Recommendations

1. **Actions to improve understanding of the ecological functioning of the Muskoka environment:**

   a. **Strengthen and broaden the existing monitoring of lakes in Muskoka.** We know far more about Muskoka's lakes than is the case for most other regions, but there remains much we do not know. Our ability to anticipate, and perhaps to mitigate, changes to our watershed due to the changing climate requires an enhanced water quality monitoring program. Building on existing water quality monitoring programs (MOECC Lake Partner Program, DMM Water Quality Monitoring Program, and numerous lake association-based citizen monitoring efforts), we recommend that Muskoka Watershed Council bring together representatives of Muskoka Lakes Association, Lake of Bays Association, other lake associations with monitoring programs, Georgian Bay Biosphere Reserve, other environmental NGOs with activities in lake monitoring, the DMM Planning Department, the MOECC Dorset Environmental Science Centre, and the MNRF Muskoka office to plan and build a coordinated implementation of an enhanced citizen-driven, science-based water monitoring program. The group should seek ways to pool resources, develop specific interim and final monitoring goals, and plan to begin roll-out of an enhanced monitoring program, which should include monitoring within Muskoka's wetlands and streams in addition to its lakes, within two years (2018). This new watershed-wide program should monitor for attributes useful for tracking the anticipated climate-driven changes in water quality and lake biota. Only with scientifically sound data will our community be in a position to identify locations facing critical stresses, or locations where proactive remedial action may be most useful in striving to retain system quality and resilience.

   b. **Develop new research program on causes and management of algal blooms in Muskoka Lakes.** MWC, with Friends of the Muskoka Watershed (FMW), should seek to have funding in place, and participation from academia, the MOECC Dorset Environmental Science Centre, and other key research organizations for a substantive research program centered on causes and management of algal blooms in Muskoka lakes. Topics might include causes and dynamics of blooms, effective algal monitoring techniques suitable to citizen science, and active management techniques that could be installed in sensitive lakes to preserve lake amenity. Relevant partnerships and funding should be sought immediately, with program initiation to follow expeditiously (2017).

   c. **Develop new research program on the effects of road salt on Muskoka aquatic systems.** MWC should build on its existing efforts, and with FMW, coordinate increased participation from academia, the MOECC Dorset Environmental Science Centre, and other key organizations within three years (2019), for research to characterize the effects of road salt on aquatic ecological processes, with the goal of developing sound guidelines for use and management of salt use on Canadian Shield environments. Efforts by industry, Ministry of Transport, municipalities, or others to develop improved winter road maintenance technology are welcome and encouraged.

   d. **Develop new research program on the combined effects of calcium decline and climate change on forest ecosystems in Muskoka.** MWC should build on its existing efforts, and with FMW, have funding in place and participation from academia, MNRF, and other key research organizations within three years (2019), for research into the combined effects of calcium decline, warming and drought on forest composition, regrowth capacity, and on assistive management techniques.

   e. **Undertake a review of wetland ecosystem values and active management techniques for retaining these in the face of increasing summer/fall**

drought. In continuing to support and assist the ongoing provincial efforts to develop a wetland management strategy, MWC should, within two years (2018), conduct a review of available science and make specific recommendations to landowners and to municipalities on ways to retain wetlands on the landscape. This review could explore passive conservation, active wetland maintenance, and indirect enhancement through such things as strengthened protections for beavers. Muskoka's environmental values are certain to be diminished if we permit extensive loss of wetlands across the region as climate changes.

2. **Actions to address anticipated impacts of climate change on the Muskoka environment:**

    a. **Plan and implement policies and infrastructure that will permit some capacity to control water flow through the Muskoka River watershed.** The shift to a more seasonal pattern of water delivery risks some deterioration of water quality and considerable loss of amenity of Muskoka's waterways. Through the Climate Adaptation Steering Committee (below), DMM should facilitate a partnership, to be led by MNRF and area energy producers, with active participation from DMM, MWC, and other agencies appropriate to undertake a substantial plan, to be implemented by the Province, to hold back some water delivered to the system during winter and spring for flow maintenance during summer and fall. The first step will be to develop a hydrological model for the entire watershed capable of projecting flows under different specified climates. This model should be made available to all as a permanent management resource. Detailed future planning will use information on future hydrology of the system from this model, with the goal of compensating to the degree feasible for the anticipated shift of precipitation to the winter months. By modifying or replacing infrastructure, it should be possible to hold water back for late summer/fall flow, thereby ensuring retention of environmental, and societal values of this water system, while mitigating flood risk. This planning process will require new science specific to this waterway, and its implementation could require significant new investment in infrastructure as well as creative use of existing wetlands and lakes. The goal should be to have a final plan in place by 2020, and a program for implementation by appropriate agencies during the decade to 2030. The existing Muskoka River Water Management Plan should be merged into this new, more comprehensive program.

    Additionally, and whenever possible, DMM and other organizations should encourage the Province's recognition and incorporation of Muskoka's mid-century climate projections as outlined in this paper into any upcoming and/or ongoing review of the Muskoka River Water Management Plan.

    b. **Undertake a review of planning documents to ensure that floodplains are appropriately delineated for the climate anticipated for mid- to late-century.** Through the Official Plan Review process, and in consultation with MNRF, DMM and the area municipalities should each ensure that regulations and advice governing built structures in floodplains are appropriate, and based on accurate, up-to-date information on likely patterns of water level fluctuations on our lakes and waterways in coming years.

    c. **Develop up-to-date information for landowners on methods for maintaining their forested land.** By spring of 2019, MWC and FMW, in collaboration with Muskoka Conservancy, and with the help of MNRF, MOECC, and Westwind Forest Stewardship Inc. should develop materials and a community outreach program to promote specific, science-based, proactive management strategies that property owners and managers can use to help ensure retention of the economic value and the intrinsic ecological value of forested land in the face of climate change and associated factors.

3. **Actions to prepare our built infrastructure and its management for the climate of mid-century:**

   a. **Plan for added capacity for winter road maintenance under a higher precipitation winter climate.** Beginning in 2016, and then routinely every five years, DMM and Area Municipalities should review existing capacity relative to anticipated need, and put in place phased programs for infrastructure renewal to ensure they keep pace with the growing demands of the new climate. Efforts by Ontario Ministry of Transportation, industry, municipalities and others to develop new technologies for winter road maintenance should be encouraged.

   b. **Regularly scheduled reviews, and planning for retrofit or expansion of any municipal infrastructure, should incorporate the latest information on local impacts of climate change.** Municipal public works departments should ensure that upgrades are designed to adapt to those impacts. Such reviews should include but not be limited to the following:

      - **Review adequacy and program replacement/upgrade of stormwater handling infrastructure.** By 2020, DMM and Area Municipalities should each undertake a review of all stormwater management infrastructure (including swales and lagoons as well as hard structures), and develop a phased program of upgrade/replacement to ensure adequacy under the demands of the new climate.

      - **Review adequacy of fire prevention and fire-fighting capacity, and implement a program for capacity improvement as required.** Starting immediately, and then routinely every five years, Area Municipalities will each complete a review and put in place a phased plan for up-grading of capacity – vehicles, equipment, staffing -- in preparation for the hotter, dryer summer/fall climate of mid-century.

   c. **Encourage the construction of energy-neutral housing and other buildings in Muskoka.** By 2020, MWC should undertake a review of available technologies and develop brochures and other materials for property owners and the construction industry making an environmental and economic case for highly efficient or energy-neutral construction. DMM and Area Municipalities should consider implementing financial and other inducements to encourage energy-neutral construction. Energy-neutral buildings can be achieved using any and all of passive solar design, green walls and green roofs, superior insulation, energy efficiency in heating, cooling and major appliances, use of smart home technology (the web of things) to regulate/minimize energy use, installation of solar cells or on-site wind power to replace energy drawn from the grid. This recommendation adapts our buildings to the new climate while also reducing per capita energy use in our community thereby contributing directly to mitigation of greenhouse gas emissions. With enthusiastic uptake, Muskoka could showcase itself as the most environmentally sustainable place to live in Ontario. This would sustain our second home/tourism economy while also strengthening/diversifying our economy by attracting new permanent residents who want to live in an environmentally sustainable way.

   d. **Plan for electrical production and distribution upgrades that will increase resilience of the electricity grid to the more extreme weather patterns expected with climate change.** Hydro One and associated power generation facilities within Muskoka should ensure infrastructure to support less carbon-intensive lifestyles is present in Muskoka. This infrastructure enhancement will be supported by rapidly evolving distributed energy technologies such as storage (both ahead of and behind the meter) and "smart grid" features that have been demonstrated to increase grid stability, reliability, and promise to eventually lower the cost of power to consumers. The data management associated with these grid enhancements encourages synergies between electricity and data services - a phenomenon already apparent in Muskoka.

4. **Action to facilitate the effective implementation of these recommendations:**

    a. **Every individual Muskokan should undertake to become informed on climate change issues, and take real steps to reduce his/her own carbon footprint.** Permanent and seasonal-residents can all find ways to change behavior to reduce use of energy or choose non-polluting forms – active transport, energy-wise home renovation, use of energy-efficient cars and household appliances, or locally-grown produce all help. Each individual can also support initiatives to combat climate change and encourage those political leaders who strive to improve our ability to adapt to or ameliorate its impacts.

    b. **Establish the position of Director of Climate Adaptation within the District Municipality of Muskoka government.** This individual, who should be appointed as soon as possible, will have a leadership role for all aspects of the District's response to climate change, and will coordinate inter-departmental District actions on climate adaptation with those of Area Municipalities; MOECC, MNRF, MOT and other relevant provincial agencies; the business community; MWC and other local community groups; and the general public.

    c. **Convene a Steering Committee to facilitate the collaborations needed, and to ensure implementation is on track.** DMM should convene a Steering Committee to bring municipalities, provincial government agencies, and representatives of economic sectors and community groups together to share, and where appropriate coordinate and collaborate on planning and implementation of specific actions to address climate change. The DMM Director of Climate Adaptation will chair this committee. MWC would expect to be represented, but the importance of this committee requires that it be convened by government. The committee should plan on a minimum of two meetings per year with the goal of building a blueprint for actions to be taken, and then tracking that action through time. While the dispersed responsibility for action (both between government and the community, and among governments) precludes a top-down command-and-control approach to managing advice and execution, this Steering Committee can provide the necessary encouragement to keep projects on track.

8. Conclusions

Our climate is already changing. We have growing information on how it is likely to change. We will be able to cope more effectively, and more economically, with these changes if we plan ahead and begin to make the necessary infrastructural and management changes now. This is a task for all members of the Muskoka community, as individuals, as members of community groups, as businesses and as government. Coordinated and integrated actions are required.

While we can adapt to the changes coming over the next few decades, there is every reason to advocate strongly for concerted activities at local, provincial, national and international scale that will mitigate climate change by strongly reducing and eventually eliminating a major portion of our releases of greenhouse gases. This global mitigation effort should have begun decades ago. Here in Muskoka, we already have the capacity to switch to renewable energy sources for all activities except transportation at no increase in cost. Challenges lie ahead, but technologies and attitudes are changing more rapidly than our climate itself, so there is also room for some real optimism.

Photo by John McQuarrie

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Glossary

Anoxia: Lake waters contain oxygen dissolved from the atmosphere. During the warmer part of the year when the lake is stratified, biological activity in the hypolimnion may substantially reduce oxygen concentrations or exhaust all oxygen present there. These conditions are respectively hypoxia and anoxia.

Climate normal: The long-term average of (usually daily) weather measurements over a period of 30 years. This is the standard number of years used to describe climate by the United Nations World Meteorological Organization.

Climate: The average over usually three decades of weather conditions measured daily or more frequently to obtain a description of the typical annual cycle of weather.

Coupled Model Intercomparison Project, Phase 5 -- CMIP5: This major global climate modelling experiment was established at a global meeting involving members of 20 climate modelling research groups in 2008. It comprises over 800 projections of the global climate, generated by 61 different GCMs running under four specific RCPs. CMIP5 is described at http://cmip-pcmdi.llnl.gov/index.html?submenuheader=0.

Emissions scenario: A specified pattern of change over this century in the global economy, energy sources driving it, and GHG emissions. IPCC has created several alternative emissions scenarios to be used to drive GCMs to project the resulting likely future climate.

GCM – Global Climate Model: A complex computer model that captures the various processes linking solar energy input, atmosphere, land and oceans at a global scale to generate our climate. A good GCM can reliably reproduce observed past patterns in climate at global and regional scales, and can be used to project likely future climate at these same scales under specific assumptions concerning such things as human activities that release or sequester greenhouse gases.

GHG – greenhouse gas: Any gas present in the atmosphere which is transparent to light energy but acts to impede loss of heat through radiation into space.

Intergovernmental Panel on Climate Change – IPCC: The scientific intergovernmental body under the auspices of the United Nations, set up at the request of member governments. It was established in 1988 by two UN organizations, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), and later endorsed by the United Nations General Assembly. It includes thousands of climate and environmental scientists who work in a volunteer capacity to review the underlying science, and develop a consensus understanding of climate change and its consequences. The most recent IPCC report, Assessment Report 5 or AR5, was completed in 2014, and is available at https://www.ipcc.ch/report/ar5/.

Internal loading: When dissolved oxygen levels become critically low in the deep waters of a lake, chemical processes called internal loading occur. These liberate nutrients such as phosphorus that are otherwise bound in the sediments. These newly released nutrients can stimulate algal, bacterial and animal life in the lake.

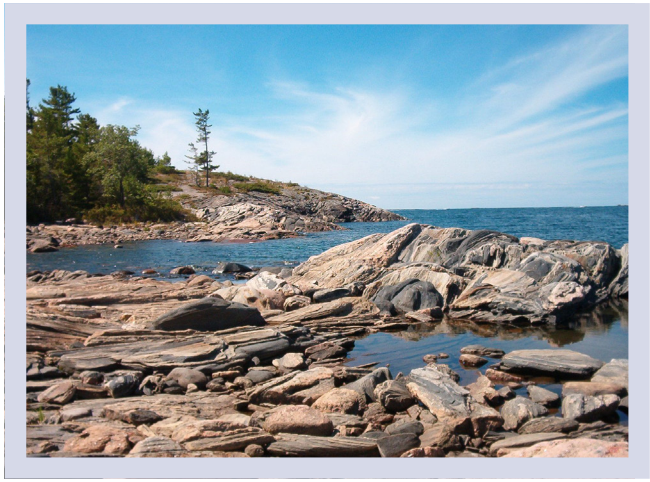
Representative Concentration Pathway – RCP: The term used by IPCC for an emissions scenario. RCP8.5 is often called the ‘business-as-usual’ scenario. RCP4.5 and RCP2.6 are examples of scenarios with more aggressive efforts to reduce GHG emissions. The RCPs were developed for use in the 5th Assessment Report (AR5), and are described in detail in Chapter 12 of the Report from Working Group 1, comprising one part of AR5. It is available at http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter12_FINAL.pdf.

Successional stage: Ecological communities change through time as populations become established, grow in abundance, and are replaced by others more suited to the now changed environmental conditions. This progressive replacement is termed succession. Succession in a particular type of community may have several distinct stages typified by specific sets of species.

Weather: Measurements of temperature, precipitation, wind speed, etc. at a specified location together characterize prevailing atmospheric conditions.

Web of things: The coming alignment of smart technology to link building climate control, energy use, major appliances, security systems, and communication into a seamless, web-based network.

Muskoka Watershed Council



Muskoka Watershed Council (MWC) is a volunteer-based non-profit organization with the mandate to champion watershed health.

MWC is a collaboration of Friends of the Muskoka Watershed and The District Municipality of Muskoka. It is comprised of representatives from a wide range of stakeholders, including municipal, provincial and federal governments; lake and area ratepayer associations; local industry, tourism, real estate and other interests from across our watersheds.

In Muskoka, where there is no conservation authority, MWC provides a coordinated voice on issues affecting the environmental quality of our watersheds. It is not a regulatory or enforcement agency. Instead, it provides information to decision-makers, managers and the general public on ways to protect and restore the resources of our watersheds.

MWC's Objectives

1. **Evaluate the Watersheds** - Develop and implement science-based programs to research, assess, monitor and evaluate.

2. **Speak for the Watersheds** - Advise on sound air, land and water use planning, as well as management practices and policies.

3. **Communicate and Educate** - Develop and implement public information and education programs that promote sustainable lifestyle choices and an understanding of the impact of human actions on the watersheds.

4. **Promote and Demonstrate** - Promote and facilitate demonstration activities and best practices that support an environmentally sustainable economy and a healthy community structure.

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Planning for Climate Change in Muskoka