Muskoka Watershed Report Card 2023

CHAPTER 13 – WEATHER AND CLIMATE

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Along with human alterations to the natural environment, weather and climate control many of the changes we see in Muskoka. This chapter presents several sections describing;

- Trends in the long-term observations of temperature and precipitation,
- Ice-on and ice-off dates for lakes in Muskoka,
- The meteorological conditions and pre-conditions required for spring floods, and
- A discussion of climate change impacts and what you can do.

LONG-TERM TEMPERATURE AND PRECIPITATION TRENDS IN MUSKOKA

WHAT IS CLIMATE CHANGE AND WHY IS IT IMPORTANT IN MUSKOKA?

In Muskoka, local ecological, social, and economic systems are impacted by changing climatic conditions caused by the global warming trend being driven by modern society's excessive emissions of greenhouse gases. Although climate change science is advancing, the Earth's climate is extremely complex, which makes projections of the future climate challenging, especially on a local scale. However, as local data are collected, it is evident that climate change is already a reality in Muskoka (Sale et al., 2016), and our understanding of its current and future effects is improving with time. The indicators used in this chapter focus on physical changes the Muskoka Watershed has undergone due to climate change, measured by temperature and precipitation.

Muskoka Watershed Council (MWC) has reported on climate change several times. In 2007 and 2018, climate was featured in the Muskoka Watershed Report Card. In 2010, MWC released a paper, *Climate change and adaption in Muskoka*, to provide information on how the changing climate will affect Muskoka's natural and socio-economic communities. A more comprehensive report, *Planning for climate change in Muskoka*, was released in 2016 and examined the likely impacts climate change will have on Muskoka's natural systems by mid-century.

This section of the Report Card will report on climate-related trends that have been observed over long time periods in the Muskoka River watershed and what they mean for our weather, lakes, forests, and our health.

HOW IS CLIMATE CHANGE MEASURED IN MUSKOKA?

The impacts of climate change can be demonstrated through several measurements. Some of these are the changing patterns of precipitation and the increase in air temperature. While climate change is a planet-scale process, impacts and changes are felt by individuals and so examination of local-scale measurements can clarify our understanding of local climate change and the resulting local consequences for the Muskoka watersheds. Two useful measurements are temperature and precipitation from observational weather stations. These data are collected year-round by the Canadian federal government and, for some meteorological stations have been collected for over a century. The temperature and precipitation measurements can be downloaded from historical records spanning as far back as the 1880s (https://climate.weather.gc.ca), providing us with very long-term local trends. Such local weather data is fundamental to our understanding of climate change and represents a key measure within the scientific community (IPCC, 2021). Changes in temperature and precipitation affect our land, lake, and river ecosystems, lake freeze-up and break-up times, wildlife patterns, flooding, drought, and human health.

Data Sources: The longest meteorological record in Muskoka comes from several stations in Beatrice, located in central Muskoka, with precipitation beginning in March 1876 and complete temperature records beginning in January 1878. Until recently the long-term record was split among multiple stations established successively through time in the vicinity of Beatrice, however, researchers at Environment and Climate Change Canada (ECCC) have joined the records of these different stations and adjusted and harmonized the data to make a single time series for temperature (Vincent et al., 2020) and precipitation (Mekis and Vincent, 2011). This new data set, known as the Adjusted and Homogenized Canadian Climate Data (AHCCD), was specifically designed for exploring climate change. The entire available record of the Beatrice AHCCD station number 6110606 was used for this report. The Muskoka airport station, with only temperature data and a much shorter time frame, was excluded.

Data processing: Data files for precipitation (daily rain, snow, and total precipitation) and temperature (daily minimum, maximum and mean temperatures) along with available documentation were downloaded from the ECCC data server (ECCC, 2022).

Indicator selection: A list of climate indicators was assembled based on existing scientific papers, reports and websites. A total of 22 temperature-based and 19 precipitation-based indices were identified (a complete list available from R.B. Lammers). This list was then reduced to those indices that were considered understandable and interpretable by most people and straightforward to calculate (see Williams and Eggleston, 2017; and Trewin et al., 2021 for a discussion of indices for communication). These indices were calculated, graphed, and presented to the MWC Report Card Sub-committee for comments. Based on this feedback, the indices were selected for presentation in this background report.

Disclaimer: The reader should bear in mind several caveats when interpreting the meteorological data presented here. First, these results are derived from one location in Muskoka and for any given weather event there is great variation between locales. For this reason, we chose robust climate indices that are likely to be similar to those at other meteorological stations in the region. Second, these data represent historical observations and do not automatically imply these changes will follow the same trends into the future. Third, the time period selected for calculation of the trends will have an impact on the slope values. The shorter the time period, the more sensitive the trend will be to occasional extreme records. For this reason, we have chosen to examine trends only over the maximum timeframe available to ensure more stable trend lines.

RESULTS

Numerous indices were plotted for the two fundamental meteorological variables widely collected, temperature and precipitation. Indices covering annual, seasonal, and monthly time periods were generated and the following section discusses those indices where we see the larger changes over time.

TEMPERATURE CHANGES

The largest change over time in seasonal temperatures was in the seasonal mean (average) of the daily maximum temperatures in the winter (the 90 days of January, February, and March) and in the fall (the 92 days of October, November, and December). Based on the trend line, mean daily maximum temperature in the winter has increased over 1 °C per 100 years (Figure

19) and by just under 1 °C per 100 years in the fall (Figure 20). These increases in seasonal maximum temperature were driven by strong positive trends in the months of February and March in the winter and November and December in the fall. The tendency of days to become warmer was less pronounced at other times of the year. Daily minimum temperature trends were lower than daily maximum temperature trends except in December when it was equal to the daily maximum temperature trend.

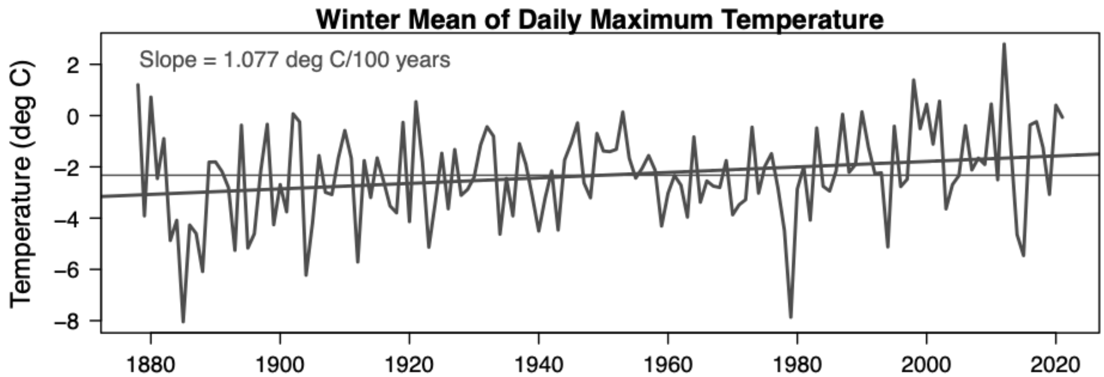

Figure 19. Seasonal mean of daily maximum temperatures for winter (January, February, and March) with trend line and change over time. The thin horizontal lines show the average over the full time series and the thick inclined lines show the slope of the linear regression line (trend).

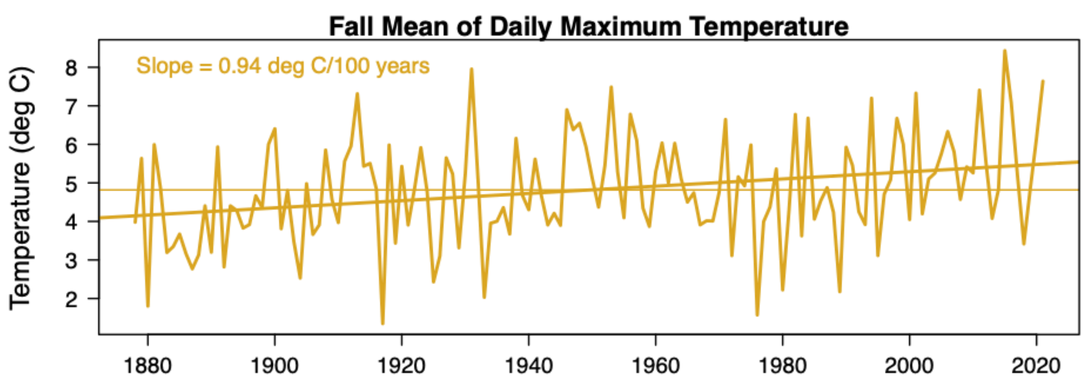

Figure 20. Seasonal mean of daily maximum temperatures for fall (October, November, and December) with trend line and change over time. The thin horizontal lines show the average over the full time series and the thick inclined lines show the slope of the linear regression line (trend).

Another way of looking at changing temperature is through a count of days in each year where the temperature exceeds some threshold value. Two different measures are used here: *summer days:* the number of days in each year where the daily maximum temperature is greater than 20 °C (Figure 21) and *icing days:* the number of days in each year where the daily maximum temperature is less than 0 °C (Figure 22). The summer days index shows an increase of over 7 days per 100 years and the icing days index sees a decline of over 9 days per 100 years. For icing days, we treated years as extending from 1st July to 30th June so that the count of icing days would be for a single cold-season.

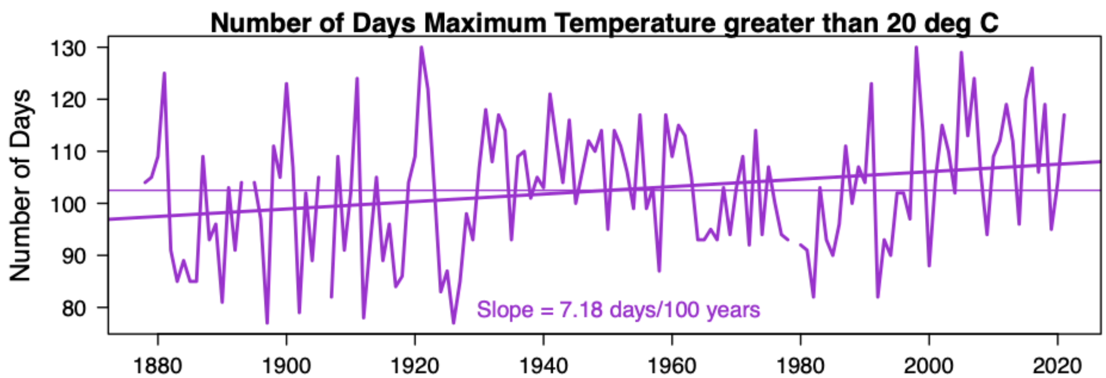

Figure 21. Summer days: the number of days in each year that daily maximum temperature is greater than 20 °C. The thin horizontal line shows the average over the full time series and the thick inclined lines show the slope of the linear regression line (trend).

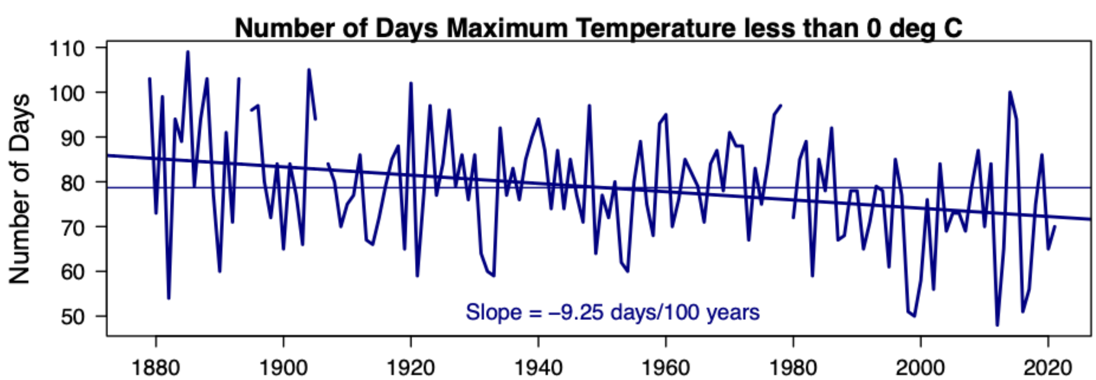

Figure 22. Icing days: the number of days each winter that maximum temperature is less than 0 °C. The thin horizontal line shows the average over the full time series and the thick inclined lines show the slope of the linear regression line (trend).

PRECIPITATION CHANGES

The second fundamental meteorological variable is precipitation, which is divided into rain and snow. Total annual precipitation (Figure 23) and the total annual rain component (Figure 24) both show increases over the 140-year record. Total annual precipitation averages 1,121 mm per year with 71.4%, or 801 mm per year arriving as rain and the rest as snow but the graph shows an increasing trend in rainfall and in total precipitation. The amount of snow does not appear to have increased (Figure 25). Both total precipitation and rain alone have increased approximately 1.3 mm per year over the 140 years. The total increase is almost entirely due to rain as the snow trend is negligible.

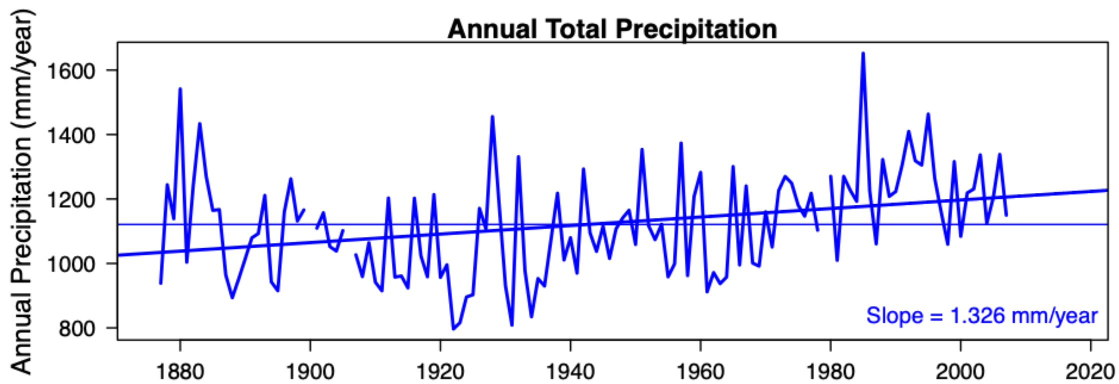

Figure 23. Annual total precipitation (rain plus snow). The thin horizontal line shows the average over the full time series and the thick inclined lines show the slope of the linear regression line (trend).

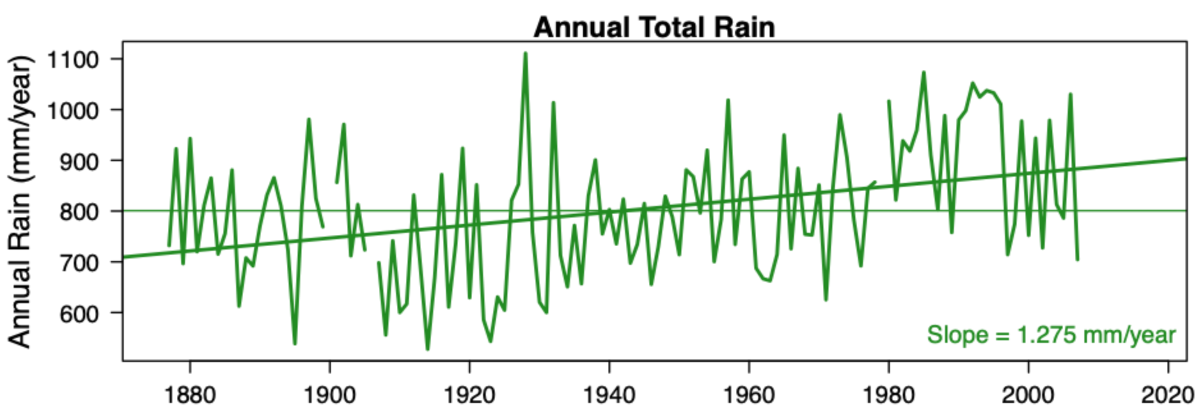

Figure 24. Annual total rain. The thin horizontal line shows the average over the full time series and the thick inclined line shows the slope of the linear regression line (trend).

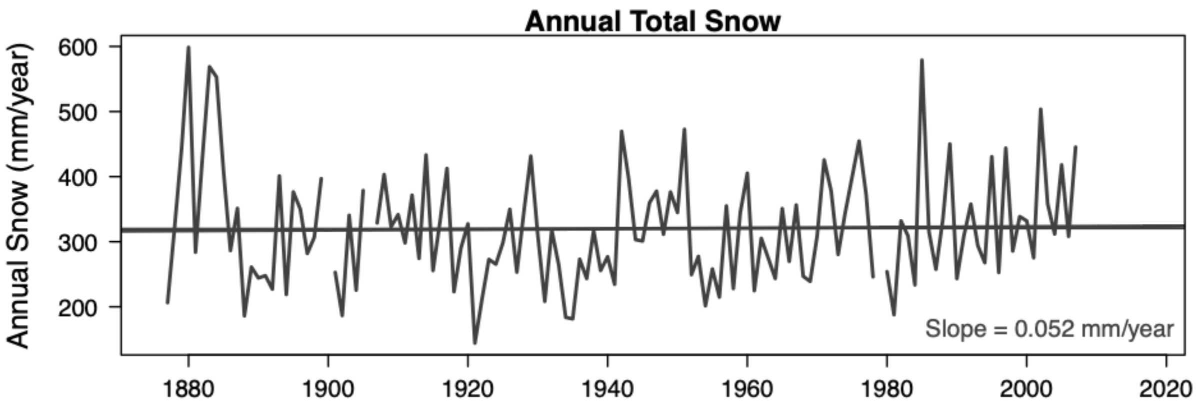

Figure 25. Annual total snow. The thin horizontal line shows the average over the full time series and the thick inclined line show the slope of the linear regression line (trend). The lower trend line overlaps the horizontal average line.

Other characteristics of precipitation can be seen through the *annual precipitation days* index, a count of the number of days in each year with any precipitation (Figure 26). For the annual precipitation days index the daily precipitation must be greater than 1 mm per day to count as rain. This index shows an increase of 0.36 days per year representing 36 additional days of precipitation over a span of 100 years.

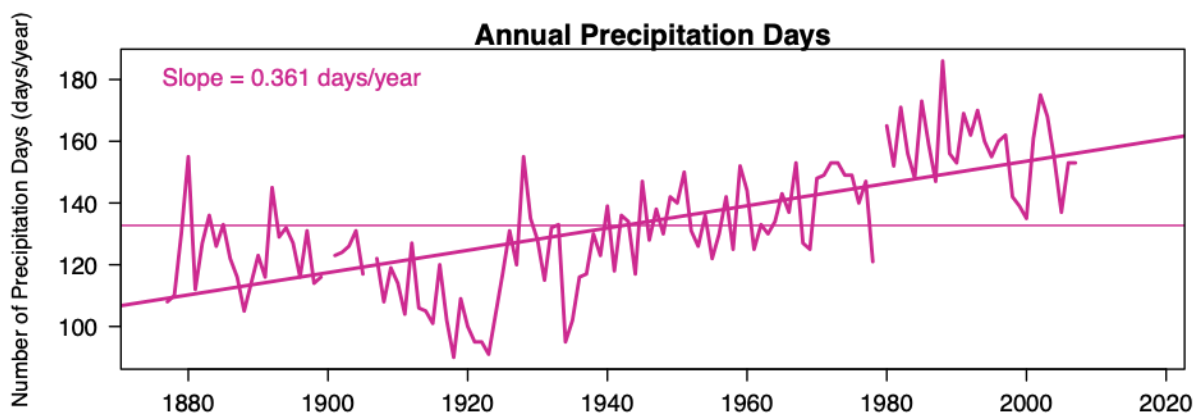

Figure 26. Number of days each year with precipitation greater than 1 mm per day. The thin horizontal line shows the average over the full time series and the thick inclined line shows the slope of the linear regression line (trend).

WHAT DOES IT ALL MEAN?

Temperature is important for controlling rain/snow mix and the timing of snow melt. Temperature also governs water loss in Muskoka through evapotranspiration. Precipitation is important as it is the supplier of water for the entire system. Changes in our climate will not just lead to changes in the weather because these changes will have a wide range of impacts on our environment and our lives, including on our lakes, our forests, and our health.

In reviewing the long-term climate trends, we see that Muskoka has been getting warmer and wetter. The greatest warming occurred primarily from late fall to the end of winter. An increase in the number of warm days suggests we may be getting more heat waves (Figure 22), however there is no observed increase in the number of days with daily maximum temperature greater than 30 °C (not shown). Therefore, Muskoka has seen an increase in warm summer days, but little increase in the very hot days that can impact ecosystem and human health. The decrease in the number of days when daily maximum temperatures are below 0 °C indicates a larger number of days in which the snowpack is likely to be melting. What happens to the water during a mid-winter snow melt event remains an open question. If the meltwater refreezes deeper in the snowpack, then the snowpack becomes denser, and that water remains available for the spring freshet. If the meltwater enters the river system in mid-winter, then some of the spring freshet is released earlier in the winter, thus reducing high water levels in the spring.

The increased temperatures (Figures 20 and 21) and the shift of snow into December and January (not shown) point to a narrower snow season length. The increase in annual total precipitation is driven almost entirely by the increase in rain with the snow trend remaining nearly constant (Figure 25) suggesting that in the shorter snow season, winter snowfalls are more frequent and/or heavier.

There is an increase in the number of precipitation days per year (Figure 26). This indicates the possibility of increasing precipitation frequency: however, further work would be required to better understand these changes.

If these observed long term trends continue through to the end of the 21st Century, then Muskoka is on a course to see much more than 1 °C of warming in the fall and winter. However, the current expectation is that warming will be much greater than this as climate model results show winter temperatures are anticipated to increase by 2 to 7 °C across a range of climate scenarios (Figure 4.6 in Bush and Lemmen, 2019). These same model results indicate summer warming to be in the range of 1 to 7 °C (Figure 4.7 in Bush and Lemmen, 2019). If Muskoka follows the more extreme scenarios, then the temperature changes will be much more extreme than those we have experienced in the last 140 years.

Estimates of changes in precipitation to the end of this century are much more variable in the climate models. Annual precipitation changes in Muskoka are estimated to remain the same or increase by up to 20% with more precipitation in the winter and less in the summer (Figures 4.17, 4.18, 4.19 in Bush and Lemmen, 2019). The historical changes observed in the precipitation record fall within this range.

WINTER ICE

Lake ice-on and -off dates for selected lakes have been compiled by the Dorset Environmental Science Centre (DESC) since 1975 and were reported in the 2018 Report Card. The data comprise ice-on (Figure 27) and ice-off (Figure 28) dates from which the number of days during which the lake is completely ice-covered can be calculated (Figure 29). The ice-on or ice-off date is charted by its calendar day number. For example, in a non-leap year, December 1st is day number 335 out of 365. Most of the data is from Grandview Lake, located outside of Baysville, ON.

ICE-ON DATES

Initially in the DESC data, the day on which ice covered the lake, occurred in November or early December (Figure 27). Since 1996, with 2018 being the exception, ice coverage now begins in December. The trendline for ice-on dates suggests that lake ice is forming later in the year by approximately 3.8 days over 10 years.

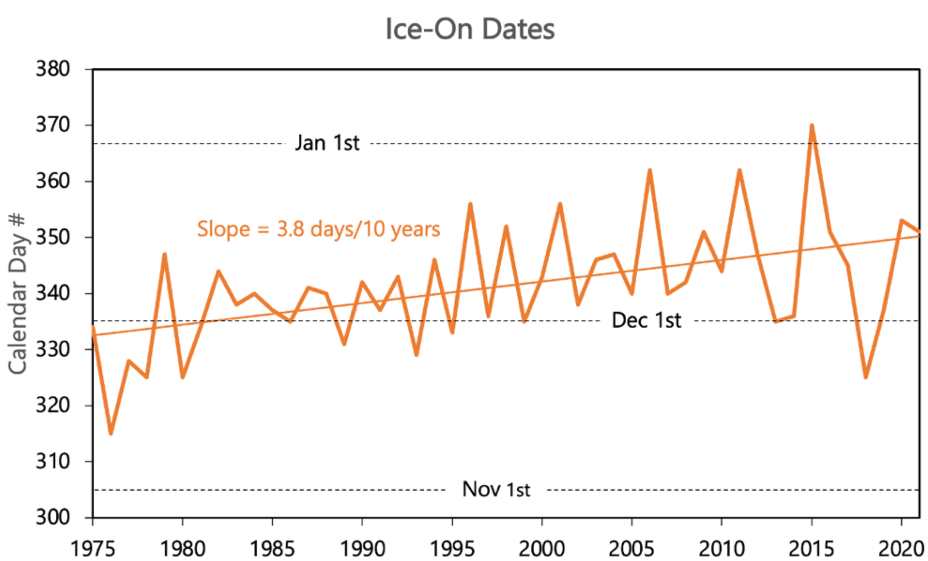

Figure 27. Ice-on Dates since 1975: Dates are represented as the numerical day of the year with January 1st equal to day 1. The straight line through the data is the linear regression of ice-on date, with a shift towards later dates of 3.8 days per 10 years. Unpublished DESC data.

ICE-OFF DATES

Since 1975, ice-off dates appear to be occurring slightly earlier in the year (Figure 28), however the degree of change since 1975 is less than the change in ice-on date. On average, the ice is leaving the lake approximately 0.6 days earlier over a 10-year period.

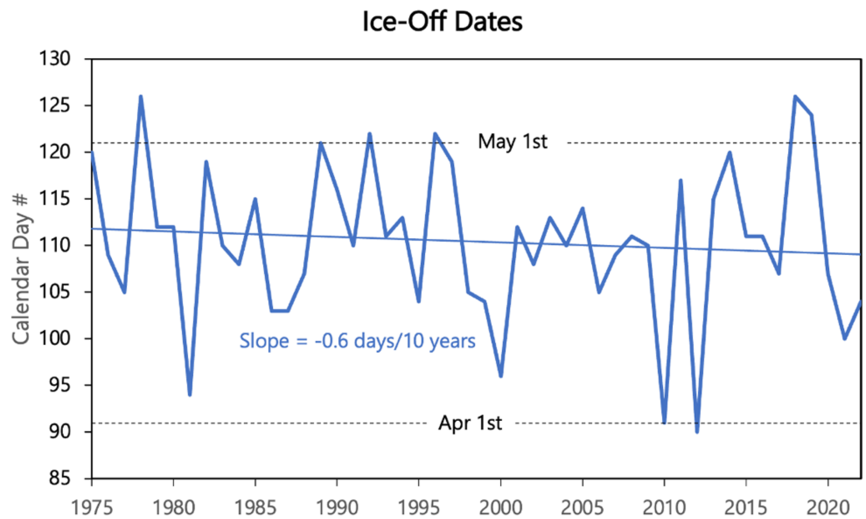

Figure 28. Ice-off Dates since 1975: Dates are represented as the numerical day of the year with January 1st equal to day 1. The straight line through the data is the linear regression of ice-off date, a very small shift towards earlier dates of 0.6 days per 10 years. Unpublished DESC data.

ICE COVER

As a result of lake ice forming later in the year and melting earlier in the following year, the number of days of ice coverage has decreased at a rate of 4.4 days over 10 years (Figure 29).

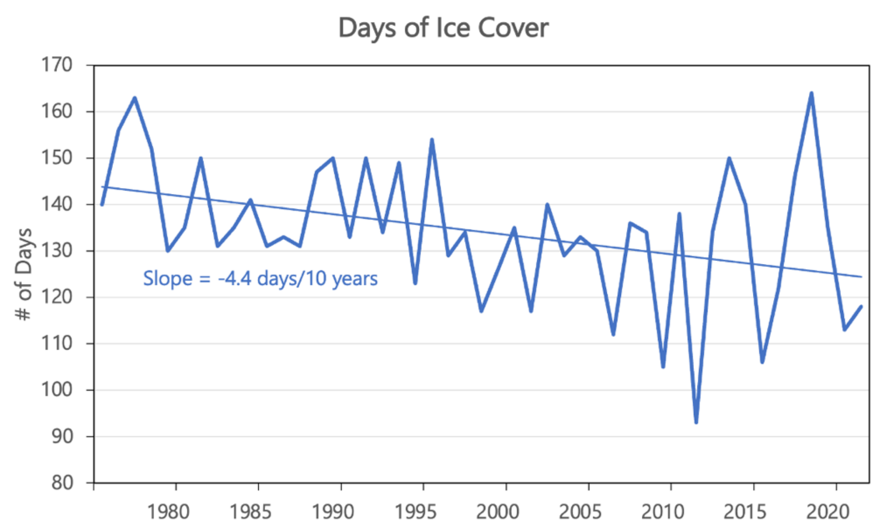

Figure 29. Days of Ice Cover since 1975: The number of days of winter ice cover. The straight line through the data is the linear regression of winter ice cover showing a decrease of 4.4 days per 10 years. Unpublished DESC data.

STORMS AND THEIR CONNECTION TO MUSKOKA FLOODS

Heavy rainstorms during snowmelt are a key contributor to spring flooding. These storms rise in the American south-west and are usually labelled Colorado lows or Texas lows. Increasing temperatures can enable these storms by warming the waters in the Gulf of Mexico or Pacific Ocean which increases evaporation allowing more moisture to escape into the atmosphere for northward transport. Such storms were contributors to the Muskoka floods in 2013 and 2019 (Table 20) and yielded a near-miss flood in 2023.

Table 20. Flood Events & Spring Heavy Rainfall in Muskoka for selected years 1985-2023: Rows, in bold, represent the year of Lake Muskoka flooding events. Rows, in italics, are flooding near-misses.

Year	Snow (SWE)	Heavy Rain >50 mm	More Rain >25 mm (1 week)	Flooding (Elevation)*
2023	*176 mm*	*66 mm*	*Yes, but 10 days later*	*Near Miss (225.95 m)*
2019	**187 mm**	**58 mm**	**Yes**	**Yes (226.45 m)**
2016	**82 mm**	**55 mm**	**Yes**	**Yes (226.04 m)**
2013	**134 mm**	**76 mm**	**Yes**	**Yes (226.25 m)**
2008	*194 mm*	*46 mm*	*No*	*Near Miss [225.93 m]*
2007	87 mm	57 mm	No	No [225.72 m]
1998	125 mm	57 mm	No	No
1985	**202 mm**	**59 mm**	**Yes**	**Yes**

** Flood elevation for Lake Muskoka is 225.97 m*

When a heavy snowpack, rapid melting and subsequent heavy rain combine, the total amount of water released in the watershed exceeds the capacity of the lakes and rivers to contain it. When this happens, water spills over the lake shorelines and riverbanks and submerges roads, structures, docks, and boathouses. Study of these past floods has helped identify these risk factors. The flooding risk looks like a decision tree (Figure 30).

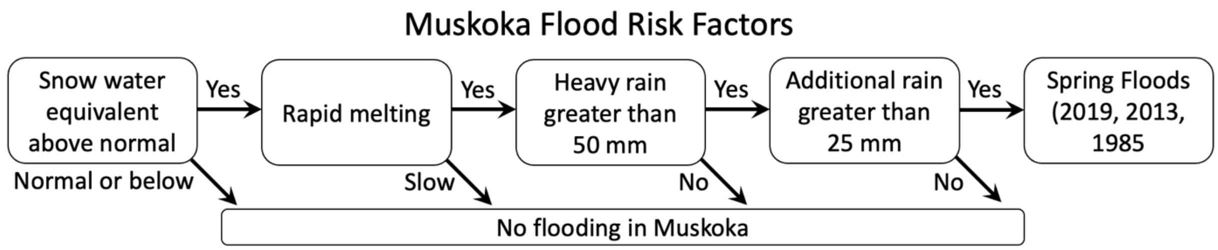

Figure 30. Muskoka flood risk factors showing the sequence of events and conditions that are required to produce flooding in Lake Muskoka.

In sequence, if there is enough snow, if it melts quickly, if heavy rain falls during the melt period, and if further significant rain also falls before the watershed drains then these components combine. If they result in 250 mm to 300 mm of water accumulation, then the watershed cannot contain this amount of water, nor can it release the water downstream fast enough due to physical constraints in the geography and we get flooding. On the other hand, if any of these factors are not present, or do not occur in close proximity in time, then flooding is avoided.

How much snow is a concern and how do we measure it? Typically snow cores are taken at several locations around the watershed by the Ontario Ministry of Natural Resources and Forestry and the amount of water in the melted core is recorded. This measure is called snow water equivalent. Past flooding records have shown that flooding becomes possible when there is 150 mm or more of snow water.

Next, the snow must melt rapidly to become a problem. Slow melting enables the melt water to be carried by our rivers and streams and delivered to Georgian Bay, so there is no problem. The Muskoka River Water Management Plan (Ontario Ministry of Natural Resources, 2006) tells us that dangerous melting occurs when two or more days have peak temperatures exceeding 10 ^{o}C.

The next step in the flood risk decision tree is heavy rain falling on the already melting snow. This both swells the volume of water and accelerates the speed of the melt. Past records show heavy rain as being more than 50 mm over a two-day period. Typically, Muskoka gets high rainfall when cross-continental storms, known as Colorado Lows or Texas Lows, transport “atmospheric rivers” of water from either the Pacific Ocean or the Gulf of Mexico. Environment Canada reports (Bush and Lemmon, 2019) that the frequency and intensity of such storms is increasing due to climate change (Figure 31).

This is already being experienced in Muskoka. The number of storms producing >51 mm rain in the 20-year period from 2000 to 2019 was double the number in the preceding 30 years (Table 21).

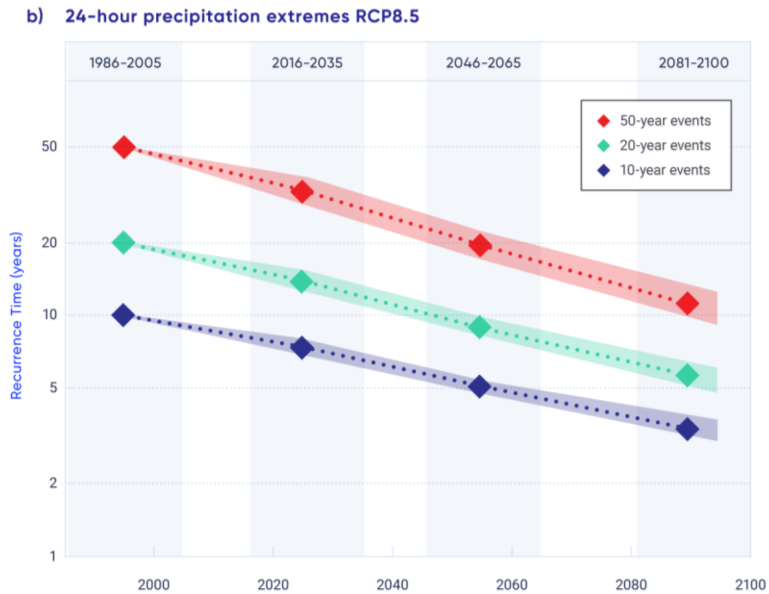

Figure 31. Predicted 24-hour precipitation extremes for a high warming future scenario. Recurrence time is the average amount of time between these extreme precipitation events. Reproduced from Bush and Lemmen (2019), figure 4.20.

Table 21. 20-year and 30-year storm frequency in Muskoka.

Time Period	# Spring Storms >51 mm	# Spring Storms >25 mm
2000 – 2019 (20 years)	6	31
1970 – 1999 (30 years)	3	30

In addition to strong storms, climate change is enabling persistent rainy weather by weakening the Jet Stream. This produces stuck or blocked weather patterns characterized by an Omega Wave shape jet Stream (Figure 32). The implication of these weather pattern changes is an increased risk of flooding during high snowfall years in Muskoka.

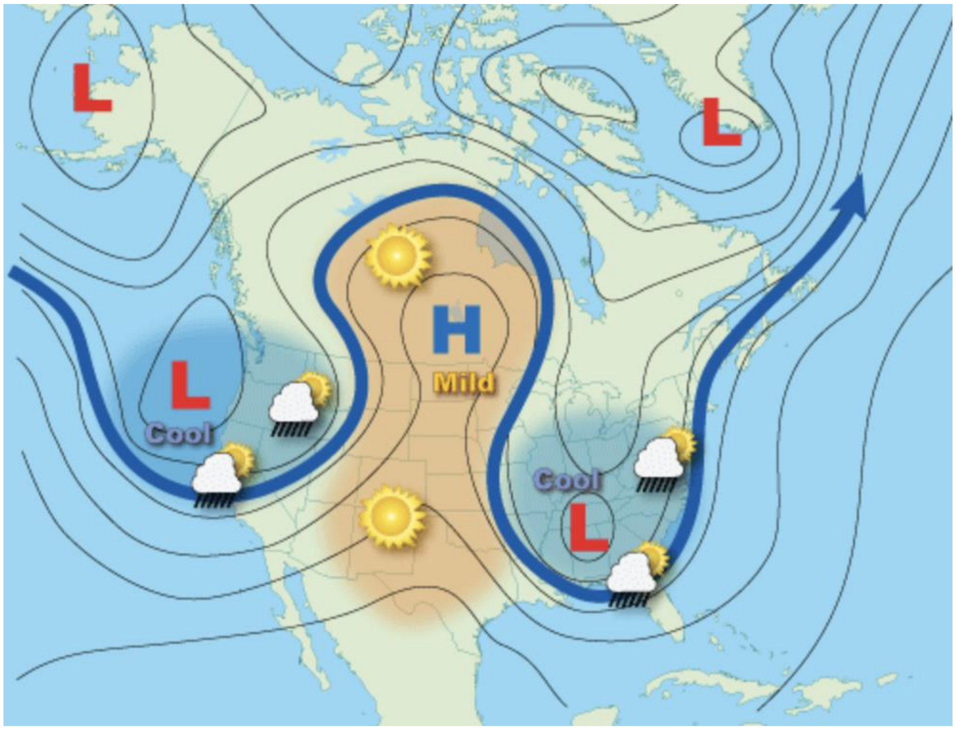

Figure 32. Blocked weather patterns leading to high rainfall or drought. https://www.noaa.gov/jetstream/upper-air-charts/basic-wave-patterns

Lastly in the decision tree, subsequent significant rainfall of 25 mm or more can add to the water volume vying for space within watercourses and lakes of the watershed. If this occurs within a week of the previous melt and storm then it adds to the water volume before the watershed has a chance to drain, exacerbating the situation.

What happened in 2023? For Lake Muskoka, the flood zone starts when water in the lake rises to an elevation of 225.97 m. Table 20 shows, for Lake Muskoka in 2023; snow water near 2019 levels, heavier rain than 2019, melting temperatures in the 20 °C range and a near-miss flooding event because the subsequent rain arrived more than one week later allowing some of the lake water to drain. Nevertheless, many shoreline properties built at lower levels were submerged. Additionally, ice out occurred early so there was no ice damage during high water.

These combined factors allow us to understand, identify and, in some cases prepare for, spring floods.

YOU, ME, AND CLIMATE CHANGE

HOW MIGHT CLIMATE CHANGE IMPACT OUR LIVES?

The more variable weather anticipated in the future will challenge winter road transport, and increase the risk of fire, flood, and drought (and, in turn, the cost of property insurance). Summer and fall drought will impact the tourism value of iconic streams and rivers and will also raise issues for homeowners dependent on wells for domestic water supply. The projected shift in seasonal pattern of precipitation toward the winter months and the expected increase in frequency of severe weather events will have major impacts on winter road maintenance, stormwater management, and the need for road salt application, which will increase the chloride which is now at harmful levels in many of our lakes and streams. Read Chapter 4 to better understand the impact of chloride on our environments.

Climate change is also likely to have some significant impacts on public health due to the new opportunities for insect- or tick-borne pathogens that, until now, have been unable to tolerate our climate.

WHAT CAN YOU DO?

Help mitigate climate change on a local scale by improving your own understanding of the Muskoka environment and how it will respond to a changing climate, and talk to others about this issue. You can also actively participate in local monitoring programs, seek to reduce your carbon footprint, and support local policies that include climate change adaption strategies. See Climate Action Muskoka (https://www.climateactionmuskoka.org) and the District of Muskoka Climate Action Plan (https://www.muskoka.on.ca/en/environment/muskoka-s-climate-action.aspx) for more guidance.

- **Local monitoring programs:** District of Muskoka's Biological Monitoring Program, Ontario's Lake Partner Program, NatureWatch, and other programs supported by your Lake Association or community. Make use of the available data from sources such as the Muskoka Water Web http://www.muskokawaterweb.ca.
- **Reduce your carbon footprint:** Be energy efficient by buying energy efficient vehicles, when possible, hang your laundry outside instead of using a dryer, install a programmable thermostat, and change your light bulbs to LEDs. Our food preferences can also impact our climate. Choose organic and locally grown foods, or better yet, grow some of your own food

when possible. Meat and dairy production are responsible for 18% of greenhouse gas emissions (Sale et al., 2016), so try a plant-based diet. Further, accumulating garbage in landfills produce methane, a potent greenhouse gas, which can easily be reduced by composting and recycling as much as possible.

- **Advocate for change:** Write to your area politicians at all levels of government and demand action to address climate change issues.