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Projected Extreme Weather due to Climate Change for Wawa and Goderich

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Executive Summary

This study is but one component of a larger 3-year project, funded by the Ministry of Agriculture, Food and Rural Affairs and Wilfrid Laurier University, whose goal was to assess the current emergency management planning and preparedness capacities of rural Ontario municipalities to climate change-related threats across key critical infrastructure sectors.

During this project, two communities, Goderich and Wawa, Ontario, participated as case studies. This report focuses on providing these two communities with projections of the likely impacts of climate change and associated extreme weather for their locations. In addition, the approach used in this study was specifically developed to be transferable so that other communities could generate their own future climate projections to make relevant decisions on climate adaptation and mitigation. To that end, the details of the elements required (Table 2.1) and methods used to develop this report are presented as an appendix and associated series of videos (Appendix 1). A Climate Modelling Primer is also provided in this document for those who would like to learn more about Global Circulation Models (GCM), the impact of greenhouse gases in our atmosphere, information about Representative Concentration Pathways (RCPs) and the downscaling of GCM data to local scales (Box 1).

Regions and places throughout Canada are already experiencing changes in climatic conditions such as higher mean temperatures, altered precipitation patterns, and an increase in the frequency and intensity of extreme weather events. Previous regional studies report that in Ontario, climate change will likely cause a wide range impacts on temperatures, precipitation, and storms. The summers in the future are expected to experience an increase in the frequency and intensity of severe storms with heavy rain and strong winds. These types of storms will likely result in an increase in flash flooding, hail events, and wind damage. The number of extremely hot summer days is expected to surge which will intensify energy use, and potentially result in an increase of wildfires and smog days. In the winters, the regional studies report warming temperatures and an increase in the number of frost free days which could extend the

planting season and reduce heating costs. However, warmer winter temperatures can also result in more frequent freeze-thaw periods and the associated damage to roads and masonry. Winter precipitation is also expected to decrease but with warmer temperatures, freezing-rain events and intense winter storms are projected to increase. It's important to note that these general regional scale projections may not reflect the effects of climate change at a local scale because climatic patterns are not uniform but vary greatly depending on location and so too do the modelled GCM projections.

Municipalities must respond to the vulnerabilities and the risks associated with the current climate patterns and changing conditions along with the extreme weather events unique to their location. Changes in climatic patterns can result in a variety of impacts on local communities because infrastructure, homes and other buildings were built based on an understanding of past climatic conditions to withstand the expected extremes of the past. Our best option to anticipate and plan for future extreme events and protect critical infrastructure and reduce property damage, anticipate increased health risks and limit economic losses due to things like infrastructure repair, agricultural damage, and emergency services are the projections of GCM models.

For both Wawa and Goderich, projections of seasonal temperatures and precipitation have been completed for 4 climate periods: 1960-1990 (baseline); 2011- 2040 (current); 2041-2070 (mid-century); and 2071- 2100 (turn-of-the-century). The projected differences in temperatures and precipitation are assessed by how much they deviate from the baseline climate period (1960 -1990). For each of these climate periods, two different future greenhouse gas (GHG) emissions scenarios or RCPs are presented. The scenarios used in this study are RCP 8.5 which represents our current trajectory as a global society of “business as usual” economic growth without reducing GHG emissions and RCP 4.5 which is an optimistic scenario where global GHG emissions increase slowly and peak at 2040 after which they decrease dramatically. A switch to the RCP 4.5 would require international cooperation in aggressively reducing GHG emissions and a substantial commitment to technological, social and economic reforms and transformations.

This study reports seasonal change projections of extreme climate indices with the one exception of annual mean temperatures. Mean temperatures indirectly measure extremes because when averaged over a 30-year period it takes a significant number of days with temperatures far from normal to pull the mean up or down. Annual mean temperatures are a useful metric for general temperature trends and for comparison with regional and global scale projections. The tables below summarize how temperatures and precipitation are expected to change for both Goderich and Wawa and when we expect these changes to occur.

Temperature Indices and Outcomes	**Goderich Projections Changes from Baseline**	**Wawa Projections Changes from Baseline**
Mean Annual Temperatures •both are expected to see an increase of 2°C as early as this climate period and a continual warming trend to as much as +6°C for Goderich and +7°C for Wawa in the late century •little difference between the increases for both locations	+2°C current +3°C to +4°C mid-century +4°C to +6°C turn-of-the-century	+2°C current +3°C to +4°C mid-century +4°C to +7°C turn-of-the-century
Mean Seasonal Temperatures • all seasons will be hotter for both locations •little difference in the warming increases expected for both locations in spring, summer, and fall •Wawa's winters warm more by mid-century to late century than Goderich's	Fall +1.7°C to +1.9°C current +2.7°C to +3.6°C mid-century +3.5°C to +5.7°C turn-of-the-century Winter +2.2°C to +2.8°C current +3.6°C to +4.4°C mid-century +4.3°C to +6.8°C turn-of-the-century Spring +1.6°C to +2.1°C current +2.7°C to +3.4°C mid-century +3.3°C to +5.3°C turn-of-the-century Summer +1.6°C current +2.7°C to +3.7°C mid-century +3.4°C to +6.2°C turn-of-the-century	Fall +1.8°C to +2.0°C current +3.0°C to +3.7°C mid-century +3.6°C to +6.0°C turn-of-the-century Winter +2.4°C to +2.6°C current +3.6°C to +5.0°C mid-century +5.1°C to +8.1°C turn-of-the-century Spring +1.5°C to +1.6°C current +2.9°C to +3.3°C mid-century +3.5°C to +5.8°C turn-of-the-century Summer +1.6°C to +1.8°C current +2.8°C to +3.6°C mid-century +3.3°C to +6.0°C turn-of-the-century

Temperature Indices and Outcomes	Goderich Projections Changes from Baseline	Wawa Projections Changes from Baseline
Extreme Heat Days (maximum temperatures >30°C) - Goderich to experience considerably more than Wawa	Summer (percent change) +15% to 17% current +26% to 35% mid-century +30% to 52% turn-of-the-century	Summer (percent change) +4% to 5% current +9% to 14% mid-century +11% to 34% turn-of-the-century
Tropical Nights (minimum temperatures >20°C) - Goderich to experience considerably more than Wawa - Goderich to experience more frequent heat waves - Wawa likely to experience heat waves by end of century	Summer (percent change) +11% to +13% current +20% to +29% mid-century +26% to +48% turn-of-the-century	Summer (percent change) +2% current +4% to +8% mid-century +5% to +20% turn-of-the-century
Frost Free Winter Days (minimum temperatures >0°C) - both to experience a doubling or more as early as this climate period - by the mid-century to late century a tripling, quadrupling or more expected for both locations - Goderich to experience considerably more than Wawa but Wawa has a greater increase above their baseline	Winter (percent change) +99% to +111% current +183% to +243% mid-century +232% to +399% turn-of-the-century	Winter (percent change) +149% to +170% current +304% to +362% mid-century +337% to +813% turn-of-the-century
Extremely Cold Winter Nights (minimum temperatures: Goderich >-14°C; Wawa >-27.4°C) - Goderich's calculated extreme cold threshold is about half of Wawa's calculated threshold - both locations experience a decrease to about half as many days as early as this climate period - by the mid-century to late century a further decline of ¾ or more in the number of days are expected for both locations -Goderich is projected to experience a few less extremely cold days than Wawa is in all climate periods	Winter (percent change) -52% to -57%current -76% to -84% mid-century -77% to -95% turn-of-the-century	Winter (percent change) -43% to -46% current -69% to -77% mid-century -77% to -93% turn-of-the-century

Note: Percent change = (projection value – baseline value) / baseline value ×100

Precipitation Indices and Outcomes	Goderich Projections Changes from Baseline	Wawa Projections Changes from Baseline

Precipitation Indices and Outcomes	Goderich Projections Changes from Baseline	Wawa Projections Changes from Baseline
Extremely Heavy Precipitation Days (above highest threshold values) - overall biggest increases are in the winter and spring for both locations -the number of winter days for Wawa are expected to double as early as this climate period - warmer winter seasons means storms could be freezing-rain or rain storms instead of snow storms for both locations -summer is the only season with decreases for both locations	Fall (percent change) +2% to +14% current +12% to +19% mid-century +12% to +17% turn-of-the-century Winter (percent change) +16% to +42% current +53% to +74% mid-century +42% to +89% turn-of-the-century Spring (percent change) +32% to +42% current +68% to +71% mid-century +65% to +84% turn-of-the-century Summer (percent change) -11% current +13% to +22% mid-century -7% to +2% turn-of-the-century	Fall (percent change) +23% to +26% current +30% to +39% mid-century +33% to +38% turn-of-the-century Winter (percent change) +91% to +109% current +109% to +118% mid-century +100% to +200% turn-of-the-century Spring (percent change) +38% to +40% current +33% to +63% mid-century +43% to +85% turn-of-the-century Summer (percent change) -11% to -13% current -13% to -21% mid-century -9% to -11% turn-of-the-century
Dry spell maximum length (number of consecutive days without precipitation) - overall this climate index doesn't conform to much of a pattern and the - the potential change in the number of consecutive dry days is within the narrow range of 5 fewer or 6 more days added to their baseline dry spells	Winter (difference) +5 to -2 current +5 to -4 mid-century +2 to +4 turn-of-the-century Spring (difference) +5 to +5 current +5 to +6 mid-century +2 to 0 turn-of-the-century Summer (difference) 0 to -2 current +2 to +3 mid-century +3 to 0 turn-of-the-century Fall (difference) -2 to -3 current -4 mid-century +1 to 0 turn-of-the-century	Winter (difference) 0 to +1 current +3 to +1 mid-century +2 to +3 turn-of-the-century Spring (difference) +3 to +4 current -2 to -3 mid-century -1 to +1 turn-of-the-century Summer (difference) 0 to +1 current +2 mid-century +3 turn-of-the-century Fall (difference) +1 to +2 current -3 to -3 mid-century -2 to -3 turn-of-the-century

Precipitation Indices and Outcomes	Goderich Projections Changes from Baseline	Wawa Projections Changes from Baseline
Frequency of dry spell periods (5-day dry periods) - overall this climate index doesn't conform to much of a pattern - the spring, summers and falls of the current period for both locations should experience fewer 5-day dry spells - Wawa's mid-century spring projections are for many fewer 5-day dry spells - both communities will likely experience fewer summer 5-day dry spells and by the end of the century many fewer - Goderich's fall will experience a few more but Wawa will experience a few less 5-day dry spells	Winter (difference) -6 to -5 current -5 mid-century +3 turn-of-the-century Spring (difference) -4 current 0 to -2 mid-century -2 to -3 turn-of-the-century Summer (difference) -1 to -12 current -3 to +1 mid-century -14 to -22 turn-of-the-century Fall (difference) +1 to +2 current +2 to +4 mid-century +2 to +1 turn-of-the-century	Winter (difference) -7 to -5 current 0 to +2 mid-century -7 to +5 turn-of-the-century Spring (difference) +1 current -14 to -18 mid-century -8 turn-of-the-century Summer (difference) -5 to -4 current -3 to -2 mid-century +1 to -15 turn-of-the-century Fall (difference) -6 to 4 current +1 mid-century -8 to -5 turn-of-the-century

Projections of future temperature indices produced by using RCP 4.5 input data often level off at the mid-century and may even decline a bit by the turn-of-the-century, while the same indices produced by using the RCP 8.5 data don't level off but continue along their trajectory. These temperature patterns reflect the influence of each RCP, for example under the 4.5 pathway greenhouse gases peak around 2040 and then drastically decline towards the turn-of-the-century. Hence, the levelling off at the mid-century and beyond of climate indices computed with RCP 4.5 input. The RCP 8.5 represents the pathway we as a global society are currently on with the highest GHG emissions and instead of levelling off the temperatures continue to warm. These patterns are not as clear in the precipitation indices because the influence of GHGs on precipitation is less well understood and each GCM utilizes different algorithms.

Finally, there are several extreme weather events like tornados (e.g. Goderich 2011), bitter cold outbreaks due the polar vortex dipping into the mid-latitudes (e.g. Northern Hemisphere, Winter of 2015), and the stalling of severe weather systems (e.g. Hurricane Harry

2017). Scientists are investigating these phenomena and future climate models will likely incorporate the drivers for these events once there is a better understanding. So, for now we can make general qualitative projections based on our knowledge of basic meteorological and climatological relationships. For example, more wind gust events are expected in Southern Ontario by the end of the century, as both large-scale frontal storms and local convective windstorms are projected to occur more frequently. The warming of the Arctic may destabilize the barrier confines the polar vortex to the upper latitudes allowing more frequent extreme cold outbreaks.

Despite the limitations of the current GCM projections, the analysis presented in this report clearly indicates that Ontario's rural communities are expected to face increasing challenges from the impacts of climate change on critical infrastructure over the next century and that the exposure to weather extremes will vary by location. In addition, other components of the larger project have exposed the ways in which the adaptive capacity within rural communities also varies across the province. Given these dual contexts, to develop climate resilience, rural communities will need climate change projections tailored to their local area to inform local risk mitigation and climate change adaptation initiatives. Ultimately, to be successful, these communities will also require significant political, financial and personnel support from higher levels of government.

1.0 Introduction

The goal of this three-year project, funded by the Ministry of Agriculture, Food and Rural Affairs and Wilfrid Laurier University, was to assess the current emergency management planning and preparedness capacities of rural Ontario municipalities to climate change-related threats across key critical infrastructure sectors. 335 (75%) of all municipalities in Ontario are either rural or partially rural. As is argued in the policy brief developed for this project, in Ontario, despite notable strengths, the challenges confronting rural communities require differentiated and specific support to be able to address their distinct vulnerabilities and resiliencies to actively cope with climate change impacts, including the effects of extreme events on critical infrastructure. Part of that support involves access to information about climate change impacts for their locale to facilitate evidence-based adaptation planning and decision-making.

During this project, two municipalities, Goderich and Wawa, Ontario, participated as case studies. This report focuses on providing these two communities with projections of the likely impacts of climate change and associated extreme weather for their locations. In addition, the approach used in this study was specifically developed to be transferable so that other communities could generate their own future climate projections to make relevant decisions on climate adaptation and mitigation. To that end, the details of methods used to develop this report are presented as an appendix and associated series of videos (Appendix 1).

2016 was the third year in a row where average global temperatures exceeded the 20th century mean and set a new record and 16 of the warmest 17 years on record occurred between 2001-2016 (Faust, Climate facts 2016, 2017). The Intergovernmental Panel on Climate Change (IPCC) Fifth Report (AR5) on the Physical Science Basis states that “it is virtually certain that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales…very likely that heat waves will occur with a higher frequency and duration” (IPCC, 2013, p. 20). Extreme precipitation events over the mid-latitudes will very likely become more frequent and intense by the end of this century as global mean temperatures increase (IPCC, 2013).

Regions and places throughout Canada are already experiencing changes in climatic conditions such as higher average temperatures, altered precipitation patterns, and an increase in the frequency and intensity of extreme weather events. In Ontario, climate change will likely cause a wide range of impacts. In summers, Ontario’s mean temperatures are expected to increase by 3.3°C to 4.9 °C by the mid-century and 3.3°C to 8.5°C by the turn-of-the-century

(McDermid, Fera, & Hogg, 2015). But the extent of warming will not be uniform across the province and the greatest warming is expected to occur in the far north of the Hudson Bay basin where temperatures for the same period will rise 10°C while those in the Great Lakes Basin are expected to rise by 1.5°C to 7°C (McDermid, Fera, & Hogg, 2015). An associated increase in the number of extremely hot days will likely result in an increased draw of power to cool homes and work places. Hotter summers may also result in an increase in wildfires like those experienced by Fort McMurray in 2016 and the British Columbia interior in 2017 if these high temperatures coincide with low precipitation or dry spells. Warmer summer temperatures can also fuel intense storms with associated heavy rainfall, strong winds, hail and an increase in flash flooding. The McDermid et al. (2015) study projected drier summers in Ontario's North-West and the Great Lakes Basin by the-turn-of-the-century. Winter warming is expected to exceed summer warming throughout the province (McDermid, Fera, & Hogg, 2015). In the winters, there's an expected increase in mean temperatures and frost-free days which could extend the planting season and reduce heating costs. Freezing rain and intense winter storms are projected to increase (Bruce, 2011) and winter precipitation, in general, is expected to increase with as much as 158 mm above historical levels in the Great Lakes Basin (McDermid, Fera, & Hogg, 2015).

Part of the reason there are differing projections in the magnitude of climatic changes is because the effects of a warming planet are not uniform but vary greatly depending on location. Local characteristics like latitude, proximity to water bodies, elevation and other bio-physical factors all influence local climatic conditions. Since climate change impacts are local and context specific, the role and capacities of municipal governments is considered crucial to successful adaptation efforts. Local governments are well positioned to undertake strategic climate change adaptation planning, including emergency management, because they have the mandated responsibility to ensure the safety and welfare of their communities. Local governments, with adequate support from higher levels of government, can tailor adaptation approaches to address local circumstances and impacts so anticipatory, proactive planning can capitalize on these existing strengths, to create new opportunities and reduce vulnerabilities. Climate change adaptation encompasses adjustments in practices, processes or structures in response to projected or actual climate and extreme weather events. It requires the capacity to act, despite uncertainty and limited knowledge.

One thing to keep in mind is that in this report we are talking about climate. Climate differs from weather in that we're looking at the long-term averages of the day-to-day weather. Climates fluctuate over years, for example some summers are warmer or drier than others. A 30-year average is the standard time period used to smooth out these fluctuations (World Meteorlogical Organization, 2017). These averages form a reference point or baseline to use for comparison with current weather or climate. As the World Meteorlogical Organization (2017) says on their website these baseline climate averages can be used to answer questions like, "Are we having a hotter month, season or year than average?" The climate of a location is determined by looking at 30-year temperature and precipitation long-term trends in the weather data. See the Climate Modelling Primer for details about Global Circulation Models, the impact of greenhouse gases, the information about GCM scenarios called Representative Concentration Pathways and the downscaling of GCM data to local scales (Box 1). Section 2.0 presents a summary of the methods. To help other communities develop similar projections for their locations, a detailed description of the methods used and a link to the videos is provided as Appendix 1. The extreme weather results are outlined in Section 3.0 and the complete set of results are provided in Appendix 2. Section 4.0 provides a summary of the extreme climate projections for both locations.

BOX1: CLIMATE MODELLING PRIMER

Climate models or Global Circulation Models (GCMs) use mathematical equations and algorithms to simulate the flow and interactions between energy and different characteristics of the climate system including, GHGs, aerosols and many other components of the atmosphere the ocean and the land. Spatially these models divide the earth into thousands of three-dimensional boxes. These grid boxes have a horizontal scale between 250 and 600 km, 10 to 20 vertical atmospheric layers and up to 30 oceanic layers (IPCC, 2013).

Even though these GCMs are quite complex and have improved over time, models by necessity are simplifications of reality. Numerous GCMs have been independently developed and each of them may simulate various feedback mechanisms and physical relationships differently. For this reason, each GCM may simulate the same processes and feedbacks between climate components yet produce quite different responses and output (IPCC, 2013). Therefore, instead of using a single GCM several of the independently developed models are used in combination to produce the best results. By doing this it minimizes any errors that may exist within a single model and improves the confidence in the projected outputs simulating future climate.

Greenhouse Gases and Representative Concentration Pathway Scenarios

The role of greenhouse gases (GHGs) in a warming atmospheric environment is sometimes misunderstood. Some of this misunderstanding likely comes from the term 'greenhouse'. In a real greenhouse, the sun's energy enters inside very quickly since the very intense short-wave radiation easily penetrates through the glass. This energy is then absorbed and warms the surfaces it contacts within the greenhouse. These heated surfaces slowly radiate back long-wave radiation that gets trapped because the longer waves can't pass through the windows as easily (think about how hot the inside of your car gets when it's parked outside on a sunny day with all the windows and doors closed). GHGs in our atmosphere, like carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and water vapour (H_2O) don't actually trap long-wave radiation like the glass of a greenhouse but they are excellent absorbers of this type of energy. Long-wave radiation emitted from an earth's surface that was warmed by the absorption of solar energy travels through our atmosphere towards outer space. But if it encounters a GHG molecule along the way it is absorbed, heats up the molecule and is re-emitted in all directions radiating outward. Some of this re-emitted energy continues its journey into outer space while the rest is reabsorbed by other GHGs (think about the difference between night time temperatures when the sky is clear vs nights when the sky is overcast. Cloudy nights are warmer because the long-wave energy radiated from the earth's surface is absorbed by the water vapour that make-up the clouds and is re-radiated allowing only some of that energy to continue its journey to outer space. On clear nights that long-wave energy continues its journey without being interrupted and the atmosphere cools more rapidly.) So GHGs don't trap heat but instead intercept some of the energy that would have been lost to outer space, and having those gases in our atmosphere has allowed our planet to avoid the extreme temperature fluctuations experienced by other planets and our moon. However, humans have changed the atmosphere's chemistry by pumping more GHGs molecules into the atmosphere and making it a more efficient at warming the planet.

As long as human activities and the burning of fossil fuels continue to emit GHGs like CO_2 it continues to build up in the atmosphere. In order to estimate how the increase in GHGs in our atmosphere will affect future temperature and precipitation patterns, 'scenarios' have been developed. These scenarios are the input data sets for the GCMs. In 2000, the IPCC released the Special Report on Emissions Scenarios (SRES) describing greenhouse gas emission scenarios. These scenarios were used in the Third Assessment Report (TAR, 2001) and Fourth Assessment Report (AR4, 2007) IPCC reports. The SRES were designed to improve upon the previous scenario set which, although ground-breaking in 1992 when published by 1994, when reviewed were found to be missing several parameters which had become recognized as being important factors for future GHGs emissions. For example, incorporating current and future measures that would curb greenhouse gas emissions (e.g. commitments made in connection with UNFCCC, 1997), or incorporate rates of technological change and the potential of a narrowing in the economic gap between industrialized and developing countries (IPCC, 2000). In response to the needs of policy makers and a growing interest in risk management a new set of scenarios that allowed exploration of different reduction and increases in emission rates or approaches to achieving climate targets (like limiting change to +2°C) was needed for the Fifth IPCC report (AR5). These new scenarios also had to meet the input requirements necessitated by the scientific advances made in GCMs (Bjørnæs, 2015).

The GCM scenarios currently in use are called the Representative Concentration Pathways (RCPs). "RCPs are referred to as pathways in order to emphasize that their primary purpose is to provide time-dependent projections of atmospheric greenhouse gas (GHG) concentrations." (Richard Moss, 2008, p. 5). Not only are they time dependent but they are space dependent as well including changes in land use and the resultant changes in GHG emissions. Bjørnæs (2015) in his guide to Represnetative Concentration Pathways describes the 4 scenarios as follows:

RCP 8.5 – High emissions

This RCP is consistent with a future with no policy changes to reduce emissions. It was developed by the International Institute for Applied System Analysis in Austria and is characterized by increasing greenhouse gas emissions that lead to high greenhouse gas concentrations over time. Comparable SRES scenario: A1 F1.
This future is consistent with:
-Three times today's CO2 emissions by 2100
-Rapid increase in methane emissions
-Increased use of croplands and grassland which is driven by an increase in population
-A world population of 12 billion by 2100
-Lower rate of technology development
-Heavy reliance on fossil fuels
-High energy intensity
-No implementation of climate policies

RCP 6.0 – Intermediate emmissions

This RCP is developed by the National Institute for Environmental Studies in Japan. Radiative forcing is stabilized shortly after year 2100, which is consistent with the application of a range of technologies and strategies for reducing greenhouse gas emissions.
Comparable SRES scenario: B2
This future is consistent with:
-Heavy reliance on fossil fuels
-Intermediate energy intensity
-Increasing use of croplands and declining use of grasslands-
-Stable methane emissions
-CO_2 emissions peak in 2060 at 75 per cent above today's levels, then decline to 25 per cent above today

RCP 4.5 – Intermediate emissions

This RCP is developed by the Pacific Northwest National Laboratory in the US. Here radiative forcing is stabilized shortly after year 2100, consistent with a future with relatively ambitious emissions reductions. Comparable SRES scenario: B1

This future is consistent with:

-*Lower energy intensity*
-*Strong reforestation programmes*
-*Decreasing use of croplands and grasslands due to yield increases and dietary changes*
-*Stringent climate policies*
-*Stable methane emissions*
-*CO_2 emissions increase only slightly before decline commences around 2040*

RCP 2.6 – Low emissions

This RCP is developed by PBL Netherlands Environmental Assessment Agency. Here radiative forcing reaches 3.1 W/m2 before it returns to 2.6 W/m2 by 2100. In order to reach such forcing levels, ambitious greenhouse gas emissions reductions would be required over time. Comparable SRES scenario: None

This future would require:

-*Declining use of oil*
-*Low energy intensity*
-*A world population of 9 billion by year 2100*
-*Use of croplands increase due to bio-energy production*
-*More intensive animal husbandry*
-*Methane emissions reduced by 40 per cent*
-*CO_2 emissions stay at today's level until 2020, then decline and become negative in 2100*
-*CO_2 concentrations peak around 2050, followed by a modest decline to around 400 ppm by 2100*

Downscaling – From the Global Scale down to the Local Scale

Global Circulation Model (GCM) projections are produced at a course spatial resolution and are unable to accurately resolve sub-grid features. As a result, GCM output can not be used for local impact studies without being downscaled. Downscaling is the procedure used to accurately reduce the grid size and obtain local-scale weather and climate data from global-scale GCM output grid boxes. There are two main approaches used to downscale GCM data, dynamical and statistical. The dynamical approach takes the GCM climate output and reruns these data in climate models at a higher spatial resolution to produce local conditions in greater detail. The dynamical approach is computationally expensive. The other approach uses statistical relationships between local variables like surface air temperature and precipitation and large-scale variables like air pressure fields and then uses those relationships to simulate future climate by applying them to GCM output. This approach is often preferred because it is less computationally expensive and therefore easier to implement.

2.0 Summary of Methodology

The approach used in this study was specifically developed to be transferable so that other communities can potentially generate their own future climate projections to make relevant decisions on climate adaptation and mitigation. To this end the data sets used, the climate parameters modelled and the set of emission scenarios were decided upon as follows. Note this is a brief outline, and Table 2.1 summaries the elements of modelling extreme climate projections for full details please see Appendix 1 where you will also find the links to some instructional videos. To assess the capacity to undertake such an assessment, the parameters and procedures in Table 2.1 and Appendix 1 should be kept in mind.

Table 2.1. Elements for Modelling Extreme Climate Projections at a Local Scale

Input GCM Data (see Section 2.1)	• Downscaled daily precipitation(pr), minimum (tasmin) and maximum (tasmax) temperatures (e.g. Pacific Climate Impacts Consortium, historical and future climate data from 12 GCMs)
Scenarios (see section 2.2)	• RCP 4.5 intermediate GHGs emissions • RCP 8.5 high GHGs emissions
Climate Periods (see section 2.3)	• 1970s or baseline (1960-1990) • 2020s or current (2011-2040) • 2050s or mid-century (2041-2070) • 2080s or turn-of-the-century (2071-2100)
Computer capacity software and personnel (section 2.4)	• High speed internet connection with capacity to download large files (e.g. Wawa: 1 GCM; RCP 8.5; pr + tasmin + tasmax; 1960 to 2100 =6.20 *mb*. Therefore, 12 GCMs and 2 RCPs = 149 *mb* for a single point, if using area data then multiply this by every additional data cell your coverage) • Computers with hard drive capacity to handle, store and back up multiple files of the same size as the downloaded GCM data (all climate indices calculated will be of the same size as your input files or larger depending on the operators used to determine each index) • Software to interpret and calculate climate indices for NetCDF machine language files (e.g. Climate Data Operators (CDO)) • Software to work with climate indices output files (e.g. Excel for single point data or GIS (Geographic Information System) for point and area data sets • Personnel with an understanding of meteorology and climatology, comfort with basic command line coding, competence in quality checking, interpreting and verifying output, then graphing or mapping and interpreting results

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2.1 Climate Change Data Sets

The Pacific Climate Impacts Consortium (PCIC) provides downscaled daily climate data for all of Canada at a 10-km grid size. These data sets are based on the most recent GCM projections (the Fifth Assessment Report or AR5) and historically gridded climate data for Canada (Pacific Climate Impacts Consortium, 2014) and can be downloaded for free from their website. An ensemble of 12 climate models were downscaled by PCIC to provide for the widest spread in projected future climate conditions. All 12 GCMs12 were used in this study and are listed in Table 2.2.

Table 2.2. Global Circulation Models used in this Study

GCM Model Name	Institution
MPI-ESM-LR-r3	Max Planck Institute for Meteorology (MPI-M)
inmcm4-r1	Institute for Numerical Mathematics
CNRM-CM5-r1	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique
CSIRO-Mk3-6-0-r1	Commonwealth Scientific and Industrial Research Organisation in collaboration with the Queensland Climate Change Centre of Excellence
HadGEM2-ES-r1	Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)
CanESM2-r1	Canadian Centre for Climate Modelling and Analysis
MRI-CGCM3-r1	Meteorological Research Institute
CCSM4-r2	National Center for Atmospheric Research
MIROC5-r3	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
ACCESS1-0-r1	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia), and BOM (Bureau of Meteorology, Australia)
HadGEM2-CC-r1	Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)
GFDL-ESM2G-r1	NOAA/Geophysical Fluid Dynamics Laboratory, United States

For each of the 12 GCMs two different downscaling approaches were used, Bias-Correction Spatial Disaggregation (BCSD) and Bias Correction/Constructed Analogues with Quantile mapping (BCCAQ). The PCIC webpage provides detailed descriptions and multiple references and we direct you to their page for more information about their methodology (PCIC, 2014). For this study, the BCSD data sets were used because of previous experience with this data set.

Finally, the three climate parameters downscaled by the PCIC include maximum and minimum daily temperatures in Celsius and daily precipitation in millimeters.

2.2 Representative Concentration Pathways 4.5 and 8.5

The output data generated by two Representative Concentration Pathway (RCP) scenarios were used in this study. RCP 8.5 is the highest emission scenario. It was chosen because it is the path we as a planet are currently following and is often referred to as “business as usual” scenario. RCP 4.5 was chosen because we could still achieve the emission reductions and the social and technological changes needed to move toward this lower emission pathway. It was decided not to include the lowest emission scenario RCP 2.6 because 2016 was the first full year where the planet exceeded a milestone and atmospheric CO_2 concentrations stayed above 400ppm (parts per million is the ratio of the number of gas molecules to the total number of dry air molecules) (Jones, 2017). Not only did we surpass the 2100 target for CO_2 outlined in RCP 2.6 but the annual rate of increase between 2005-2014 was 2.1 ppm per year (Jones, 2017) and this trend has yet to slow down. Therefore, this report focuses on RCP 4.5 and 8.5 alone.

2.3 Climate Periods

The climate periods in this study are all 30-years in length which is the standard defined by the World Meteorological Organization. The IPCC Data Distribution Center recommends using a baseline data set over a 30-year period and to compare the future projected by the GCMs with these baseline data. Table 2.3 outlines the baseline and future climate periods used in this study. The baseline period of 1960-1990 was chosen in part because it was the standard used in the previous set of IPCC AR4 models so comparisons with previous studies could easily be done and because the PCIP data were calibrated with observed climate data that covers this period (1950-2005). The projection periods of this study (Table 2.3) were chosen to coincide with the IPCC standards including the 2020s, 2050s, and 2080s. Please take note of the naming conventions and abbreviations used to refer to the baseline and three projection climate periods.

You will find these abbreviations used interchangeably throughout the text in the graphs and tables of this report.

Table 2.3. Climate Time Periods

Climate Periods	Years Covered	Abbreviations Used in this Study
Baseline	1960 -1990	1970s
Current	2011-2040	2020s
Mid-century	2041-2070	2050s
Turn-of-the-century	2071-2100	2080s

2.4 Downloading and Preprocessing Data

The PCIC website allows you to select a single grid cell to download or use their rectangular selection tool to select a region of data and download all the grid cells with that region. For this study a single point (-81.70834, 43.70833) for Goderich and another single point for Wawa (-84.79167, 47.95833) were used to download the climate data from all 12 GCMs, of both RCPs 4.5 and 8.5 for the 4 climate periods used in this study.

GCM climate data sets are provided in a machine language format called NetCDF and therefore software tools are needed to work with these data. For this study, the Climate Data Operators (CDO) package developed by Uwe Schulzweida at the Max Planck Institute for Meteorology was chosen and downloaded (Climate Data Operators, 2017). This free software is a collection of simple format command line modules or operators that require little prior experience with coding or programing to use and is designed manipulate and analyze climate data sets. Two versions are available, one for a Unix system or alternatively, CDO can be used within Cygwin, a Linux-like environment for Windows (Cygwin, 2017). The CDO package contains a collection of more than 600 operators with at least 35 dedicated to computing indices of temperature and precipitation extremes (Climate indices with CDO, 2015).

Once the data sets had been downloaded for both RCP 4.5 and 8.5 a few more climate variables were created using CDO. The daily mean temperature was calculated by adding the maximum (tasmax) and minimum (tasmin) temperatures for that day and dividing by two, creating tasmean. A subset of the precipitation data sets containing only those days with precipitation (pr) was greater than 1 mm was also created. To do so all pr values between 0 and 1mm were assigned a missing value, so CDO modules would ignore them in statistical computations. Finally, all the climate data sets were subdivided by season. The extreme climate indices produced from these data sets using the CDO modules are summarized in Table 2.4.

Table 2.4. The Extreme Climate Indices

Climate Data Input	Extreme Climate Indices
Temperature	Mean temperatures (annually and seasonally)
	Number of days with: Extreme Heat (>30°C) Tropical Nights (>20°C) Frost Free (>0°C) Extreme Cold (below the 10th percentile of baseline minimum temperatures)
Precipitation	Number of days with Heavy Precipitation (>20mm) and (> the 95th percentile of baseline precipitation)
	Dry Spells (maximum number of consecutive dry days) and (number of 5-day dry periods)

3.0 Localized climate Projections for Wawa and Goderich

In this section, the results for the localized climate projections for both Goderich and Wawa (Figure 3.1) are presented by climate extreme indices. Climate change is assessed by comparing the future projected temperatures and precipitation with the baseline data set. For each extreme weather index, a brief description will be given of how it was derived, the calculated output will be reported comparing the baseline values with those projected by the GCMs accompanied by a table or graph and some context for the implications of the projected results will be given. Although projections are reported up to 2100 there will be future improvements and adjustments made to the climate modelling techniques, and changes in technology or policies that may reduce emission rates or sequester GHGs. However, even if all emissions were to be suddenly stopped today the amount of GHGs currently in our atmosphere will be there for a long time and up until the mid-century at least will be influencing our climate (Wagstaffe, 2017).

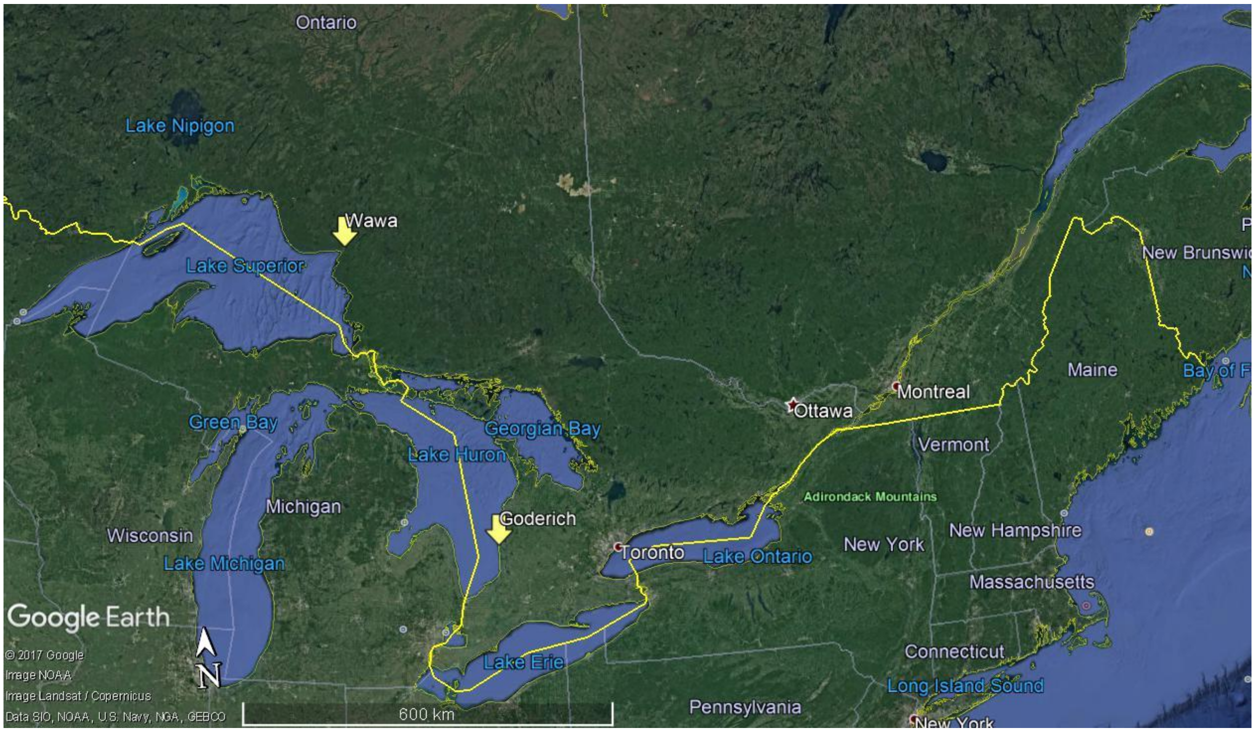


Figure 3.1. Map Showing the Locations of Goderich and Wawa, Ontario. Source Google Earth

3.1 Mean Temperature

Mean temperatures are calculated by taking the average of the minimum and maximum daily temperatures. Taking the average of all the mean daily temperatures for a year results in the annual mean temperature and when you average 30-years of annual mean temperatures the result is the annual climate mean temperature. Although the climate mean temperature value has little pragmatic use, its calculation dampens the day-to-day and year-to-year variability to produce a climatic trend. The change in mean temperature is commonly used to estimate the impact of climate change on temperature and can be used to relate global mean warming projections reported by the IPCC reports with those projected at the local scale (Interdisciplinary Centre on Climate Change, 2015). Table 3.1 shows the increase in mean annual temperatures for Goderich from their 7°C baseline value. By the 2050s their mean temperature is projected to increase by 3°C to 4°C and, at the end of the century, by 4°C to 6°C, which are within the range of projections for Ontario (McDermid, Fera, & Hogg, 2015). For example, these projections suggest that by the 2080s the mean annual temperature in Goderich could be as high as 13°C, an increase of 6°C from the 1960-1990 baseline mean temperature (7°C baseline + 6°C warming =13°C).

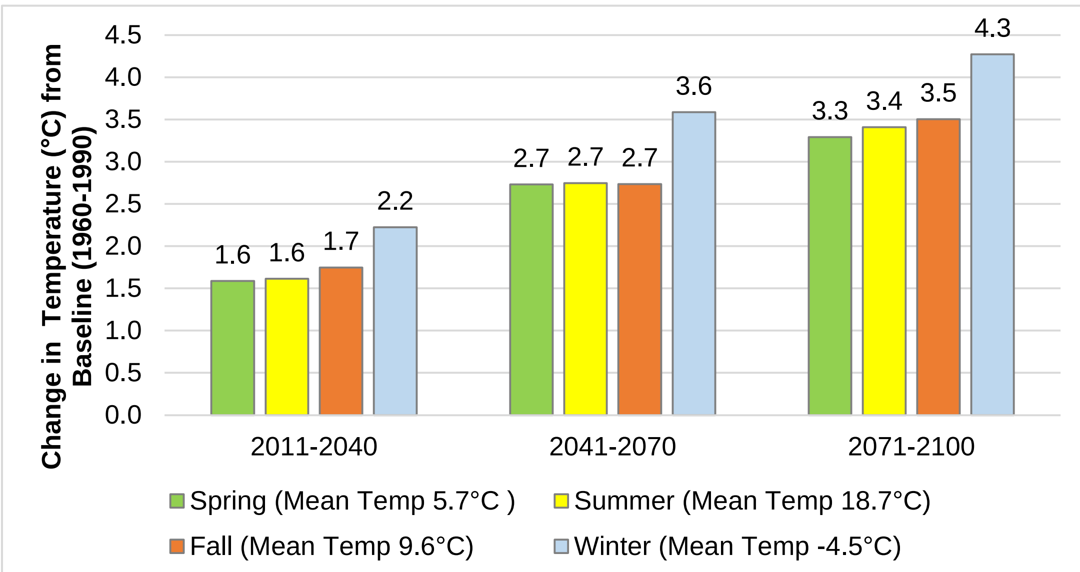
The RCP 4.5 mean annual temperature projections for Goderich are 1°C lower than those projected for the whole Lake Huron Basin by the 2050s and the 2080s and the RCP 8.5 projected mean annual temperatures are 2°C lower (McDermid, Fera, & Hogg, 2015). These discrepancies are an example of the difference between generalized projections for large areas and those projected for a local scale. The whole Lake Huron Basin used by McDermid et al. (2015) to delineate a region of Ontario includes a much wider variation in mean annual temperatures than Goderich because it includes inland cities and towns far removed from the moderating effect of the lake on temperatures.

Table 3.1. The Difference in Goderich's Mean Temperatures from its 7°C baseline (1960-1990) for Future Climate Periods

	2020s (2011-2040)	2050s (2041-2070)	2080s (2071-2100)
RCP 4.5	+2°C	+3°C	+4°C
RCP 8.5	+2°C	+4°C	+6°C

Annual mean temperatures are useful when projecting a general trend but the seasonal mean temperatures provide information more relevant for planning. Figures 3.2 and 3.3 show the seasonal changes in Goderich's mean temperatures for both RCP 4.5 and 8.5. These two charts show that the winter season has warmed more than the rest of the seasons. In the RCP 4.5 scenario (Figure 3.2) the winter mean temperatures increase by 3.6°C bringing the mean temperature from the baseline's spring temperature of -4.5°C up to -1.0°C by 2050s and by 2080s the projected increase of 4.3°C brings the mean winter temperature up to -0.3°C. In Figure 3.3 we see that the RCP 8.5 projects an increase in mean winter temperatures of 4.4°C by 2050s which brings the mean up to -0.2°C and a 6.8°C increase is projected by the 2080s climate period bringing the mean up above freezing to 2.3°C. These increases in mean temperatures so close to freezing indicate that winters will not only be warmer but likely there will be many days above freezing by the mid-century and even more by the turn-of-the-century. This has implications for things like road maintenance and repair due to an increase in freeze-thaw cycles (see section 3.5).

Summer mean temperatures are also warming for both RCPs, 2.7°C to 3.4°C for RCP 4.5 and 2.7°C to 3.5°C for RCP 8.5 (Figures 3.2 and 3.3). These higher temperatures will likely result in higher power demands for air conditioning (see sections 3.2 and 3.3). The warmer spring and fall temperatures may extend the future growing seasons beyond what it was in the



1960-1990 period.

Figure 3.2. Increases in Goderich's Seasonal Mean Temperatures (shown in the legend) projected by RCP 4.5.

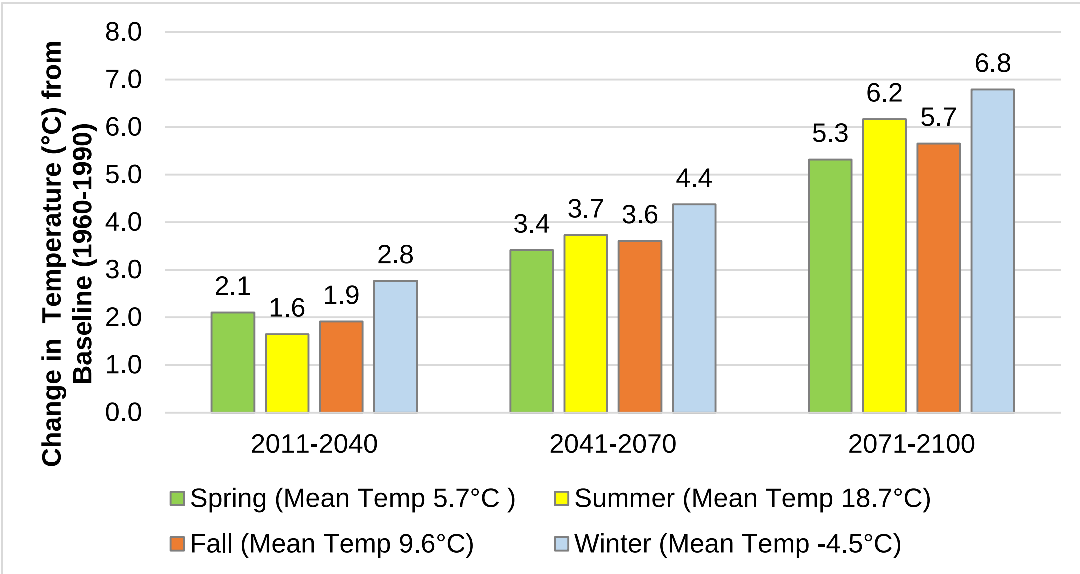


Figure 3.3. Increases in Goderich's seasonal mean temperatures (shown in the legend) projected by RCP 8.5

The annual mean baseline temperature for Wawa was 2°C. By the mid-century the mean temperature is projected to increase by 3°C to 4°C and by 4°C to 7°C by the end of the century (Table 3.2). These projections are 1°C lower than those projected by McDermid et al. (2015) for the Lake Superior Basin for both future climate periods and RCPs.

Once again, we found that the winter mean temperatures for both RCP scenarios have warmed more than Wawa's other seasons (Figures 3.4 and 3.5). The increases in the mean future temperatures are mostly greater for Wawa, 3.6°C to 5.1°C by mid-century and 5.0°C to 8.1°C by the end of the century than they were for Goderich. However, because the baseline mean temperature of -12.2°C is much lower than Goderich's -4.5°C even in the future scenarios the winter temperatures, for the most part, remain below freezing (see section 3.5).

Table 3.2. The difference in mean temperatures from Wawa's baseline mean of 2°C (1960-1990) for each future climate period

	2011-2040s	2041-2070	2081-2100
RCP 4.5	+2	+3	+4
RCP 8.5	+2	+4	+7

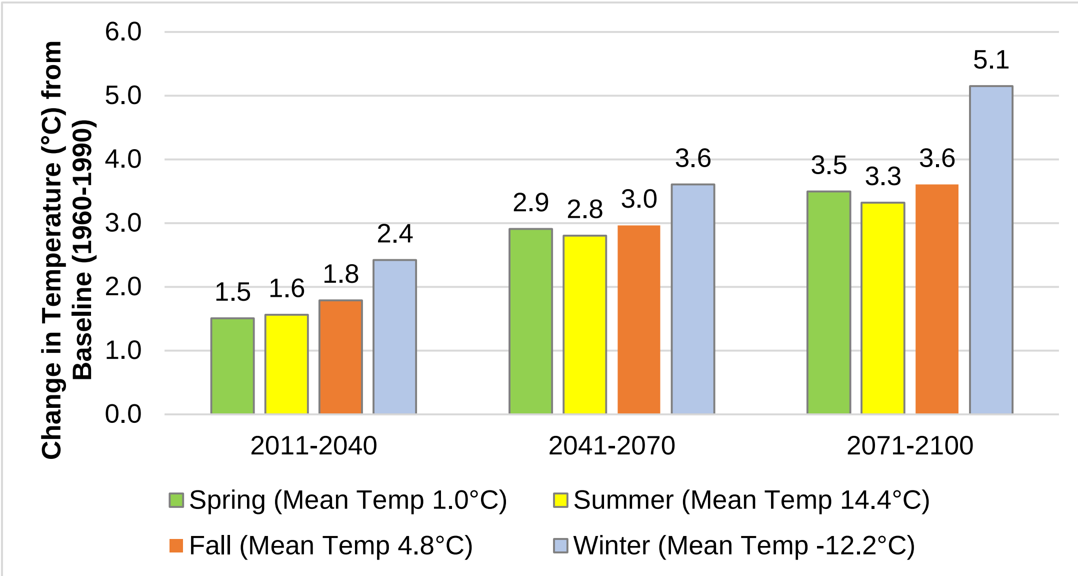


Figure 3.4. Increases in Wawa's Seasonal Mean Temperatures (shown in the legend) projected by RCP 4.5

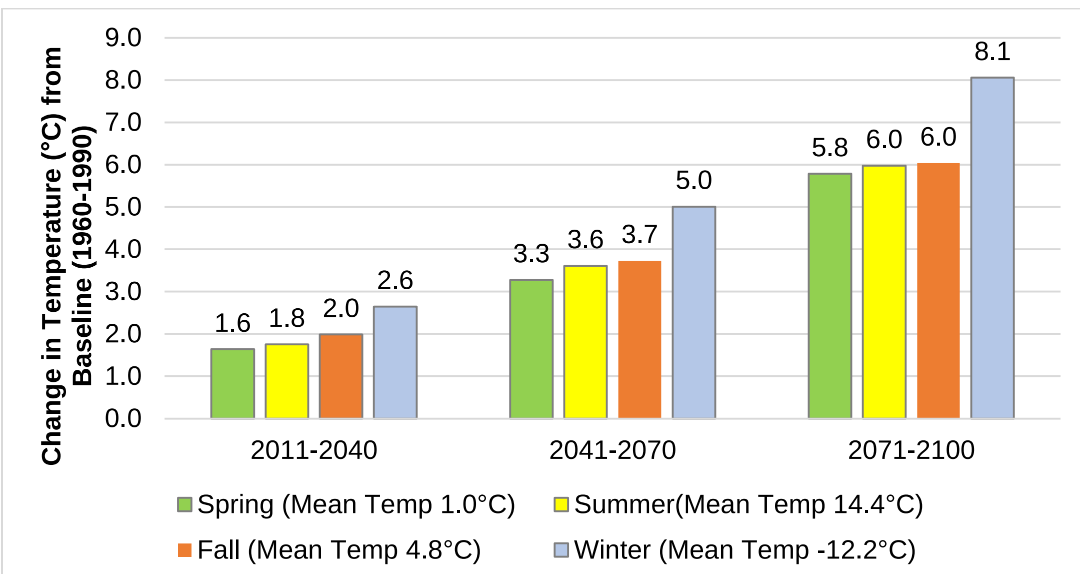


Figure 3.5. Increases in Wawa's Seasonal Mean Temperatures (shown in the legend) projected RCP 8.5

3.1.1 Wind Speed

Wind speed is closely tied to temperature and air pressure, and the frequency and speed of wind gusts and storms are expected to increase as these mean temperatures get warmer. More wind gust events are expected, as both large-scale frontal storms and local convective windstorms could occur more frequently. Canada's building code is currently being revised to mitigate damage associated with climate change (Scotti, 2017). Some proposed improvements in the building of roofs could include the use of 'hurricane straps', specific nail types and nailing patterns on roof decking to ensure the roof doesn't blow off.

3.2 Extreme Heat

When temperatures are above 30°C mortality rates increase (Gasparrini, et al., 2015) as does heat related illness and poor air quality (Basu, 2009). This puts a strain on health services including an increase in emergency room visits and the need to open cooling centres for vulnerable populations such as infants, those with medical conditions, elderly people and residents without air conditioning. These extremely hot days temperatures will also likely increase the energy demand for air conditioning. When extreme heat is combined with drought conditions, additional impacts could include increased strains on the supply and quality of drinking, irrigation and navigable water; elevated risk of rural-urban interface fires and added premature deterioration of road surfaces (tarmac) and bridges. For instance, paved roadways are designed for a specific temperature range and hot temperatures can lead to rutting and heaving. On June 21, 2012, a new record was set in Toronto when the temperature hit 34°C and two lanes of the 401 Highway were closed when the asphalt buckled in the extreme heat (Slaughter, 2012).

The number of days where the maximum temperature exceeded 30°C were filtered out and summed on an annual basis for the baseline period and the other three climate periods. The results were analyzed and reviewed before the averages were computed. It is these average numbers that are presented in this section. Three seasons, spring, summer and fall were used for this calculation.

For Goderich (Figure 3.6), the spring seasons of the baseline period (1960-1990) had 25 days with temperatures over 30°C, the summers had 446 days and the falls had 62, for a total of 533 days during that 30-year period. To put these numbers into a more relatable context the proportion of each season with extremely hot days was calculated (projected number of days/number of days in climate period × 100 = proportion of days). For example, of the 2760 summer days in that climate period 16% of them were above 30°C. Overall, 1% of the spring days from 1960-1990 were above 30°C and 2% of the fall days in this baseline period. The projected number of extremely hot spring, summer and fall days increases under both RCP scenarios for the future climate periods. But it’s the summer where the number of these days really add up. Under the RCP 4.5 scenario in our current climate period (2011-2040) the number of extremely hot summer days jumps up to 843 or another way to say this is 31% of the summer days. By 2050s, 1162 days are projected to be above 30°C or 42% of the summer season days will have a maximum daily temperature of 30°C or more. At the turn-of-the-century 46% of the summer days are projected to be extremely hot (1357 over the 30-year period between 2071-2100). These numbers are a bit startling, but they compare favorably with those of a localized study done for the Waterloo region (Interdisciplinary Centre on Climate Change, 2015).

The spring and fall seasons were also analyzed to see if these warm temperatures would bleed into the shoulder seasons. By 2050s, for RCP 4.5 the spring seasons are projected to have an increase of 72 additional days over the baseline climate period with temperatures above 30°C for 97 days (Figure 3.6). Another way of looking at this is that while the extremely hot spring days in the 30-year baseline period accounted for less than 1%, this increases to 3% of the spring days during the 30-year period 2041-2070. 184 or 7% of the fall days during this mid-century period are expected to be extremely hot, which is an increase of 106 days or 5% over the baseline fall seasons. By 2080s, the spring season is projected to have about 131 extremely hot days or 4% over this 30-year climate period, while the fall has 245 or 9%.

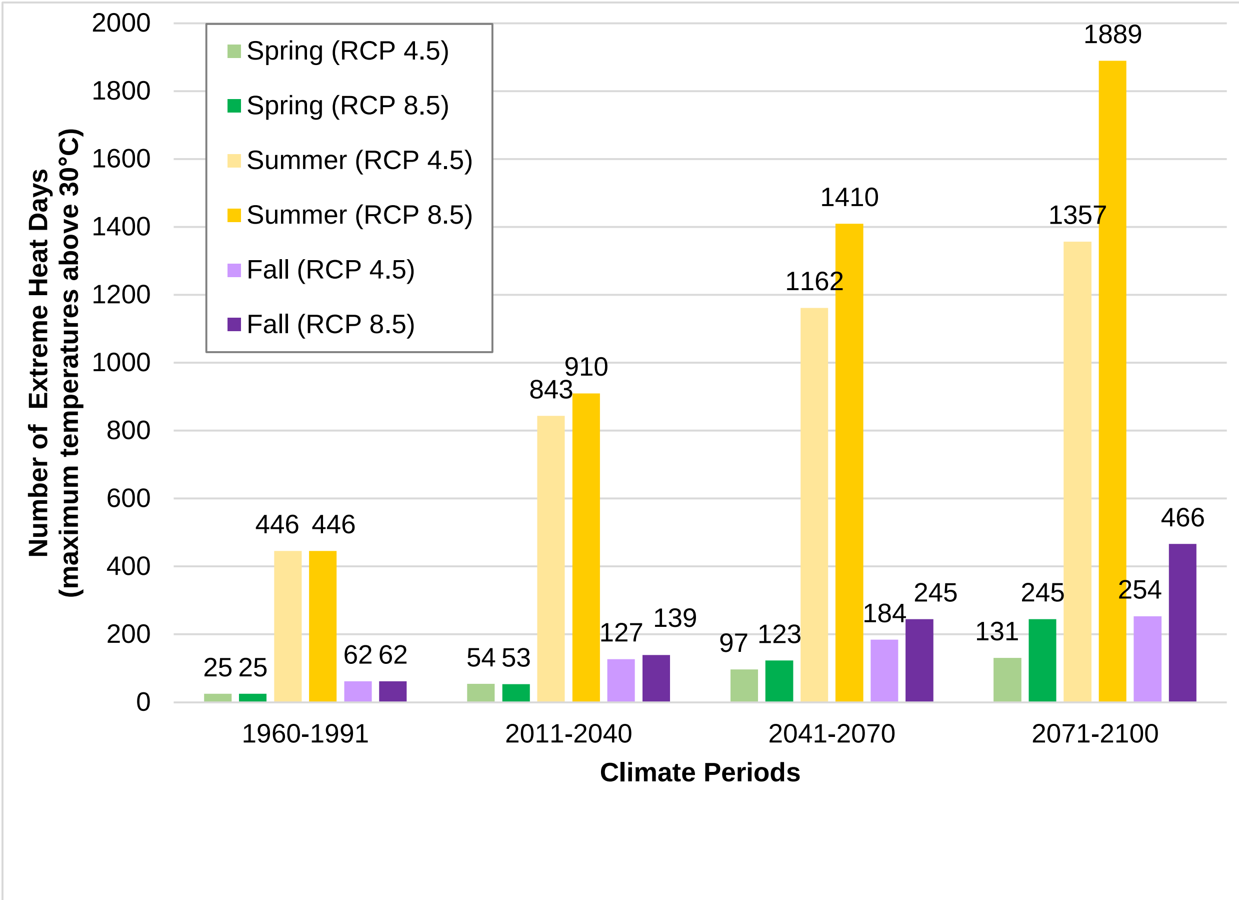


Figure 3.6. The Number of Goderich's Extremely Hot Days (RCPs 4.5 and 8.5 Projections)

Under the RCP 8.5 scenario all the seasons are projected to experience many more days over 30°C than those projected by the lower emissions scenario. The baseline summer seasons had 16% of their days over 30°C and once again, the future summers are projected to be very hot with 51% of their days above the 30°C threshold by 2050s and 68% by 2080s.

For Wawa (Figure 3.7), both the RCPs 4.5 and 8.5 Projections have an increase in the number of extremely hot days for three all seasons over the 30-year baseline values of 4 days in the spring, 39 days in the summer and 3 days in the fall. The proportion of spring days above 30°C is below 1% with 0.14% of extremely hot days. The summer has 1% and the fall's number of extremely hot days falls far below 1% with 0.09% of the baseline climate period. The RCP 4.5 data set for the current climate period projects 142 summer days with temperatures over 30°C, an increase of more than 100 days over the baseline period. This increase translates into 5% of the summer days between 2011-2040 are expected to be above 30°C. By the mid-century the number of these extremely hot days has grown by 7 times above the baseline to 276 days or 10% of the summer's days. For the 2071-2100 climate period at the turn-of-the-century this climbs to 12% when 343 days of extreme heat are projected.

The RCP 8.5 projects that during our current climate period the number of extremely hot days quadruples from the baseline's 39 days to 166 days or 6%. By the mid-century the summer seasons have a total of 419 days, or 15% of the days in the 2041-2070 climate period. At the turn-of-the-century that number increases to 846 days or 35% of the 2070-2100 climate period.

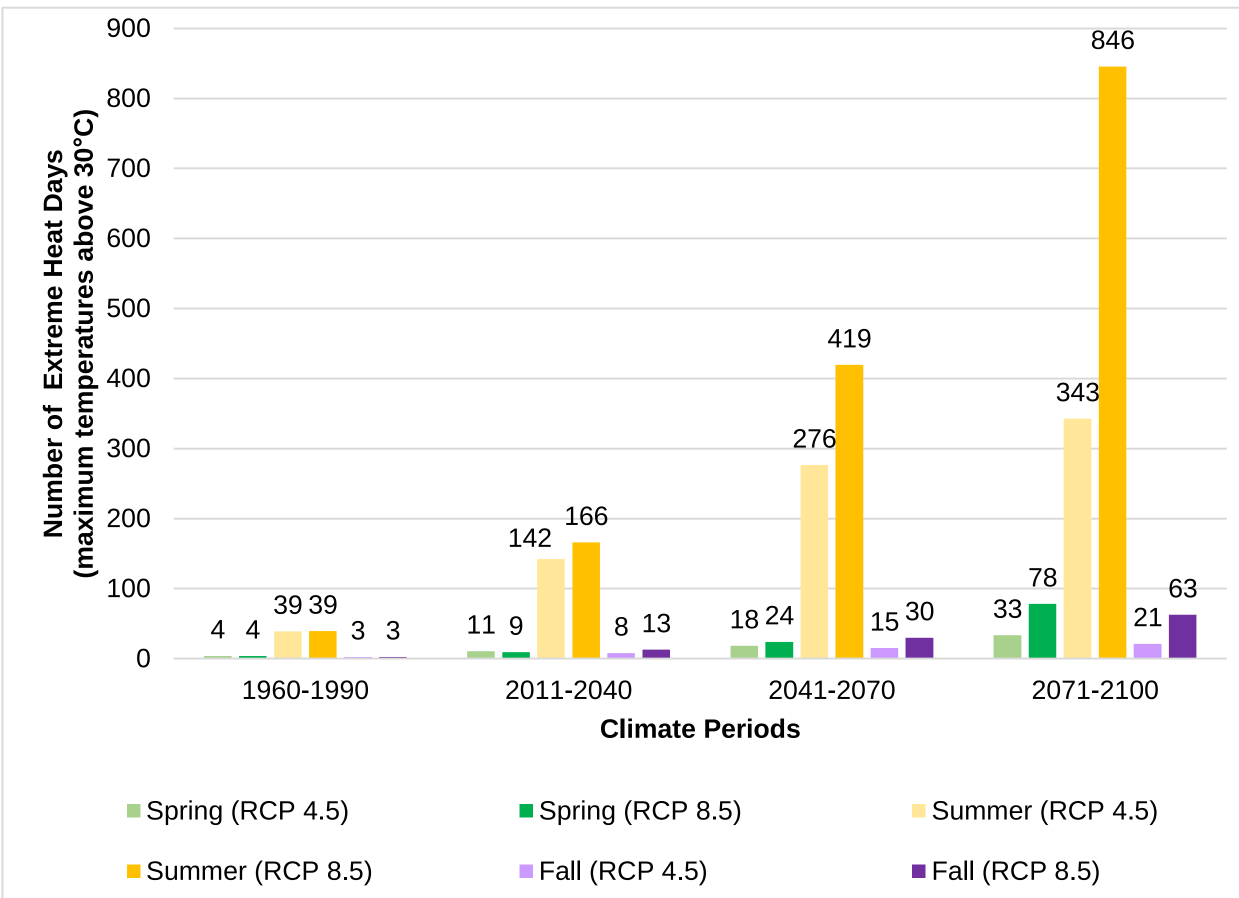


Figure 3.7. The Number of Wawa's Extremely Hot Days (RCPs 4.5 and 8.5 Projections)

The spring and fall seasons had less than 5 days of extremely hot days in the baseline period or less than 1% of each season's days. By the mid-century 24 spring and 30 fall days are projected by RCP 8.5, meaning that 1% of each season will likely have temperatures above 30°C. By the 2080s spring is projected to have 78 extremely hot days and 63 fall days or 3% and 2% of these seasons under RCP 8.5.

Overall, looking at all three seasons and the number of days above 30°C, Goderich has a much higher number of days that surpass the extreme heat threshold than Wawa does. Therefore, the risks associated with extreme heat and the water and energy demands will be higher for Goderich too. Although in comparison with Goderich the increase in Wawa's extremely hot days seems low, this modest increase can have impacts on water quality and quantity, energy demands for cooling and, if they coincide with dry days, could also increase the forest fire risk.

Another important point is the difference in the baseline data for these two Ontario municipalities. For example, when comparing hot summer days, Wawa had 39 days and Goderich 446 days over the historic period of 1960-1990. The wide range between these two numbers is not surprising given their different latitudes but it is an example of why local scale climate change analysis is needed instead of province-wide assessments.

3.3 Tropical Nights

Without the opportunity to cool down over night, the impacts associated with extreme daytime temperatures heat are likely to increase. When the night time temperatures remain warm, these nights along with hot days can result in heat waves. Tropical night temperatures in the study are any minimum temperatures above 20°C. The number of days where the minimum temperature exceeded 20°C were filtered out and summed for the baseline period and the other three climate periods. Three seasons, spring, summer and fall were used for this calculation.

Over the 30-year baseline period Goderich had 4 tropical nights in the spring, 335 in the summer and 49 in the fall (Figure 3.8). These numbers translate into 0.13% of the spring nights, 12% of the summer nights and 2% of the fall nights. The projected number of tropical nights for all seasons increases under both RCP scenarios for the future 30-year climate periods. Under the RCP 4.5 scenario in our current climate period (2011-2040) the number of tropical summer nights increases by 298 for a total of 633 nights or 23% almost doubling the proportion over the current climate period. By the mid-century period (2041-2070), 881 nights are projected to be above 20°C, an increase of 545 nights. In other words of the 2760 summer days in that climate period (2041-2070), 32% of them will have a nighttime temperature of 20°C or more. At the turn-of-the-century 38% of the summer nights are projected to be tropical, 1048 nights over the 30-year period between 2071-2100. These warmer nights will likely increase the frequency of heat waves and increase the power demand as people will not find relief from the day's heat over the night-time hours. For example, in the summer of 1936 the deadliest heat wave in Canada resulted in 1,180 deaths in Manitoba and Ontario, a third of which drown while trying to cool down (Schneider, 2016).

The spring seasons also have an ever-increasing number of tropical nights but never get above 1% of the current 30-year period for either of the RCPs. The RCP 4.5 projections of spring nights in the future never exceed 1%. For RCP 8.5, by the mid-century period (2041-2070) 55 spring nights or 2% of that 30-year period are projected to be tropical. At the turn-of-the-century (2071-2100) 126 spring nights or 5% of that period are tropical.

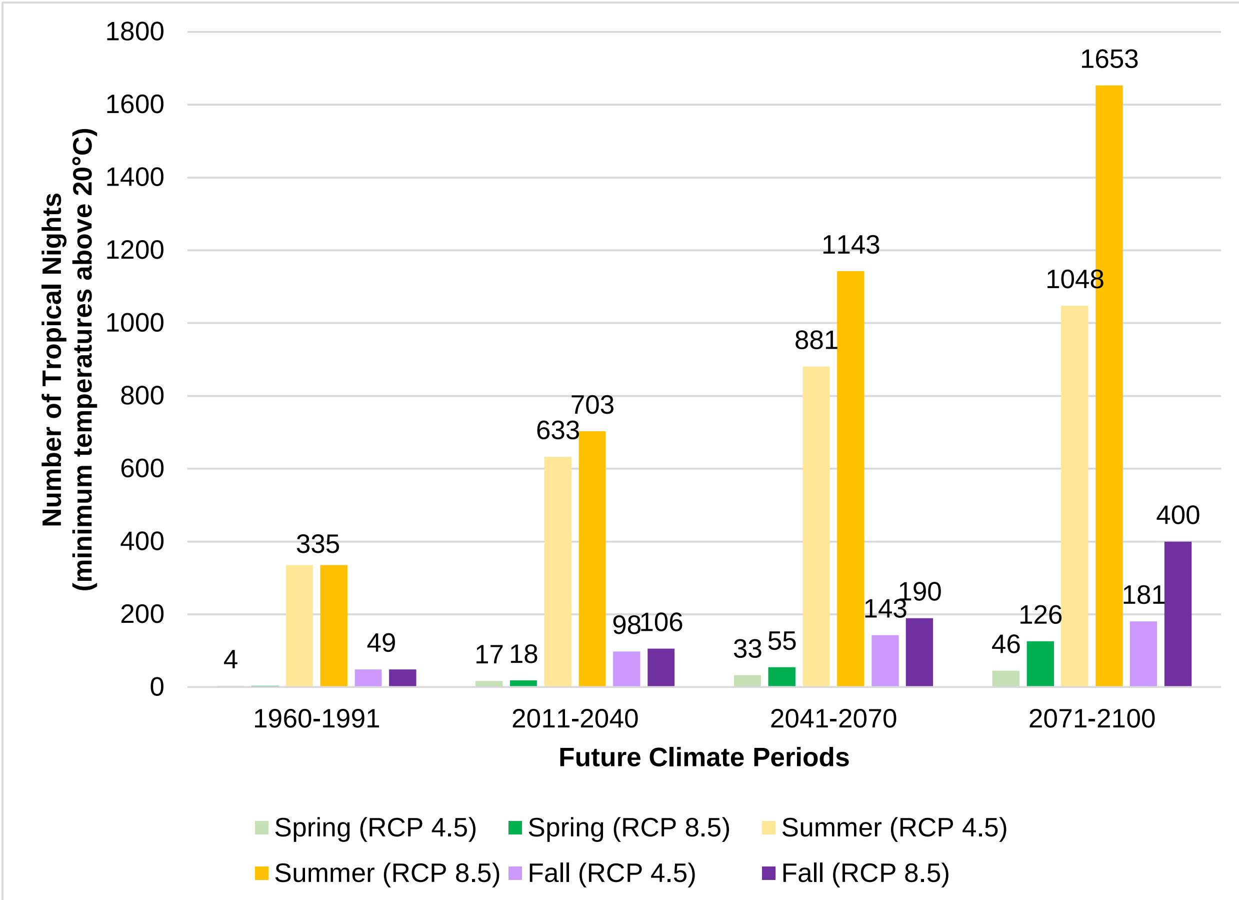


Figure 3.8. The Number of Tropical nights for Goderich (RCPs 4.5 and 8.5 Projections)

Over the 30-year baseline period Wawa had very few tropical nights with none in the spring, 12 in the summer and 2 in the fall (Figure 3.9). All are less than 1% of the nights in each season. The projected number of tropical nights for all seasons increases under both RCP scenarios for the future 30-year climate periods. Under the RCP 4.5 scenario in our current climate period (2011-2040) the number of tropical summer nights increases by 39 for a total of 51 nights or 2%. By the mid-century period (2041-2070), the number of nights has doubled (to 102) an increase of 142 nights. Of the 2760 summer days in that climate period (2041-2070), 4% of them will have a nighttime temperature of 20°C or more. By the turn-of-the-century 5% of the summer nights are projected to be tropical, 147 over the 30-year period between 2071-2100. The spring seasons in the future only experience 1 night under the RCP 4.5 with tropical temperatures. Under the RCP 8.5 by the 2080s, 8 nights are projected for the whole 30-year period, still far below 1%. Fall seasons in Wawa have an ever-increasing number of tropical nights but their count never reaches more than 1% in any 30-year future climate period under the RCP 4.5 projections. Under RCP 8.5 1% of the nights by the mid-century and 4% by the end of the century are projected to have temperatures above 20°C.

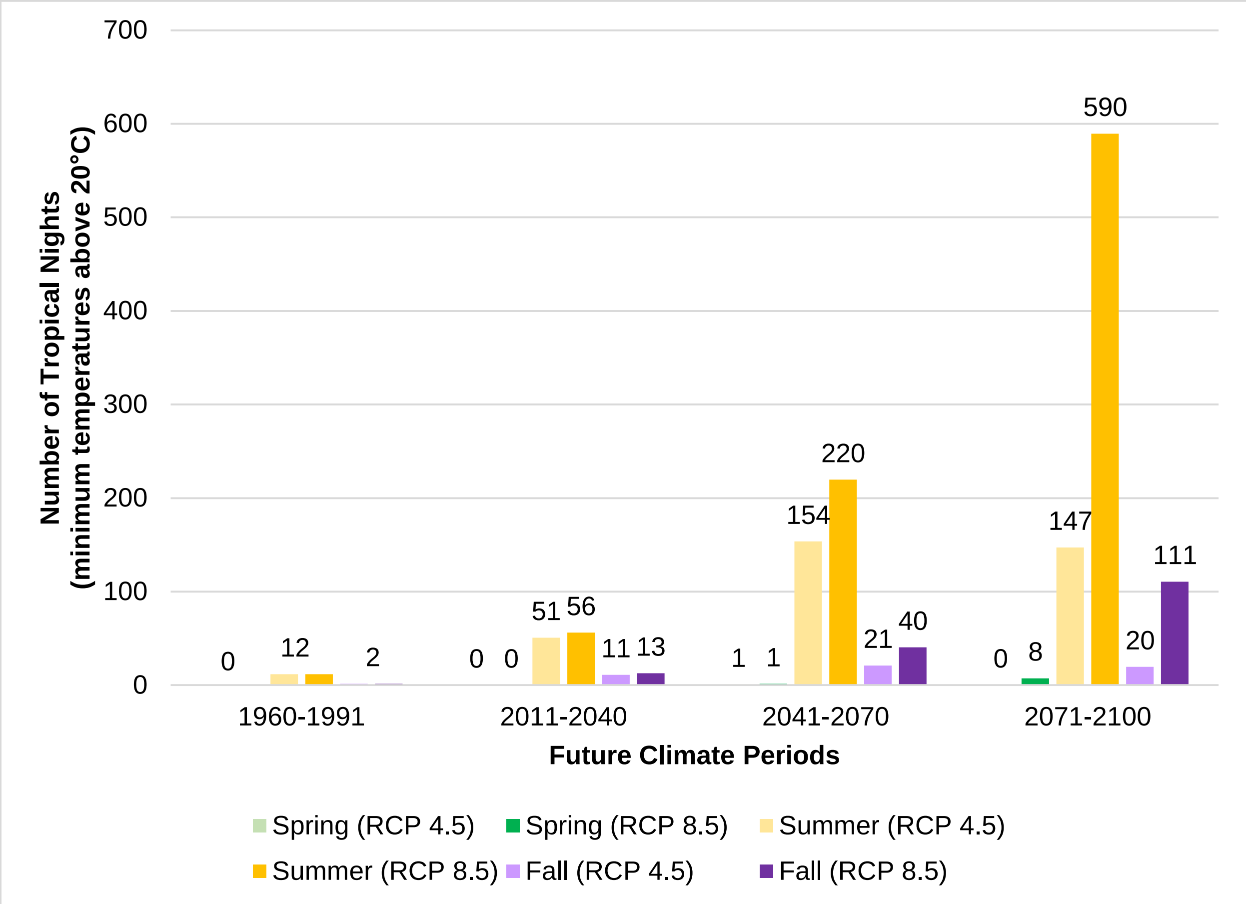


Figure 3.9. The Number of Tropical nights for Wawa (RCPs 4.5 and 8.5 Projections)

Overall, Goderich is expected to experience quite a few more summer tropical nights in the future than Wawa is expected to experience. Without the opportunity to cool down over night, the number of heat waves are likely to increase. Therefore, the risks associated with extreme heat and the water and energy demands will be higher for Goderich too. While this analysis suggests that tropical nights will likely have less of an impact in Wawa, these changes could still contribute to an increase in future heatwaves – a phenomenon rarely experienced in the past.

3.4 Extremely Cold Winter Days for Wawa and Goderich

Extremely cold winter temperatures can affect people's health, freeze water system infrastructure and pipes in buildings and increase energy demands for heating. The people most vulnerable to cold temperature related-health risks are the elderly, infants and young children, those with heart or chronic respiratory conditions, those that work outside and those who are marginally housed or homeless (Toronto Public Health, 2017). Cold temperatures can also aggravate cardiovascular and respiratory conditions, resulting in an increased need for medical attention and potential strains on the health system.

A period of extremely cold winter days can advance the frost line below its normal level resulting in the freezing of underground water pipes. The frost line or freezing depth is the depth to which ground water in the soil is expected to freeze and depends on the climatic conditions of an area. In 2015, Southern Ontario experienced record-breaking cold temperatures and a series of extremely cold days. In the city of Guelph, February's extremely low temperatures and prolonged cold conditions advanced the frost line below the depth of historically installed water mains and pipes delivering water to homes and businesses causing these water service lines to freeze (City of Guelph, 2017) . Water mains burst and at one point around 400 homes were dealing with frozen pipes and no access to the city's water (CBC News Kitchener-Waterloo, 2015). The energy demand for heating increases when the temperatures are extremely low and especially so for poorly insulated homes and buildings. Uninsulated pipes within buildings are also at risk of freezing when temperatures are extremely low.

Some extreme climate indices are defined by a fixed threshold value, for example 30°C for extremely hot days, while other indices are defined by a location specific threshold value. These location specific values are defined as a percentile of the climate data set of interest. The baseline climate data set of daily minimum temperatures is used to identify a unique threshold value (the 10th percentile) for a specific location's extremely cold days. In other words, the temperature 10% above the coldest temperature for that 30-year climate period is used as the threshold value. Once this value is determined the winter's days with temperatures equal to or less than the 10th percentile threshold temperature are filtered out and summed on an annual basis. These annual sums are averaged for each future climate period and the baseline to determine their number of extremely cold days.

For Goderich, which is located on one of the Great Lakes (Figure 3.1) the threshold temperature at the 10th percentile of the baseline climate period was -14°C and for Wawa for which is much further north and inland from the Great Lakes and their moderating effect, the 10th percentile minimum temperature was -27.4°C.

The number of days colder than these 10th percentile threshold temperatures for both Wawa and Goderich showed a future decrease in extremely cold days for all climate periods (Figures 3.10 and 3.11). This decrease in the projected number of future extremely cold days compared with the higher number of those experienced in the past further supports the contention that future winters will be warmer. For Goderich, there were 274 extremely cold winter days during the baseline period (1960-1990), or 10% of the winter days in that 30-year period when the temperature fell below -14°C. Figure 3.10 shows the projected decrease in the future number of extremely cold winter days. The RCP 4.5 projects that the current climate period (2011-2040) is expected to have a little less than half of the baseline number of extremely cold days, or 5% of the winter days in this period. By the 2050s the number of extremely cold days drops further to 67, or only 2% of the winter days by mid-century. The number of extremely cold days only drops slightly further by the turn-of-the-century to 63, maintaining the 2% proportion of winter days. This leveling off of extremely cold winter days projected by RCP 4.5 reflects that under this pathway greenhouse gases peak around 2040 drastically declining towards the turn-of-the-century.

For the RCP 8.5 data set the number of extremely cold days drops from the baseline count of 274 to 119 during the current climate period (2011-2040), or 4% of the winter days in this period. By the mid-century only 44 days drop below the -14°C threshold, or 2% of the winter days. At the turn-of-the-century there are only 15 days projected or 1% of the winter days in that 30-year period where the temperature is below -14°C. The continual decline in extremely cold winter days projected by the RCP 8.5 scenario reflects the future continual warming of the planet if we as a global society do not make substantial decreases in GHG emissions.

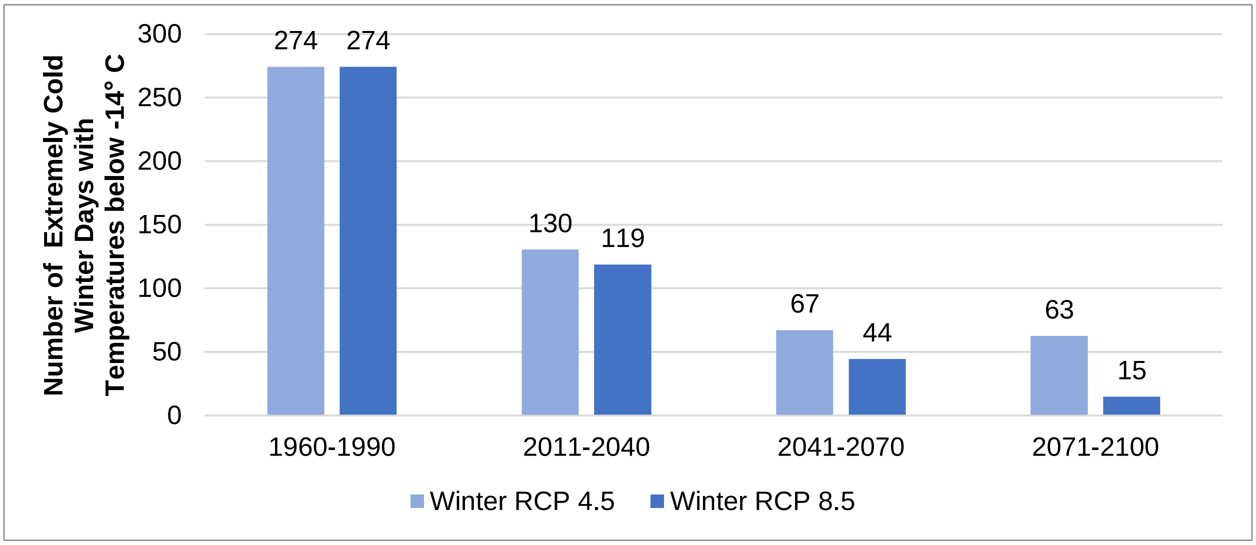


Figure 3.10. The Decreasing Numbers of Extremely Cold Winter Days for Goderich (RCPs 4.5 and 8.5 Projections)

Figure 3.11, shows that Wawa has the same steady decline pattern in the number of extremely cold days projected for future winters. During the baseline period in Wawa, there were 280 extremely cold days where the temperature fell below their 10th percentile minimum of -27.4°C. The RCP 4.5 projections of extremely cold days within the current climate period (2011-2040) drop to 161, or 6% of the winter days. By the 2050s the number of extremely cold days drops further to 87, or 3% of the winter days in that 30- year period. At the turn-of-the-century the number of extremely cold days drops to 63, about 2%. The RCP projections of extremely cold days within the current climate period drop to 152, or 6% of the winter days in the 30-year period. By the 2050s the decline in the tally of days drops further to 65, or about 2% of that period. At the turn-of-the-century only 18 days or 1% of that 30-year period are projected to have temperatures equal to or below -27.4°C.

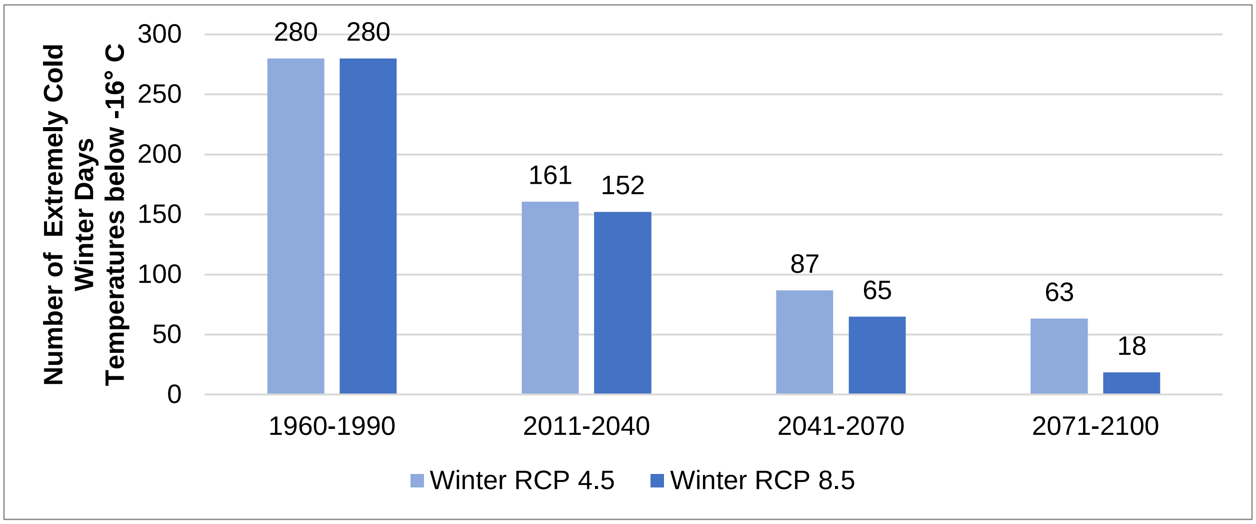


Figure 3.11. The Decreasing Numbers of Extremely Cold Winter Days for Wawa Goderich (RCPs 4.5 and 8.5 Projections)

Overall, both Goderich and Wawa are expected to experience fewer extremely cold days than they have in the past. Therefore, the communities may experience a reduction in the heating demands and infrastructure damage associated with fewer extremely cold days. However, new research is investigating the links between climate change and winters in the northern hemisphere. Indications are that as the Arctic warms the polar vortex is likely to become more destabilized resulting in more frequent mid-latitude extreme cold outbreaks (Faust & Bove, 2015) not accounted for in the current GCMs. It must be noted that research is in its preliminary stages and it will take years of further study to determine the role of climate change on the frequency and severity of Arctic air outbreaks. But given the rapid warming of the Arctic and loss of sea ice it is likely that anthropogenic climate change will play some role in what to expect in future winter seasons (Faust & Bove, 2015).

3.5 Frost Free Winter Days

Frost free winter days occur when the temperatures are above 0°C and thawing causes ice and snow to melt. Meltwater trickles in and fills cracks and spaces and when freezing temperatures return the meltwater re-freezes and expands. This is the freeze-thaw cycle that results in potholed roads, concrete fractures and masonry damage. Freeze-thaw cycles can also increase snow melt and reduce snow depth leading to root damage in trees, shrubs and plants and less consistency for winter-sport based tourism (e.g. snowmobiling and skiing). When the minimum temperature is above 0°C then the whole day experiences above freezing temperatures. But maximum temperatures above freezing may mean that the daytime has thawing conditions and refreezing occurs at nighttime when the minimum temperatures drop below 0°C. The number of days where winter minimum or maximum temperatures exceeded 0°C were filtered out and summed for the baseline period and the other three climate periods.

During the 30-year baseline period Goderich had 256 days with minimum temperatures and 1161 days with maximum temperatures above 0°C. While Wawa, which is farther north, had 52 days with minimum and 427 days with maximum temperatures above 0°C during the same 30-year period. The projections for both communities are for a continual increase in the number of days with winter temperatures above freezing. The trend lines in Figures 3.12 and 3.13 show that the magnitude of change from their baselines is far greater for Wawa than it is for Goderich. The circle symbols in these Figures also show that a greater increase in the number of days when the minimum temperatures exceed 0°C than those where the maximum temperature is above freezing are projected by both RCPs. Remember that when minimum temperatures are above freezing that whole day is above freezing. Under the RCP 8.5 scenario Wawa is expected to experience 3.6 times as many days above freezing by mid-century and 8 times as many by the end of the century (Figure 3.13). While the projections for Goderich under the 8.5 pathway are for 2.4 times as many days by mid-century and 4 times as many days by the end of the century above freezing.

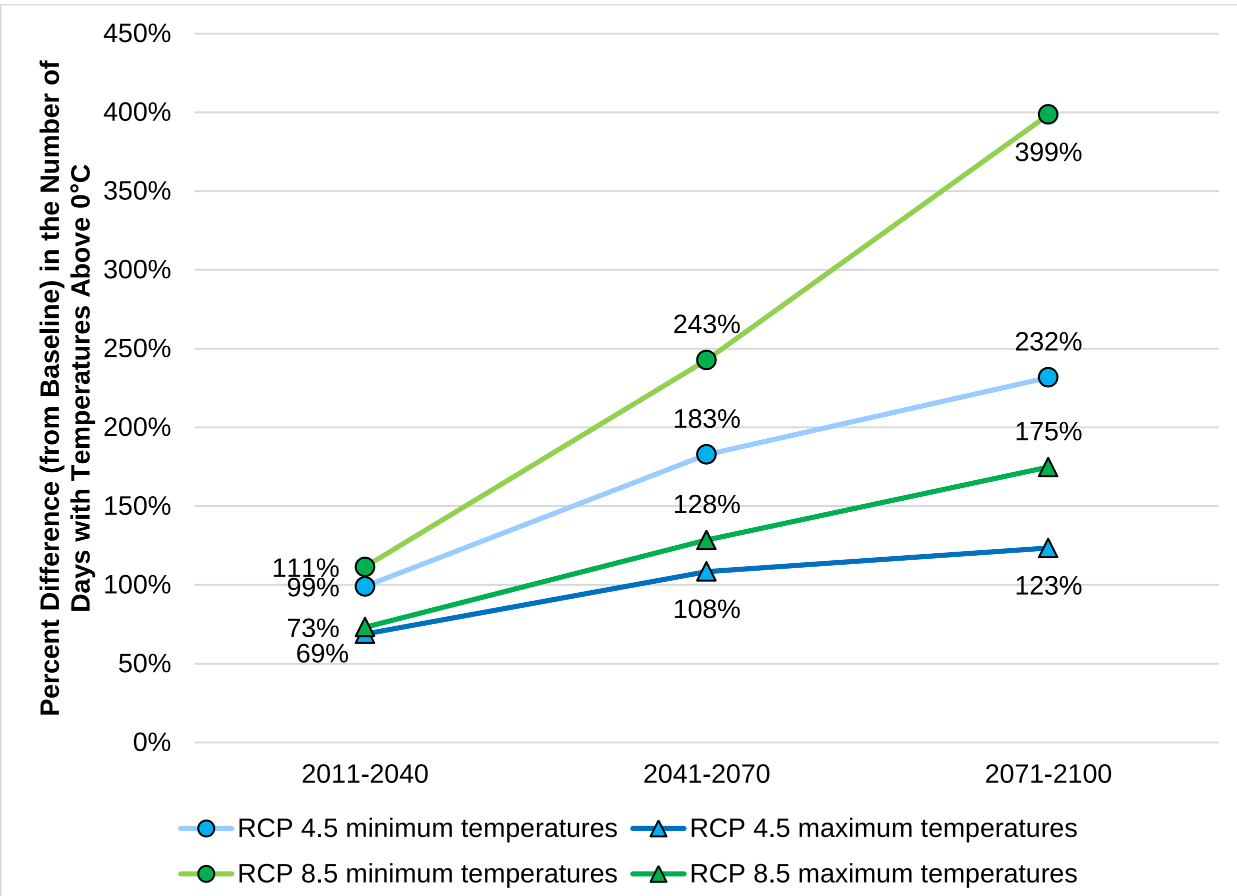


Figure 3.12. Increase in the Number of Projected Winter Days with Temperatures Above 0°C Relative to Goderich's Baseline Climate Period (1960-1990): 256 Days of Minimum Temperatures and 1161 Days of Maximum Temperatures

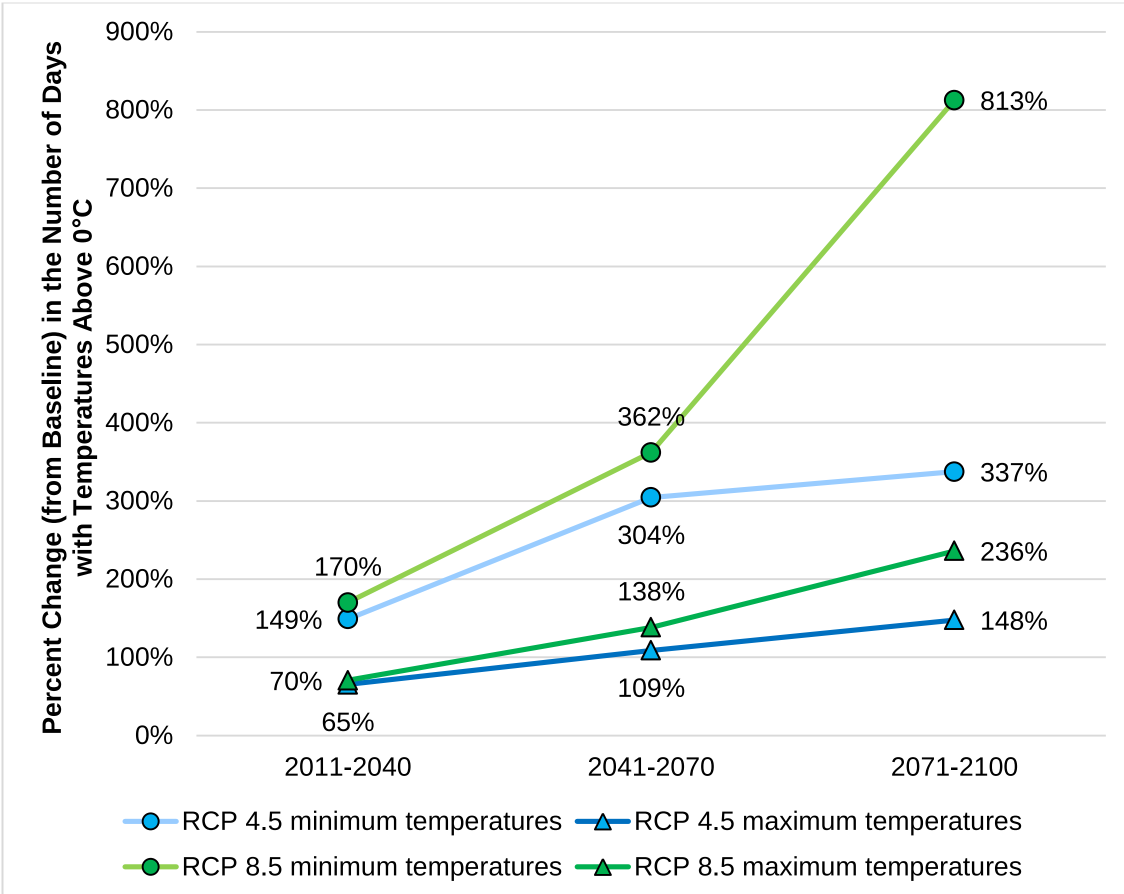


Figure 3.13. Increase in the Number of Winter Days with Temperatures Above 0°C Relative to Wawa's Baseline Climate Period (1960-1990): 52 Days of Minimum Temperatures and 427 Days of Maximum Temperatures

Table 3.3 shows the calculations for the proportion of the winter where Goderich's temperatures are projected to be above freezing. In the baseline climate period 9% of the minimum temperatures and 41% of the maximum temperatures were above freezing. Because the proportion of minimum temperatures is so low it is likely that most of those days were followed by refreezing temperatures, resulting in a freeze-thaw cycle. With such a large discrepancy between the minimum and maximum proportion of days with temperatures above freezing it is likely that most of the days when maximum temperatures were above 0°C had nighttime temperatures below freezing. So, again freeze-thaw cycles likely occurred.

The projections of both RCP's for the current and mid-century climate periods differ so slightly from each other for Goderich that they will be grouped together for this analysis (Table 3.3). In the current climate period (2011-2040), the projections of the proportion for minimum temperatures by both RCPs doubles to about 20% and the proportion of maximum temperatures above 0° rises to about 58%. These rising temperatures will likely result in an increase in freeze-thaw cycles as there is a high proportion of maximum temperatures above freezing and relatively fewer minimum temperatures. By the 2050s the projections of both RCPs for the minimum temperatures are 27%-32% above freezing and are 65%-70% of the maximum temperatures are above freezing. Although, there is still a higher number of maximum temperatures above freezing, the increase to roughly 30% of minimum temperatures above 0°C as well means that there are likely fewer diurnal freeze-thaw cycles due to fewer minimum temperatures dropping below freezing. There may even be a shortening of the 2050s winter seasons by a few days. By the turn-of-the-century the projections of the two RCPs differ greatly from each other (Figure 3.12). The RCP 4.5 scenario projections for the 2080s changes very little from the 2050s projections remaining around 31% of the minimum temperatures and 69% of the maximum temperatures above 0°. But the RCP 8.5 scenario projection for the 2080s reflects greater warming with 47% of the minimum and 79% of the maximum temperatures above freezing. It is very likely that by this time if warming continues along the pathway we now follow that the future winter seasons will have periods of mild above freezing temperature or maybe even a shortening of the season but certainly there will be fewer freeze-thaw cycles. In their report for Waterloo Region they also found that the number of freeze -thaw cycles were reduced by 2080s due to minimum temperatures remaining above freezing (Interdisciplinary Centre on Climate Change, 2015).

Table 3.3. Increase in the Proportion of Winter Days with Temperatures above 0°C for Goderich's 30-year climate periods (RCPs 4.5 and 8.5 Projections)

Climate Period	Minimum Temperatures		Maximum Temperatures	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
1960-1990	9%		41%	
2011-2040	19%	20%	57%	58%
2041-2070	27%	32%	65%	70%
2071-2100	31%	47%	69%	79%

For the Wawa community, Table 3.4 shows the proportion calculations. During the baseline climate period only 2% of the minimum temperatures in that 30-year time span were above freezing and 15% of the maximum temperatures. It is likely that most if not all of those above freezing temperatures were followed by a drop to below freezing again and resulted in freeze-thaw cycles. But with so few occurrences of above freezing temperatures it's unlikely Wawa experienced very many freeze-thaw cycles during the baseline period. The projections of both RCP's for the current and mid-century climate periods differ so slightly from each other for Wawa too, so they will be grouped together for this analysis (Table 3.4). In the current climate period (2011-2040), the projections of the proportion for minimum temperatures by both RCPs again doubles over Wawa's baseline minimum and maximum temperatures getting up to 5% and about 27% respectively (Table 3.4). During this period, there will likely be a doubling of the number of freeze-thaw cycles experienced as compared to the 1960-1990 period. By the mid-century period the proportion of minimum temperatures is projected to almost double again reaching 8% to 9% and the maximum temperatures reach 33% to 38% resulting in still further increases in freeze-thaw cycles. By the turn-of-the-century the projections for the RCP 4.5 remain about the same as the mid-century with 8% of the minimum and 39% and maximum temperatures above freezing. But the RCP 8.5 projections jump up to 18% for the minimum and 53% for the maximum temperatures above freezing (Table 3.4). The high proportion of maximum temperatures above freezing with a relatively low proportion of minimum temperatures above freezing will result in a further increase the frequency of freeze-thaw cycles.

Certainly, if the global community stays on the 8.5 pathway the projections for Wawa are for more thawing winter temperatures than they experienced in the past.

Table 3.4. Increase in the Proportion of Winter Days with Temperatures Above 0°C for Wawa's 30-year Climate Periods (RCPs 4.5 and 8.5 Projections)

Climate Period	Minimum Temperatures		Maximum Temperatures	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
1960-1990	2%		15%	
2011-2040	5%	5%	26%	27%
2041-2070	8%	9%	33%	38%
2071-2100	8%	18%	39%	53%

Overall, these trends in the proportion of winter days and nights with temperatures above 0°C suggest that Goderich, located further south, already experiences freeze-thaw cycles and the associated infrastructure damage and that this trend will not likely increase dramatically in the future time periods. These damages and the associated costs may even decrease by the turn-of-the-century. In contrast, Wawa, with its more northern location, has historically experienced far fewer freeze-thaw cycles. This is projected to change, with Wawa likely experiencing an increase in these freeze-thaw cycles and the associated impacts on local infrastructure damage and repair costs.

3.6 Number of Days with Heavy precipitation

Precipitation patterns vary over time and space due to environmental factors that influence its intensity and quantity (e.g. elevation, convection, proximity to water and position of the jet stream and El Niño events). Climate change introduces greater volatility into these varied precipitation patterns. Outcomes of these changes may be prolonged dry spells or drought, or at the other end of the spectrum extreme precipitation events. A warmer climate and a higher concentration of water vapour in the atmosphere are expected to increase the amount of rainfall and the likelihood of localized intense storms (IPCC, 2013).

Torrential rainfall by these localized storms events result in increased flooding, slope failure, washed out roads and bridges and increased pressure on government and insurance companies for disaster relief. Floods are among the most frequent causes of natural hazard damage and economic losses to public facilities like roads, railways, bridges and other infrastructure such as the public water supply (Munich RE, 2012). These localized storms with torrential rainfall can result in flash floods anywhere not just along shorelines or stream channels. This type of flooding occurs when the ground can't absorb water fast enough so the rainfall flows overland. On sloped surfaces, this can produce a rapidly growing flood wave that can wash into areas where it hasn't even rained. On flat surfaces water pools in low-lying areas, like ditches and underground parking garages. The erosion potential associated with fast-flowing surface runoff can cause buildings to collapse, culverts to be overwhelmed and ripped out, and roads and rail lines to wash out. Pollutants picked up or exposed by this overland flow can be washed into the local water supply contaminating it.

Ontario has experienced a number of these intense localized rainfall events that resulted in flooding recently. The city of Burlington was concerned about contamination of their water supply following flash flooding caused by a storm that dumped almost two months of rain in 3-hrs on August 5, 2014 (Mangione, 2014). The Weather Network reported this localized storm dumped 100-150mm of rain with amateur weather observers reporting 190mm, while nearby Toronto's Buttonville Airport got 37mm and the Pearson Airport in Mississauga only got 3mm (Martins, 2014) . On July 8, 2013 two thunderstorms dumped 126mm of rain on Toronto in 3-hours, flooding parts of the city, railway lines, subway tunnels and knocking out power (Edmiston, 2013). After these slow moving storms passed Toronto they were essentially rained out dropping 37mm in Buttonville and only 0.2mm by the time they reached Hamilton (Edmiston, 2013). Wawa, one of the municipalities in this study experienced severe damage to its infrastructure in October 2012, due to an extreme rainfall (101mm) event occurring when the ground was already saturated by the previous day's heavy rainfall (24mm). The flash flooding caused millions of dollars in damage after parts of the TransCanada highway were washed out, houses collapsed into newly formed gorges, phone lines were down including 911 service to neighbouring communities and the Michipicoten First Nation community was partially evacuated after being cut off (CBC News, 2012). Although it is too early to link these specific extreme events with climate change these are the types of localized storms expected to occur more frequently due to climate change.

The GCM projections of future precipitation patterns are more diverse than the projected future temperatures due to the different assumptions used in each model's algorithms. Measures that are often used to assess precipitation extremes count the number days precipitation exceeds a threshold value. The threshold value represents heavy or extreme amount of precipitation. There are two methods for determining these extreme threshold values, either a standardized fixed value like 20mm for very heavy precipitation (ETCCDI, 2013) or a location specific threshold representing extreme precipitation for that location.

The number of days with precipitation over 20mm per day was used to determine very heavy precipitation events. This threshold value is recommended by Climate Change Detection and Indices (ETCCI) expert team, a group formed to design international definitions and calculations of climate change indices (ETCCDI, 2013). As such it can be used as a measure to compare local projections of heavy precipitation with regional or global projections, much like mean temperature changes are used. For each of the four seasons, the days with precipitation greater than or equal to 20 mm were filtered out and summed for the baseline period and the other three climate periods. These results were averaged to produce a single value representing the number of days for each season within a 30-year period had heavy precipitation. It is these averages that are presented in this section.

Extremely rare precipitation is a climate index defined by a statistically derived location specific threshold value, much like the threshold for the extremely cold days index. As was stated earlier, precipitation patterns vary due to a unique set of a location's biophysical characteristics. Therefore, although a fixed standardized threshold is a useful measure of heavy precipitation in a general sense, only a tailored threshold value can capture the unique precipitation patterns of a specific location. For this study, we have used the 95th percentile as a threshold value to define extremely heavy precipitation events that were once a rare occurrence during the 1960-1990 30-year time span.

Before calculating the 95th percentile all days with less than 1 mm of precipitation were removed from the baseline data set so that the precipitation distributions would not be skewed by the inclusion of dry days. Next the 30-year baseline data sets for Wawa and Goderich were each divided into seasons. Then precipitation data for both municipalities was used to identify a unique threshold value (the 95th percentile) for each season for both locations. In other words, the daily precipitation amount 5% below the maximum precipitation events within the 30 winter, 30 spring, 30 summer, and 30 fall seasons became the threshold values. Table 3.5 shows the 95th percentile precipitation values for each municipality. Once these values were determined for the four seasons for both locations, the days with precipitation equal to or greater than the 95th percentile threshold values are filtered out and summed on an annual basis. These annual sums are averaged for each future climate period and the baseline to determine their number of extreme precipitation events for each season. Coincidentally, 20mm per day also represents the annual precipitation 95th percentile value for the baseline period of both municipalities.

Table 3.5 The 95th Percentile Threshold Precipitation Values Derived from the Baseline Climate Period Data Sets of Wawa and Goderich

Precipitation 95th Percentile (mm)		
Baseline Season (1960-1990)	Wawa	Goderich
Winter	12.39	13.83
Spring	18.56	17.32
Summer	24.94	23.16
Fall	20.96	20.44

The 95th percentile precipitation values derived from the baseline climate data set illustrate the difference between the fixed standard 20 mm very heavy precipitation threshold and these location specific threshold values (Table 3.5). If we were looking at annual precipitation patterns a threshold value of 20 mm would be a good approximation of an extreme threshold value. However, annual climate data misses the variation of seasonal precipitation and temperature trends. For example, based on the Wawa data set the winter 95th percentile threshold is 12.39 mm while Goderich's threshold value was calculated from its data set to be 13.83 mm. Both of these are below the 20 mm fixed value but represent extremely rare daily precipitation events for these locations. Fall is the only season where the 95th percentile for both Goderich and Wawa are almost equal to the fixed value of 20 mm. The summer season 95th percentile values are higher and closer to 25 mm per day while the spring values are a bit lower than 20 mm. Overall, Wawa's seasonal 95th percentile precipitation threshold values are higher Goderich's with the one exception of winter.

This analysis reports the projection changes in the number of future days where precipitation exceeds the fixed and 95th percentile thresholds compared to those of the baseline climate period (1960-1990). Once the analysis was completed it was clear that the projected trends are the same within any given season but the extent of these changes reflect the baseline threshold values used for these future estimates. For example, the fall's 95th percentile threshold value was calculated to be 20.44mm almost exactly the same as the fixed threshold value of 20.00 mm and the number of days during the 30-year baseline climate period when these thresholds were exceeded are also almost exactly the same, with 59 and 62 days respectively. However, the winter 95th percentile threshold value was calculated to be 13.83 mm quite a bit lower than the fixed value of 20 mm, the large difference between these two threshold values resulted in a large difference between the number of days within the 30-year baseline period when these thresholds were exceeded, 19 for the fixed threshold and 71 for the 95th percentile threshold. Table 3.6 presents the tally of the baseline number of days when these thresholds were exceeded and the percent change in the future projections in the number of days relative to the baseline period. Because these trends mirror each other and differ only due to the initial baseline day counts the following description of the results will group these two measures of precipitation change together.

Keep in mind that overall the occurrences of these rare precipitation events are very low. For both municipalities, they account for only 1%-5% of all the days in any climate period (see Appendix 2. Appends 13 and 10). The spring, fall and winter seasons for both Goderich and Wawa will likely have more days in the future with precipitation above the fixed 20mm and the statistical 95th thresholds figures than they experienced during their respective baseline climate periods. It's the summer season only where any decreases in the number of these extreme precipitation days were projected by both RCPs.

Table 3.6 The Projected Changes in the Future Number of Goderich's Days when Precipitation Exceeds Both Thresholds

Spring					
Baseline # Days and Threshold Values	31 > 20.00mm			47 > 17.32mm	
Climate Period	RCP 4.5	RCP 8.5		RCP 4.5	RCP 8.5
Current 2020s (2011-2040)	42%	32%		32%	28%
Mid-century 2050s (2041-2070)	68%	71%		49%	55%
Turn-of-the-century 2080s (2071-2100)	65%	84%		60%	78%
Summer					
Baseline # Days and Threshold Values	64 > 20.00mm			46 > 23.16mm	
Climate Period	RCP 4.5	RCP 8.5		RCP 4.5	RCP 8.5
Current 2020s (2011-2040)	-6%	-5%		-11%	-11%
Mid-century 2050s (2041-2070)	8%	13%		13%	22%
Turn-of-the-century 2080s (2071-2100)	2%	-8%		2%	-7%
Fall					
Baseline # Days and Threshold Values	62 > 20.00mm			59 > 20.44mm	
Climate Period	RCP 4.5	RCP 8.5		RCP 4.5	RCP 8.5

Current 2020s (2011-2040)	15%	2%		14%	2%
Mid-century 2050s (2041-2070)	19%	11%		19%	12%
Turn-of-the-century 2080s (2071-2100)	13%	16%		12%	17%
Winter					
Baseline # Days and Threshold Values	19 > 20.00mm			71 > 13.83mm	
Climate Period	RCP 4.5	RCP 8.5		RCP 4.5	RCP 8.5
Current 2020s (2011-2040)	16%	42%		10%	13%
Mid-century 2050s (2041-2070)	53%	74%		34%	41%
Turn-of-the-century 2080s (2071-2100)	42%	89%		24%	49%

Figure 3.18 shows the general trends in the RCP projections of Goderich's heavy spring precipitation events. In this figure RCP 8.5 projections are the dark lines and RCP 4.5 are the lighter coloured lines and both show a steady increase in the future number of heavy precipitation days above the 30-year baseline period (1960-1990). However, RCP 8.5 shows a steady increase in the number of days where these spring thresholds are expected to be exceeded in the future while RCP 4.5 follows a similar pattern up the mid-century period but then shows a leveling off or slight decrease. For Goderich's baseline spring seasons there were 31 days where daily precipitation exceeded 20mm and 45 days where precipitation exceeded 17.32mm per day (Table 3.6). Because there is little difference between threshold values and the corresponding number of days when these values are exceeded this analysis will group the results together.

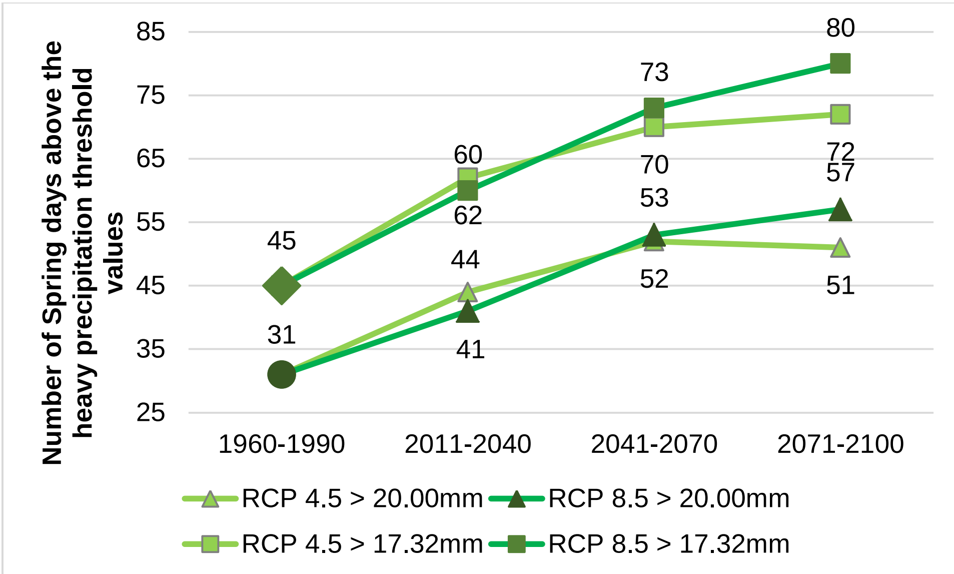


Figure 3.16 Average Number of Projected Spring Days in Goderich with Extremely High Precipitation

For the current climate period (2011-2040) RCP 4.5 projections are for an approximate 40% increase in the number of days with heavy precipitation, and RCP 8.5 projections are for an increase of about 32% (Table 3.6). By the mid-century (2041-2070), there is little difference between the two RCP projections with both expecting an increase of close to 70% above the baseline's number of days with precipitation greater than 20mm. RCP 4.5 projections are for an increase of 49% and RCP 8.5 projections are for a 55% increase in the number of days with daily precipitation of 17.32 mm or more. At the turn-of-the-century the projections of the RCPs differ for the first time. The projections for RCP 4.5 maintain roughly the same increase above baseline as those of the mid-century holding at about 60 to 65% depending on the threshold value used. However, the RCP 8.5 projections continue the ever-increasing trend in the number of days exceeding the baseline threshold for extremely heavy precipitation, with around a 78 to 84% increase depending on which threshold value is used. So, whether we as a global society remain on the worst-case scenario path (RCP 8.5) or change our ways dramatically Goderich is still likely to see an increase of around 37% in the current climate period which could result in an increase in spring flooding. A global commitment to GHG reduction now could possibly result in a drop in the atmospheric concentration after the 2050s but even if that were to happen Goderich is projected by to likely see about a 62% increase in extreme spring precipitation by mid-century, and roughly a 67% if we remain of the 8.5 pathway in number of days of what was a rare precipitation event in 1960-1990. The risk of spring flooding by the mid and end of the century is more likely to increase due to the increase in extreme precipitation events.

Figure 3.17 shows the general trends in the RCP projection for Goderich's heavy fall precipitation events. In this figure RCP 8.5 projections are the dark lines and do not show much change between the baseline and the current climate period but a steady increase in the following climate periods in the number of heavy precipitation days. The RCP 4.5 projections are the lighter lines and show an increase in the number of these heavy precipitation days peaking at the mid-century and declining thereafter. Keep in mind the narrow range of values shown in this figure make the future increases in the numbers of days appear as steep changes when really there is only a maximum overall increase of 10 days. In order to make the trend lines in this figure discernible from each other the vertical axis had to be exaggerated. For Goderich's baseline fall seasons, there were 62 days where daily precipitation exceeded 20mm and 59 days where precipitation exceeded 17.32mm per day (Figure 3.17 and Table 3.6). Because these threshold values are almost equal the RCP projections are almost equal as well and will be grouped together.

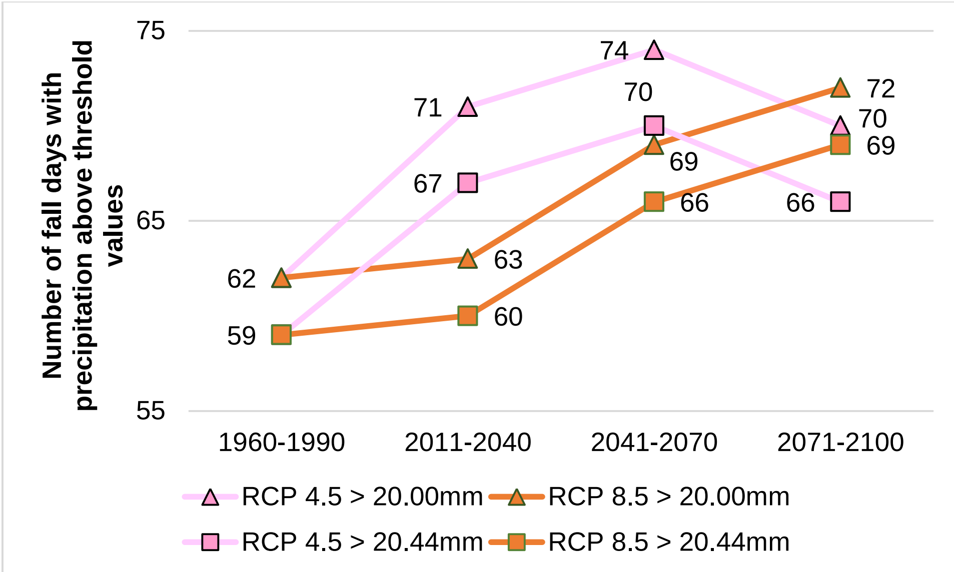


Figure 3.17 Average Number of Projected Fall Days for Goderich with Extremely High Precipitation

Goderich's future fall seasons are also projected by RCP 8.5 to experience an ever-increasing number of days with precipitation above these baseline count of days for both threshold values. While the RCP 4.5 projections follow a similar increasing trend until the mid-century when it peaks and then the number of high precipitation days declines but remains higher than the baseline's number of days with extremely heavy precipitation (Figure 3.17and Table 3.6). For the current climate period, the RCP 4.5 projects a 15% increase and the RCP 8.5 projects a 2% increase. Goderich can expect an 11% or 19% increase by the 2050s, with the higher number of days projected by the RCP 4.5 scenario. By the 2080s RCP projections drop down to about 13% and the RCP 8.5 projection of days with heavy precipitation increases by 17%. None of the projections are above a 20% increase in the number of days of extreme precipitation above that of the 1960-1990 climate period. So, the increase risk of flooding in the fall beyond what Goderich has all already experienced is low.

For Goderich's winter season 19 days during the 30-year baseline period had 20mm or more precipitation and 71 days had 13.83mm or more of precipitation. This is widest discrepancy between the number of heavy precipitation days and in this instance 20mm is likely an extremely heavy precipitation event. There is approximately a 10 to 1 relationship between rainfall and snowfall depth, so 20mm of precipitation is about 20cm of snow. Figure 3.18 shows the general trends in the RCP projection of the heavy winter precipitation events and the wide difference between the baseline day count. In this figure RCP 8.5 projections are the dark lines and show a steady increase in the future number of heavy precipitation days. The RCP 4.5 projections are the lighter lines and even with such a great difference between both the baseline days counts and the threshold values RCP 4.5 still projects a levelling off or reduction the number of days projected after the mid-century. Because of the differences in both baseline day counts and threshold values this season's analysis will be separated into two groups based on their associated threshold values.

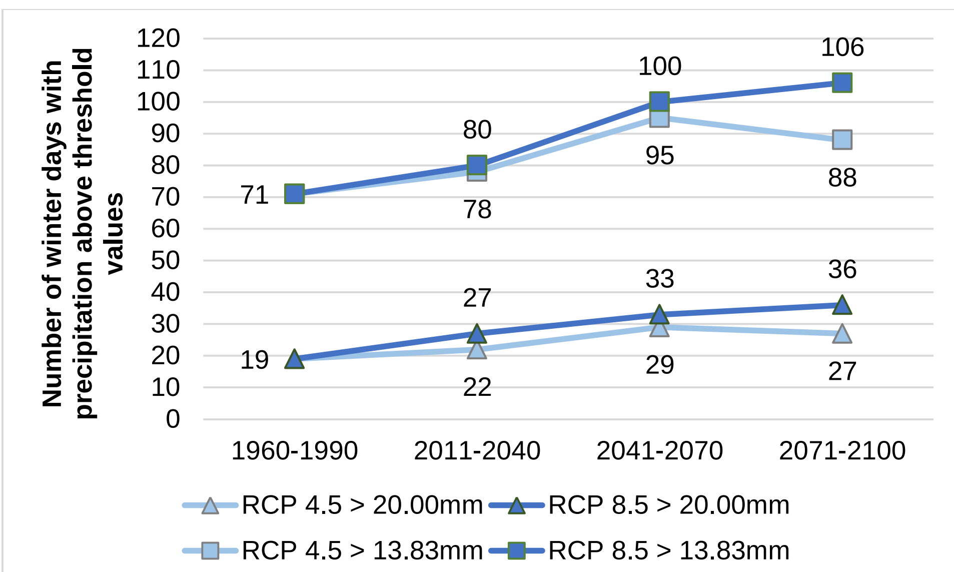


Figure 3.18 Average Number of Projected Winter Days in Goderich with Extremely High Precipitation

For the current climate period Goderich's winters are expected by the RCP 4.5 projections to get 16% more days with precipitation above the 20mm threshold and 42% more days are projected by the RCP 8.5. By mid-century a 53% increase is projected by RCP 4.5 and a 74% increase over the baseline's number of days with precipitation over 20mm is projected by the RCP 8.5 scenario. By the turn-of-the-century a 42% increase is projected by RCP 4.5 and an 89% increase is projected by RCP 8.5 or almost a doubling in the number of days with extremely heavy precipitation.

When the 95th percentile threshold value of 13.83mm was employed, the current climate period projections by both RCPs were for a 10 to13% increase in the number of days above those experienced during the baseline period. The winter projections by both RCPs are for an increase of about 34% to 41% above the baseline's number of days with more precipitation than 13.83mm by the mid-century. By the end of century RCP 4.5 projects a 24% increase while RCP 8.5 projects a 49% increase above the baseline period's heavy precipitation days. Even with a drastic cut in GHGs emissions the amount currently in our atmosphere the 30-year mid-century climate period will likely experience another 29-33 days with extremely heavy precipitation greater than 20mm and 95-100 more days with heavy precipitation of 13.83mm or more. By the end of the century an increase to 27-36 days of heavy precipitation(>20mm) and 88-106 days of extreme precipitation(>13.83mm) are projected.

The implications of the projected increases in heavy precipitation days in the winter depends on the winter temperatures. While the temperatures remain below freezing these heavy precipitation events will be snowfalls and potentially blizzards if strong winds are part of the storm system. Heavy snowfalls may result in an increased need for snow removal from the municipality's roads and potentially an increase in springtime flooding when the snow load melts. But the insulation the snow cover provides can keep the underground temperatures above freezing and protecting tree roots and buried infrastructure from the frost line advance associated with freeze- thaw cycles or extremely cold temperatures. However, it is likely that many of these events that were in the past snowfalls will be freezing rain or maybe event rain storms due to the expected warming of winter temperatures (Figure 3.3) and that as early as the present climate period 58% of the winter days are expected to have maximum temperatures above freezing with increasingly more winter temperatures above freezing projected for Goderich's future (Figure 3.13). In a study by Cheng et al. (2007) for southern Ontario they found that under the RCP 8.5 scenario there was 40% increase in freezing rain by 2050 and a 45% increase by 2100. The potential reduction in snow cover due to these warming temperatures may result in the loss of the insulting effect of a blanket of snow. The deepening of the frost line can be induced by extremely cold temperatures or repeated freeze thaw of ground without an insulating cover (City of Guelph, 2017). Therefore, the risk of frozen water pipes might increase too.

The baseline count of summer days with rainfall of 20mm or more was 64 and the count of days with 23.16mm or more derived from the 95^{th} percentile for summer precipitation was 46 days (Table 3.6). Figure 3.19 shows the RCPs projections for Goderich's future summer seasons and for the first time a decline in the heavy precipitation days below the baseline count are projected for the current climate period, followed by a peak in the number of days with heavy rainfall in the mid-century and then another decline back to or below the baseline count of days by the end of the century. Once again the vertical axis had to be exaggerated to make the trend lines in this figure visible and we are once again looking at a maximum overall change of 10 days.

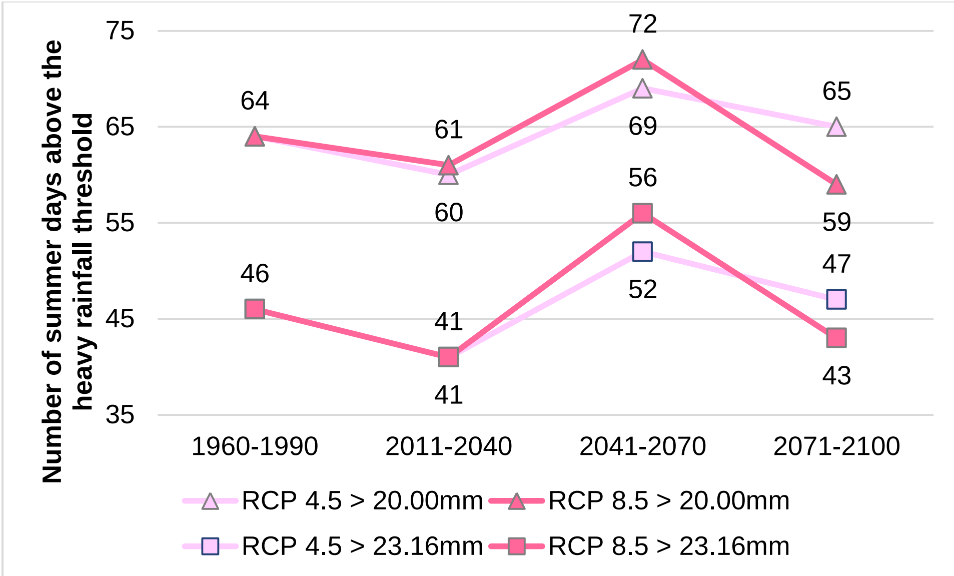


Figure 3.19 Average Number of Projected Summer Days in Goderich with Extremely High Precipitation

For the current climate period, both RCPS project a small decrease of 5%-6% from the baseline period's days with rainfall above the 20mm threshold and 11% fewer days with rainfall of 23.16mm (Table 3.6). By the 2050s, a modest increase of 8% above the number of baseline days with rainfall greater than the 20mm threshold is projected by the RCP 4.5 and 13% is projected by the RCP 8.5. The higher threshold value of 23.13mm had an increase of 13% projected by RCP 4.5 and 22% projected by RCP 8.5. By the turn-of-the-century regardless of the threshold value used, both RCPs project a decrease in days with heavy precipitation from the mid-century period retuning close to (2% for RCP 4.5) or below (-8% RCP 8.5) the baseline period's tally of days. All-in-all, the subtle changes projected by both RCPs for summertime rainfall does not indicate a significant increase in precipitation-induced flooding over those experienced during the 1960-1990 baseline climate period.

Table 3.7 The Projected Changes in the Future Number of Wawa's Days when Precipitation Exceeds Both Thresholds

Spring					
Baseline # Days and Threshold Values	40 > 20.00mm			48 > 18.56mm	
Climate Period	RCP 4.5	RCP 8.5		RCP 4.5	RCP 8.5
Current-2020s (2011-2040)	38%	40%		31%	38%
Mid-century-2050s (2041-2070)	33%	63%		31%	58%
Turn-of-the-century-2080s (2071-2100)	43%	85%		40%	77%
Summer					
Baseline # Days and Threshold Values	77 > 20.00mm			47 > 24.94mm	
Climate Period	RCP 4.5	RCP 8.5		RCP 4.5	RCP 8.5
Current 2020s (2011-2040)	-9%	-5%		-13%	-11%
Mid-century 2050s (2041-2070)	-10%	-19%		-13%	-21%
Turn-of-the-century 2080s (2071-2100)	-10%	-12%		-11%	-9%
Fall					
Baseline # Days and Threshold Values	69 > 20.00mm			61 > 20.96mm	
Climate Period	RCP 4.5	RCP 8.5		RCP 4.5	RCP 8.5
Current 2020s (2011-2040)	25%	19%		26%	23%
Mid-century 2050s (2041-2070)	33%	28%		39%	30%
Turn-of-the-century 2080s (2071-2100)	29%	33%		33%	38%
Winter					
Baseline # Days and Threshold Values	11 > 20.00mm			63 > 12.39mm	
Climate Period	RCP 4.5	RCP 8.5		RCP 4.5	RCP 8.5
Current 2020s (2011-2040)	91%	109%		44%	48%
Mid-century 2050s (2041-2070)	109%	118%		52%	65%
Turn-of-the-century 2080s (2071-2100)	100%	200%		56%	94%

For Wawa's 30-year baseline springs, there were 40 days where daily precipitation exceeded 20mm and 48 days where precipitation exceeded the 95th percentile threshold of 18.56mm per day (Table 3.7). Because there is little difference between threshold values and the corresponding number of days when these values are exceeded this analysis will group the results together. Figure 3.20 shows the general trends in the RCP projection of the springs heavy precipitation events. In this figure RCP 8.5 projections are the dark lines and show a steady increase in the future number of heavy precipitation days. The RCP 4.5 projections are the lighter lines and show a leveling off in the projected number of heavy precipitation following the current climate period with modest increases and decreases.

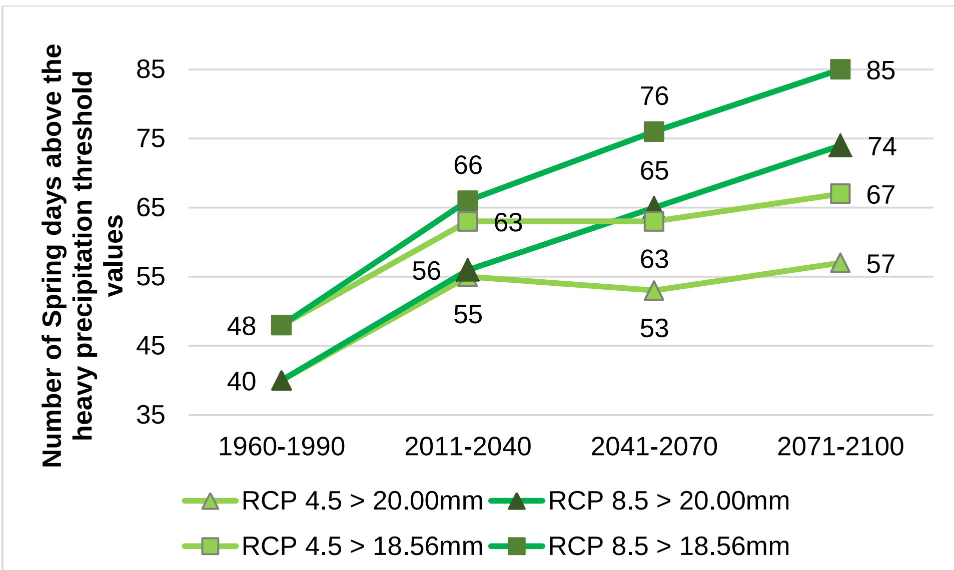


Figure 3.20 Average Number of Projected Spring Days in Wawa with Extremely High Precipitation

More specifically, an increase in the number of spring days with precipitation above these precipitation thresholds is expected for the current climate period with only one exception. Both RCPs project about a 40% increase over the day count for the baseline period, but RCP 4.5 projects a lower increase of 31% for the number of days with precipitation above 18.56mm (Figure 3.20). By the mid-century the RCP 4.5 projections of change from the baseline period hover at about 32% but the RCP 8.5 projections jump up to an increase of about 60% over the baseline period's number of heavy precipitation days. By the 2080s climate period both RCP projections are for an increase above the mid-century projections with RCP 4.5 projecting a modest increase of 44% over baseline while RCP 8.5 projections continue to grow almost doubling of the baseline projections with a 77 to 85% increase in spring days with heavy precipitation.

Given that the baseline spring mean temperature for Wawa was 1.0°C (Figures 3.4 and 3.5) some of the baseline's spring precipitation was likely snowfall. In the future with the spring temperatures warming (Figures 3.4 and 3.5) the number of spring heavy precipitation events that fall as snow will likely decrease. During the current climate period, the 31 to 40% increase in heavy spring precipitation events will likely fall as either snow, freezing rain or rain because the mean temperatures are still hovering close to the freezing point. However, by the mid-century and the end of the century the warming of spring temperatures will mean that the increases in spring precipitation above the baseline occurrences will likely induce an increase in precipitation-based flooding. This precipitation induced flooding is most likely under the business as usual of the RCP 8.5 scenario with its projections of a 60% increase by mid-century in these heavy precipitation days and an increase of 77 to 85% by the turn-of-the-century.

Wawa's fall 95th percentile for precipitation was calculated to be 20.96mm, almost equal to the fixed threshold value and as a result the number of days exceeding these threshold values are also almost equal. During the 30-year baseline period (1960-1990) 69 fall days exceeded the 20.00mm threshold for heavy precipitation and 61 days exceeded the 20.96mm threshold. Again, because there is so little difference between the threshold values and the baseline day count the future projections of the expected change from baseline will be grouped together. Figure 3.20 shows the RCP projection trend lines for heavy precipitation fall days. The RCP 8.5 projections are the dark lines and show a steady increase from the baseline period through to the end of the century in the number of heavy precipitation days. The RCP 4.5 projections are the lighter lines and show an increase in the number of these heavy precipitation days peaking at the mid-century and declining slightly by the end of the century. Because the threshold values are almost equal, the projected trends between RCP 4.5 and 8.5 have a maximum difference of 10 days but are most often 3 or 4 days apart (Figure 3.21).

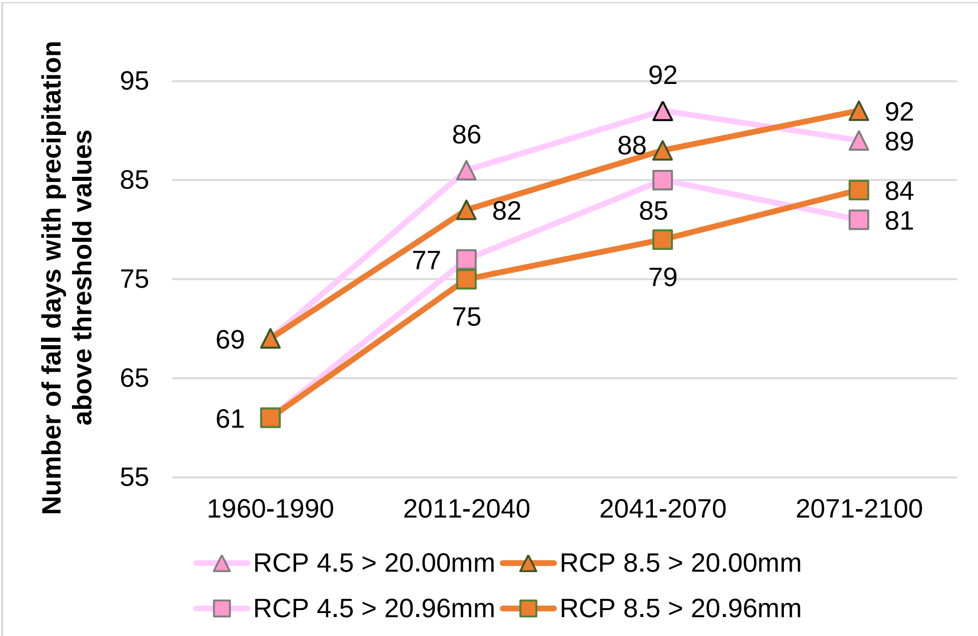


Figure 3.21 Average Number of Projected Fall Days in Wawa with Extremely High Precipitation

Wawa's future fall seasons are expected to have an increase of 20% to 39% increase in days with heavy precipitation above the baseline period projected by RCP 4.5 and 8.5 respectively (Table 3.7). By mid-century the RCP 4.5 projects an increase of 33 to 39% of heavy precipitation days over the baseline's while RCP 8.5 projects a lower percentage change of 28 to 30%. By the end of the century, RCP 4.5 projects an increase of about 30% over baseline while RCP 8.5 projects 33 to 38% over the baseline's days with heavy precipitation. These increases in precipitation could result in flooding especially if they occur in close succession.

For Wawa's winter season 11 days during the 30-year baseline period had 20mm or more precipitation and 63 days had 12.39mm or more of precipitation (Table 3.7 and Figure 3.21). Just like Goderich, this is the widest discrepancy between the number of heavy precipitation days and for this season 20mm is likely an extremely heavy precipitation event.

Remember, there is approximately a 10 to 1 relationship between rainfall and snowfall depth, so 20mm of precipitation is roughly 20cm of snow. Even with such a great difference between both the baseline days counts and the threshold values, RCP 4.5 still projects a levelling off or reduction in the number of days projected after the mid-century while RCP 8.5 projects a slight increase in these heavy precipitation events (Figure 3.22). Because of the differences in both baseline day counts and threshold values this season's analysis will be separated into two groups based on their associated threshold values.

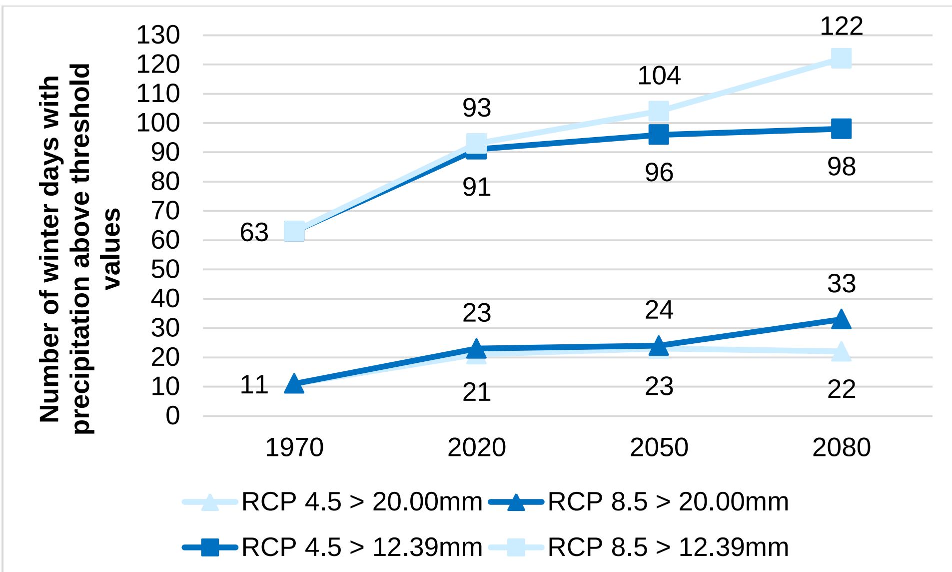


Figure 3.22 Average Number of Projected Winter Days in Wawa with Extremely High Precipitation

For Wawa's future winter seasons both RCPs project a doubling over the baseline in the number of days with precipitation over the 20mm threshold as early as the current climate period (Table 3.7). For the current climate period, an increase of 92% just shy of doubling the baseline number of days with heavy precipitation is expected, while the RCP 8.5 projects and increase of 109%. Then the projections for RCP 4.5 level off changing by only 1 or 2 days while the RCP 8.5 level off similarly up to the mid-century but by end of the century triple from their baseline values with an increase of 200% (Table 3.7). For the 95th percentile threshold of 12.39mm both RCP projections follow similar trend with the lower emission scenario (RCP 4.5) projecting a 44% increase for the current climate period and ending with a 56% increase in the number of days with heavy precipitation by the end of the century. RCP 8.5 has a continually increasing number of projected heavy precipitation days starting with a 48% increase in the current climate period and ending with a 94% increase at the end of the century.

The implications of this doubling and possible tripling of heavy precipitation days in the winter depends on the winter temperatures. When the temperatures remain below freezing this precipitation will fall as snow and potential blizzards if winds are part of the storm system. Heavy snowfalls may result in an increased need for snow removal from the municipality's roads and potentially an increase in springtime flooding when the snow load melts. But the insulation the snow cover provides can keep the underground temperatures above freezing and protect buried infrastructure from the frost line advance associated with freeze- thaw cycles or extremely cold temperatures. Due to warming of the winter seasons and the increase in winter days projected to be above freezing (Figure 3.13) it is likely that some of these heavy precipitation events will be freezing rain or maybe even rain storms by mid-century. With the maximum daily temperatures at the end of the century projections of a 39% or 53% increase in the number of days above freezing (Figure 3.13), it's increasingly likely by the turn-of-the-century that some of these storms will be freezing-rain or rainfall events (Cheng, Auld, Li, Klaassen, & Li, 2007) .

During the 30 summers of the baseline period 77 days had heavy precipitation above 20mm while 47 had 24.94mm or more precipitation. The future summer seasons for Wawa are expected to see a decline in the number of heavy precipitation events compared to those experienced during the baseline period. Figure 3.23 shows this decline is projected regardless of the threshold values used but that the RCP 4.5 projections remain steady from the current climate period to the end of the century. The RCP 8.5 projects a further dip at the mid-century that rebounds back to approximately the current century projected count of days by the end of the century.

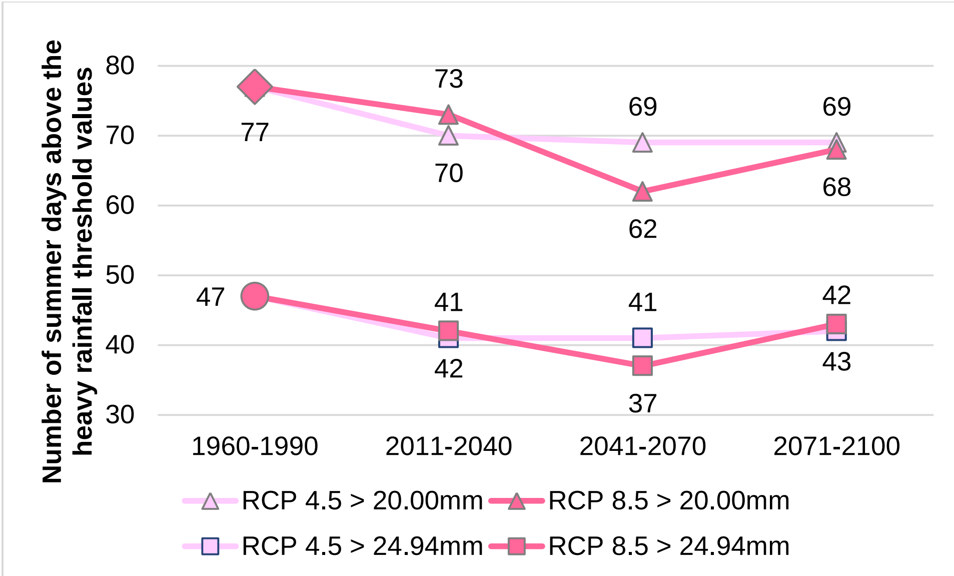


Figure 3.23 Average Number of Projected Summer Days in Wawa with Extremely High Precipitation

The RCP 4.5 projections hold steady from the current climate period to the end of the century at a decrease of about 11% in the number of heavy precipitation days below the baseline count regardless of the threshold value used. The number of heavy precipitation days projected by RCP 8.5 starts with a decrease of 5% or 11% depending on the threshold value used for the current climate period. A further drop to about 20% below the count of the baseline's days with heavy precipitation by mid-century are projected by both RCPs regardless of the threshold value used. At the end of the century the RCP 8.5 projections are practically equal to the RCP 4.5 projections for this climate period of a 10% decrease below the baseline count of heavy precipitation days.

Flooding is unlikely to occur any more frequently than it did during the summer months of the baseline period as the number of heavy precipitation days in the future is projected to be less under both emission scenarios. However, if several days of heavy rainfall occur in succession summer flooding may still occur.

Overall, the projections of the most current GCMs for the summers of both municipalities expect there to be very little change in the number of heavy precipitation days and flooding is unlikely to occur any more frequently than it did during the summer months of baseline period. The spring and winter seasons for both municipalities are expected to experience a greater increase in the number of heavy precipitation days than the fall seasons. For both municipalities, this could lead to more spring time flooding due to snow melt and rainfall. Both municipalities will likely see an increase in the number of days with heavy precipitation falling as freezing-rain or rainstorm that were once snowstorms due to temperatures hovering around 0° as the winters and springs warm.

3.7 Dry Spells

Climate change projections for many places are for an increase in the frequency and severity of dry spells or drought. To assess the changes in drought risk two dry spell measures are commonly used. One computes the maximum number of consecutive days without precipitation and the other counts the number of dry spell periods. Dry spells periods are defined as periods of 5 or more consecutive days with no precipitation. These measures are so commonly used together that CDO uses one command to compute both indices.

Spring and summer dry spells are associated with water deficits lowering crop yields, unless irrigation is provided. So, water demand increases to meet irrigation needs at the very same time as there is a decrease in the available quantity of water. Without adequate rainfall to recharge water supplies increased demand can exceed supply leading to water shortages. Dry spells in the late spring and summer and early fall can increase the risk of forest fires.

For Goderich, there is very little variation between the projections for RCPs 4.5 and 8.5 for the maximum length of consecutive dry days (Figure 3.24). So little that the two projections will be grouped together for this analysis. The baseline period had on average a maximum of 17 consecutive spring dry days; 21 consecutive summer dry days; 22 consecutive fall dry days; and 16 consecutive winter dry days.

For the springs of both the current and mid-century climate periods the maximum number of consecutive dry days increases by 5 days to about 22 consecutive days or three weeks of dry weather. By 2100 the number of dry days drops back down to about 18 consecutive days. Roughly 3 weeks of dry spring days for the current and mid-century climate periods may cause some water stress issues but as long as the winter had enough precipitation there is unlikely to be much more water stress in these future periods over the baseline period.

The future summer seasons have only a 3-day difference between the 21 consecutive dry days of the baseline period in any of the projected climate periods. Once again there is so little difference between the baseline period and any of the future projections that water stress is unlikely to be much different than that experienced during the baseline period. The future fall seasons are projected to have a shorter duration of consecutive dry days or a 1-day increase over the baseline maximum of 22 consecutive dry days.

The future winter seasons are projected to experience a decrease in the maximum number of dry days by 3 days by 2020 and 4 days by 2050 from the baseline of 16 consecutive dry days. The winter period of 2071-2100 is projected to have the largest increase under the RCP 8.5 scenario of 9 days above the baseline maximum length of consecutive dry days resulting in 25 days. However, this climate period is also associated with an increase in days with heavy precipitation (Figure 3.18), so this long dry spell is likely to have little overall impact.

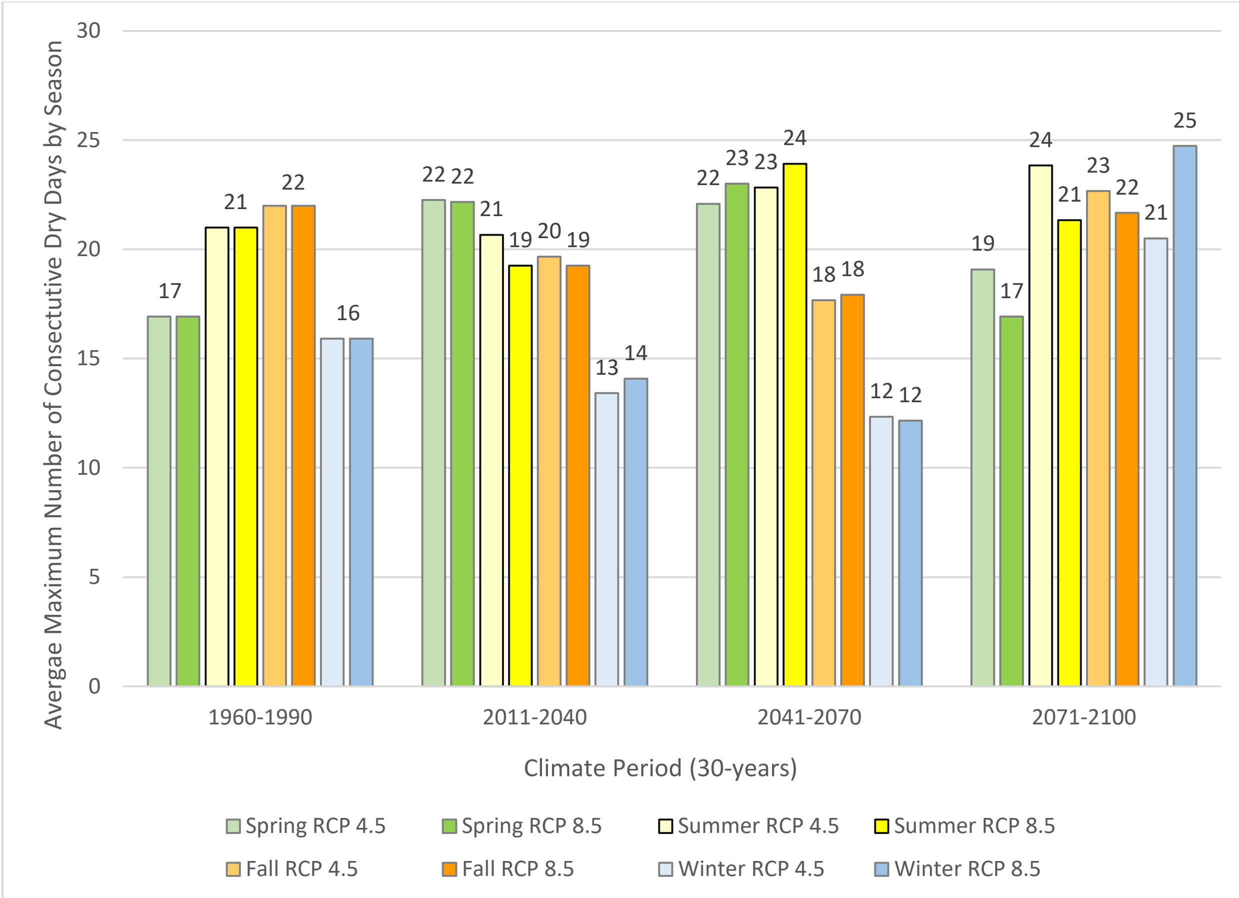


Figure 3.24 The Maximum Number of Consecutive Dry Days for Goderich by Season Projected by both RCPs 4.5 and 8.5

Projections of the frequency of 5-day dry spells for Goderich show very little change over the baseline period for all future season with few exceptions (Figure 3.25). The 30-years of baseline time period had on average 88 spring 5-day dry spells; 118 summers 5-day dry spells; 86 fall 5-day dry spells; and 41 winter 5-day dry spells. Both exceptions occur in the summer seasons. The projections for the 30 summers in the current climate period (2011-2040) have 12 to 14 fewer 5-day dry spells than the 30 summers in the baseline period (1960-1990). At the end of the century (2071-2100) the RCP 4.5 projects roughly the same amount of dry spells for the summer seasons as the baseline period but the RCP 8.5 projection shows only 96 5-day dry spells for the same climate period.

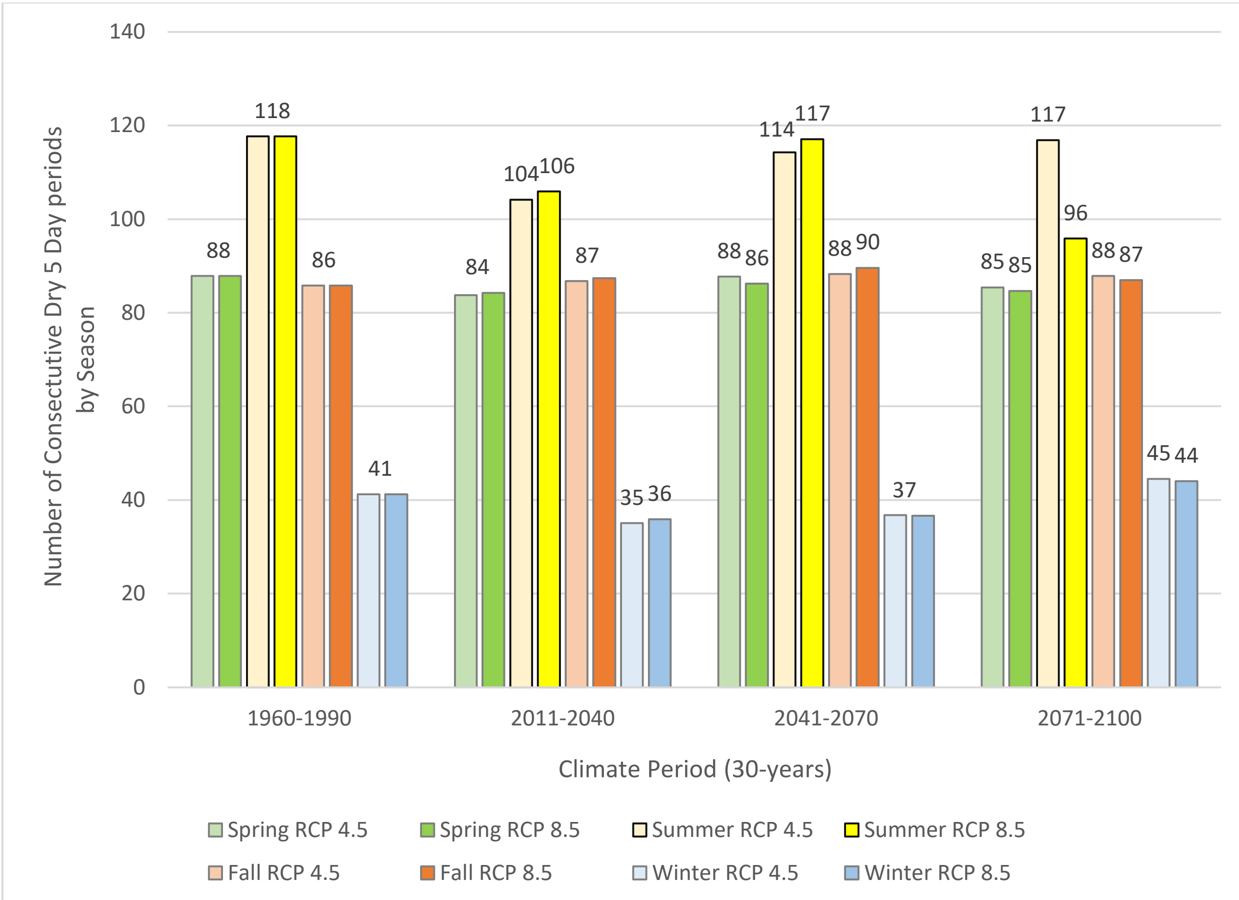


Figure 3.25 The Projections of the Frequency of 5-day Dry Spells for Goderich by Season for both RCPs 4.5 and 8.5

For Wawa, again there is very little variation between the projections for RCPs 4.5 and 8.5 for the maximum length of consecutive dry days (Figure 3.26). So little that the two projections will be grouped together for this analysis. The baseline period had on average a maximum of 25 consecutive spring dry days; 17 consecutive summer dry days; 20 consecutive fall dry days; and 15 consecutive winter dry days.

For the future climate periods the maximum consecutive number of dry days increases by only 2-5 days. The springs in the current climate period are projected to have the highest number of consecutive days of dry weather with 28 to 29 days, 4 to 5 days longer than the 30 springs on the baseline period. By the mid-century, the consecutive number of days drops back below the baseline and by the end of the century the projections of both RCPs are for a maximum number of 26 consecutive dry days approximately the same length as the baseline.

The springs for Wawa between 2011-2040 are projected by both RCPs to have the longest dry spells, up to a month in duration. If these occur early in the season when the winter's snows are still melting then these dry spells are unlikely to be an issue but if they occur later in the season, vegetation may experience water stress. If the late winter has also been dry that year, the risk of forest fires may increase.

The future summer seasons in Wawa have only a 3-day difference between the 17 consecutive dry days of the baseline period in any of the projected climate periods. Once again there is so little difference between the baseline period and any of the future projections that water stress is unlikely to be much different than that experienced during the baseline period.

The future fall seasons are projected to have a change of 2 to 3 days in the duration of consecutive dry days from the baseline maximum of 20 consecutive dry days. The 30 fall seasons of the current climate period (2011-2040) are projected to have 21 or 22 days of consecutive dry weather. But the fall seasons in the latter half of the century are projected to have their maximum length of consecutive dry days shortened by 2 to 3 days, to 17 or 18 day stretches of dry weather. Given that there is little difference between the baseline's approximately 3 week dry spell and those of the current climate period, Wawa's experience in dealing with these dry spells should be sufficient and likely no further mitigation is needed. By the latter half of the century the number of these 5-day dry spells decreases, so again it is unlikely adaptation or mitigation measures will be needed.

The future winter seasons are projected to experience a slight increase in the maximum number of dry days of 1 to 2 days in the 2011-2040 period and 1 to 3 days in the latter half of the century from the baseline of 15 consecutive dry days. The future winter seasons for 2041-2070 and 2071-2100 each have one RCP with a projection of 18 days and the other RCP projecting a lower 16 or 17 stretches of dry weather. These latter climate periods are also associated with an increase in days with heavy precipitation (Figure 3.22), so the extension of 2 to 3 days over the baseline's dry spell length is unlikely to become an issue.

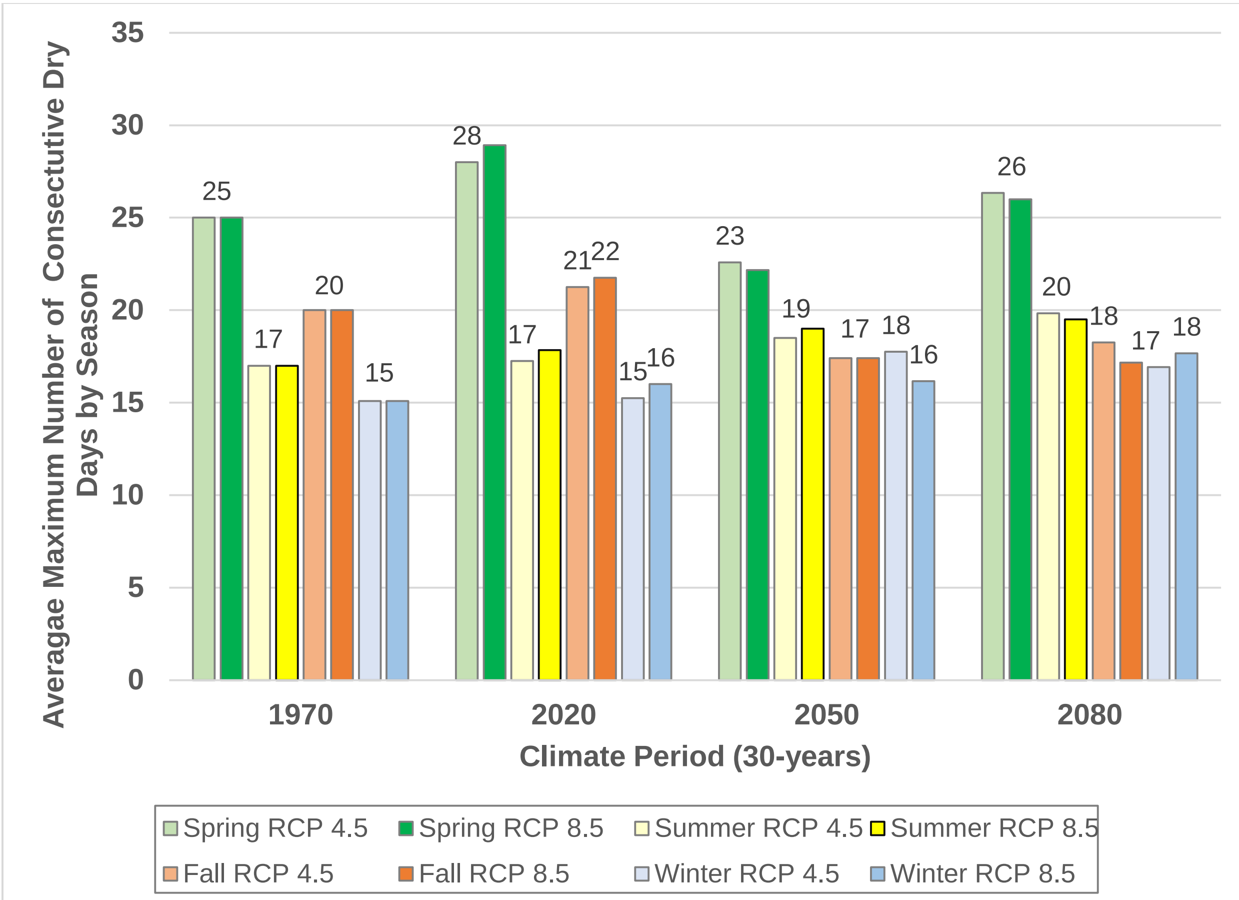


Figure 3.26 The Maximum Number of Consecutive Dry Days for Wawa by Season Projected by both RCPs 4.5 and 8.5

Projections of the frequency of 5-day dry spells for Wawa show a decrease or stay roughly the same as for the future's spring, summer and fall seasons when compared with the spring, summer and fall seasons of the baseline period (Figure 3.7). The projections for the winters of 2011-2040 and 2041-2070 also remain at about the same frequency or are projected to experience even fewer 5-day dry spells than those of the baseline period. The only exception to this somewhat steady state trend is the projections for the winters of the 2071-2100 climate period. These winters are projected to experience an increase in the frequency of 5-day dry spells with 6 to 8 more over the 30-year time span.

Overall, for both Goderich and Wawa these projections, showing little change in the length and frequency of dry spells is significant because many other parts of the world are expected to experience more frequent and longer dry spells. Although they used a different method of downsizing and dry spell calculation, the Interdisciplinary Centre on Climate Change (2015) group had similar findings of little change in dry spells for the Waterloo Region.

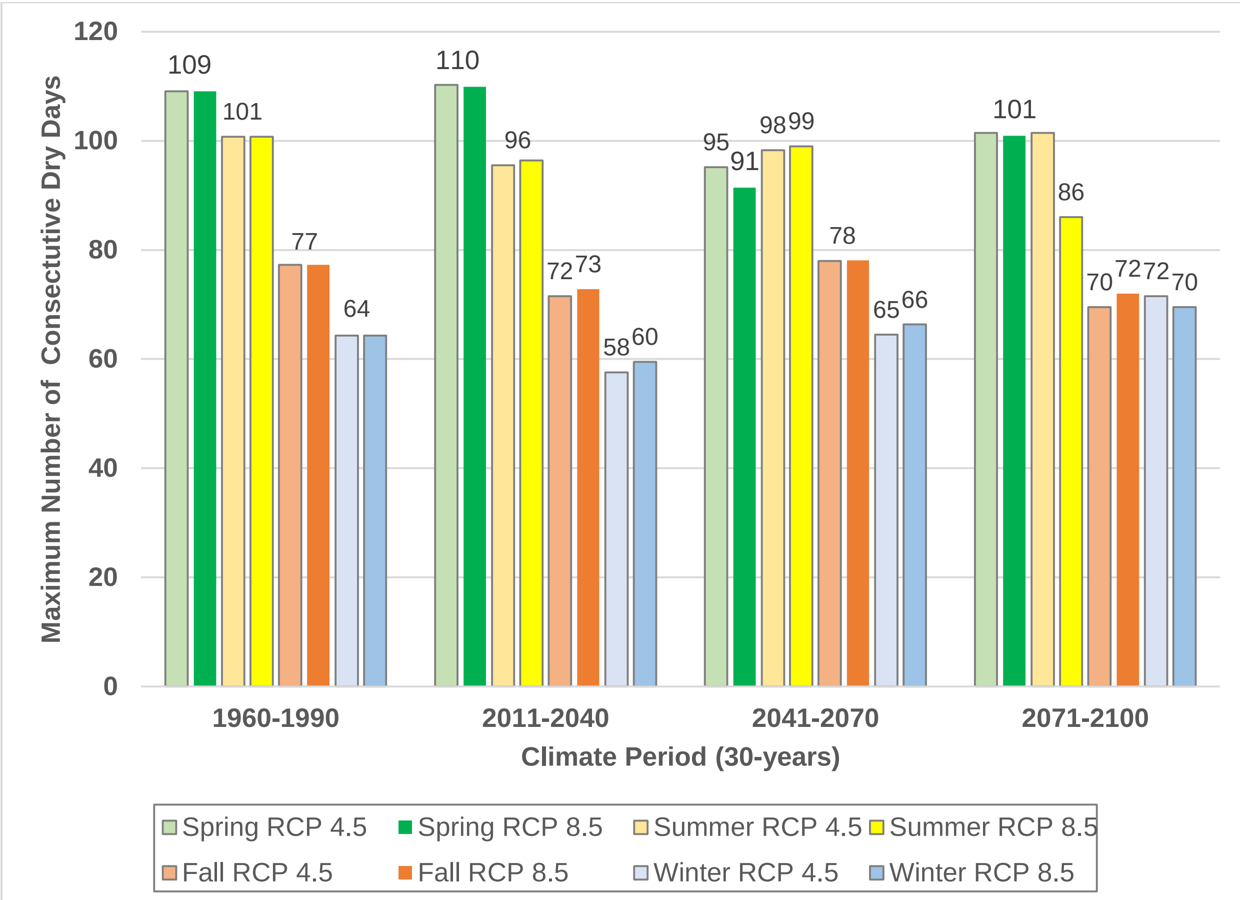


Figure 3.27 The Projections of the Frequency of 5-day Dry Spells for Wawa by Season for both RCPs 4.5 and 8.5

4.0 SUMMARY OF CHANGING CLIMATIC CONDITIONS AND RELATED IMPACTS FOR GODERICH AND WAWA

Annual Mean Temperatures

Mean temperatures are a gauge used to assess overall climate change at the global and local scale.

- Both communities are expected to see an increase of 2°C as early as this climate period and a continual warming trend to as much as +6°C for Goderich and +7°C for Wawa in the late century

Seasonal Mean Temperatures

Annual mean temperatures are useful when projecting general trends but the seasonal mean temperatures provide information to answer questions like, are future summers likely to be hotter?

- All seasons are expected to be warmer for both locations
- Little difference in the warming temperature increases expected for both locations in springs, summers, and fall seasons
- The winter seasons are expected to warm by the greatest amounts for both communities but Wawa's winters warm more than Goderich's

Extreme Heat Days

Extremely hot days are defined as days with temperatures above 30°C

- Projections for the spring, summer and fall seasons are that both locations will experience an increase in extremely hot days but the summer seasons have the largest increases
- Goderich has a much higher number of days that surpass the extreme heat threshold than Wawa

Tropical Nights

Tropical nights are defined as nights with temperatures of 20°C and without nighttime cooling the risk of heat waves and the impacts associated with extreme daytime temperature heat are likely to increase.

- Goderich has a higher number of projected tropical nights than Wawa and will likely experience more heat waves.

- if we remain on the higher emission pathway (RCP 8.5) Wawa will likely experience heat waves by the end of this century, something that is likely quite a rare occurrence for this municipality.

Extremely Cold Winter Nights

Extremely cold winter nights are defined as nights when the temperatures drop below the statistically derived 10th percentile threshold value. Goderich's 10th percentile was -14°C and Wawa's was -27.4°C, in other words 10% of the winter days between 1960-1990 had temperatures below these two threshold values.

- Goderich's calculated extreme cold threshold is about half of Wawa's calculated threshold

- By as early as the current climate period both locations experience a decrease to about half as many extremely cold days

- By the mid-century both communities expect a further decline in the number of days by about 20% to 30%

- RCP 8.5 projections for both communities by the end of the century are for about 94% fewer extremely cold days than the baseline period

Frost Free Winter Days

When minimum winter temperatures are above 0°C the whole day experiences thawing temperatures. When maximum winter temperatures are above 0°C daytime thawing occurs. A return to freezing temperatures results in a freeze-thaw cycle. Precipitation falling when temperatures are above freezing may fall as rain or freezing-rain.

- For both municipalities, there is a continual increase in the number of days where the winter minimum or maximum temperatures are above freezing

- By 2050s Goderich likely experiences fewer freeze-thaw cycles, and perhaps a shortening of the winter season, by the turn-of-the-century there will be even fewer freeze-thaw cycles and it's even more likely there will be a shortening of the season

- Wawa, with its more norther location, has historically experienced far fewer freeze-thaw cycles but will likely experiencing an increase in these freeze-thaw cycles and the associated impacts on local infrastructure damage and repair costs

Number of Days with Extremely Heavy Precipitation

Regardless of the threshold values used to define extreme precipitation (20mm or the 95^{th} percentile value for each location and season) these are the type of rare events that could result in flooding, snowstorms or freezing-rain events depending on the temperatures of the day.

- Overall biggest increases in the number of days with precipitation exceeding the threshold values are the winters and springs for both locations
- The number of Wawa's winter days with extreme precipitation are expected to double as early as the current climate period
- Warmer winter seasons means storms could be freezing-rain or rain storms instead of snow storms for both locations
- Summer is the only season with decreases in extreme precipitation events for both locations

Dry Spells

The maximum number of consecutive dry days and the number of 5-day dry periods are measures used to assess future dry spells.

- Overall, there is little projected change in the maximum length of consecutive dry days and the frequency of 5-day dry spells

5.0 References

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Appendix 1 Methodology

Here we provide more details about our methodology and descriptions of the data sets, about hardware, software, data set sizes, and expertise.

Here is a set of links to some instructional videos showing our methodology and the software used to work with the GCM climate data to produce the Extreme Weather Indices for this report.

Links to Videos to follow

Generally, the climate data were separated into the 4 seasons, the extreme weather indices were calculated by writing a set of CDO commands. The months of December, January and February formed the Winter season; March, April and May formed Spring; June, July and August formed Summer; and September, October and November formed Fall. Initially, a single GCM was chosen (usually ACCESS1-0-r1, simply because it is first alphabetically) to do a test run for the baseline climate period for both locations. The output files were reviewed to insure the command set was correct and the results made sense. Adjustments were made to the command lines if needed and once the initial runs were satisfactory the command set was run for all 12 models, for both RCPs for Goderich and Wawa. The final command lines collated the output files of the 12 models into a single file and converted that NetCDF file into a text file format. The next step was to import the files into an Excel spread sheet, where the data were graphed. Initially this was done to screen for outliers before the data were averaged to produce a single extreme value, however, there were so few outliers that their removal changed the second decimal place in the calculation of the overall average. So in the end this graphing was done mostly to recheck that data set and results made sense before the data were averaged to produce a single extreme weather index value for each RCP.

Before we continue with a detailed description of the CDO operators and input files used we have provided some background information on downscaling, the Pacific Climate Impacts Consortium data sets, and the NetCDF format of climate files.

Description of Downscaled GCM Data Sets

Downscaling GCM climate data to use for local applications has a steep learning curve and involves some specialized knowledge and computing skills. For example, GCMs do not use a latitude and longitudinal grid because the narrowing of the grid cells towards the poles distorts the model's algorithms. So, the model employs another grid system such as a rotated grid where the North pole is repositioned on a land mass near the equator. To find the GCM grid cells with future climate data for our location of interest you either have to find the corresponding coordinates in the GCMs grid system or run an algorithm to recalculate all the grid cell coordinates to a standard latitude and longitude system. Therefore, climate data already downscaled for local applications within Canada with a standard latitude and longitude grid was found and used in this study. The Pacific Climate Impacts Consortium (PCIC) provides statistically downscaled daily climate data for all of Canada at a 10-km grid size. These data sets are based on the most recent GCM projections (the Fifth Assessment Report or AR5) and historically gridded climate data for Canada (Pacific Climate Impacts Consortium, 2014). This data can be downloaded from their website and more information regarding the statistical downscaling methods they used to produce their data sets are also found there. These climate data sets are available for 3 RCP scenarios, 2.6; 4.5 and 8.5. Climate data sets are provided in the NetCDF format and therefore software tools are needed to work with the data in this form.

NetCDF is both a set of software libraries and a self-describing machine-dependent language format. The format was developed and is maintained by Unidata specifically to facilitate the creation, access and sharing of array-oriented scientific data sets (Unidata, NetCDF 4.4.1.1). They also maintain a repository of software to manipulate and display NetCDF data (Unidata). Of the hundreds of options we chose the Climate Data Operators (CDO) package developed by Uwe Schulzweida at the Max Planck Institute for Meteorology and downloaded version 1.8.2 for windows (Climate Data Operators, 2017). This free software is a collection of command line operators have a simple format that requires little prior experience with coding or programing and is designed to work in a Unix system. Alternatively, CDO can be used within Cygwin, a Linux-like environment for Windows (Cygwin, 2017). The CDO package contains a collection of more than 600 operators with at least 35 dedicated to computing climate indices of temperature and precipitation extremes (Climate indices with CDO, 2015). Another reason this package was chosen is that there is an active online forum where you can post questions. Other users and the CDO developers answer questions with a short turnaround time of 1-3 days, greatly enhancing the novice user's experience. If you are using Windows and the Cygwin interface it is strongly recommended that you consult the CDO website to see which Cygwin libraries you'll need to install (Climate Data Operators, 2017)

CDO operator Description, Commands and Input Data

A set of CDO commands were written for all 12 GCMs, 4 climate periods and two RCPs.

The output files were collated into the 4 climate periods using the *mergetime* operator. Finally, the *outputtab* operator was used to convert the machine language NetCDF files into text files.

For each index, a brief description will be given of how it was derived the CDO operators used (the name of the operator will be presented in italics).

Mean temperature

The seasonal statistical commands calculate a chosen statistic over the daily time steps within each season for each year of the input data set. The input data set was tasmean. For each of the 12 GCMs there were 30 mean values for each season. The *mergetime* and *outputtab* operators produced files in tab delimited text format that could be imported into excel.

Extreme Heat

The Summer Days Index (*eca_su)* operator was used. The input data set was tasmax but to use this operator the temperature data needs to be in degrees Kelvin. Adding 273.15 to degrees Celsius will convert the temperatures into Kelvin, so the CDO add a constant operator along with the specified constant's value (*addc,273.15*). The default value for the *eca_su* is 25°C but you can override this by specifying another value in Celsius making the operator, *eca_su,30.*

Tropical nights

CDO has a tropical nights operator, *eca_tr* with a default threshold value of 20°C. This operator filters and sums all the days with values above the threshold value. The input data sets were the minimum daily temperatures (tasmin) for the spring, summer, and fall seasons.

Extremely Cold days

To estimate the number of extremely cold days the distribution of baseline minimum temperatures for both Wawa and Goderich were used. The extreme tales of these distributions represent the 10th and the 90th percentiles. For Wawa, the temperature at the 10^{th} percentile of the baseline climate period was -27.4°C, for Goderich which is much further south and located on one of the Great Lakes the 10^{th} percentile minimum temperature was -14°C. To calculate these 10^{th} percentile values the seasonal percentile values operator was used *seaspctl,p* where *p* is defined by the user in this case we wanted the 10^{th} percentile so the number was 10 (*seaspctl,10*). Before using this operator two additional values must be derived these are the minimum and maximum tasmin temperatures for baseline data set. Once you calculated the 10^{th} percentile values another set CDO operators are used. To find all the tasmin values below the 10^{th} percentile the conditional operator, less than constant (e.g. when building the command lines for Goderich this operator would be *lec,-27.4*). This operator assigns a value of one when the condition is true and zero when it is false. To calculate the number of times the minimum daily temperature within one of our four climate periods fell below the threshold value the ones in the output file produced by the conditional operator were summed.

Number of Days with Extremely heavy Precipitation

To estimate the number of days with extremely heavy precipitation two threshold values were used, a fixed value of 20mm and the 95th percentile derived from the variable created from the baseline's precipitation pr1 (where all days with less than 1mm of precipitation were reclassified as missing values). These pr1 files were needed so that the precipitation distribution curves used to derive the 95th percentile value were not skewed. The CDO module used to determine seasonal 95th precipitation percentiles were the same as those used to derive the 10th percentile extremely cold thresholds, *seaspctl,p*. But this time we were calculating the 95th percentile so *seaspctl,95* was used. Before using this operator the two additional values the must be derived these were the minimum and maximum pr1 values from the baseline data set. The 95th percentile values were calculated for each season.

The conditional operator greater than or equal to constant (*gec*)) was used to determine how many days in each season crossed either threshold. E.g. *gec,20* for the fixed threshold value of 20mm and for Goderich the winter 95th percentile was calculated to be 12.39mm so *gec,12.39* was used. This operator assigns a value of one when the condition is true and zero when it is false. To calculate the number of times the daily precipitation exceeded a threshold ones in the output file produced by the conditional operator were summed.

Dry Spells

To estimate the number of dry days the CDO operator *eca_cdd* was used with the original GCM precipitation as input files. This module outputs the largest number of consecutive dry days and the number of 5-day dry periods.

Appendix 2. Full Results of Our Calculations

Changes in Daily Mean temperatures

Append 1. Mean temperatures for Goderich RCP 4.5

Climate Period	Winter Mean Temp °C	Spring Mean Temp °C	Summer Mean Temp °C	Fall Mean Temp °C
1970s	-4.5	5.7	18.7	9.6
2020s	-2.3	7.3	20.3	11.3
2050s	-1.0	8.4	21.4	12.3
2080s	-0.3	9.0	22.1	13.1

Append 2. Mean temperatures for Goderich RCP 8.5

Climate Period	Winter Mean Temp °C	Spring Mean Temp °C	Summer Mean Temp °C	Fall Mean Temp °C
1970s	-4.5	5.7	18.7	9.6
2020s	-1.8	7.8	20.3	11.5
2050s	-0.2	9.1	22.4	13.2
2080s	2.3	11.0	24.8	15.2

Append 3. Mean temperatures for Wawa RCP 4.5

Climate Period	Winter Mean Temp °C	Spring Mean Temp °C	Summer Mean Temp °C	Fall Mean Temp °C
1970s	-12.2	4.8	14.4	1.0
2020s	-9.8	6.6	16.0	2.5
2050s	-8.0	7.8	17.2	3.9
2080s	-7.1	8.4	17.8	4.5

Append 4. Mean temperatures for Wawa RCP 8.5

Climate Period	Winter Mean Temp °C	Spring Mean Temp °C	Summer Mean Temp °C	Fall Mean Temp °C
1970s	-12.2	1.0	14.4	4.8
2020s	-9.6	2.7	16.1	6.8
2050s	-7.2	4.3	18.0	8.5
2080s	-4.1	6.8	20.4	10.8

Extreme Heat

Append 5. Number of days for Goderich with temperatures over 30°C RCP 4.5

Climate Period	Spring Days < 30°C	Proportion of Season's days	Summer Days < 30°C	Proportion of Season's days	Fall Days < 30°C	Proportion of Season's days
1970s	4	0%	39	1%	3	0%
2020s	11	0%	142	5%	6	0%
2050s	18	1%	276	10%	15	1%
2080s	31	1%	301	11%	17	1%

Append 6. Number of days for Goderich with temperatures over 30°C RCP 8.5

Climate Period	Spring Days < 30°C	Proportion of Season's days	Summer Days < 30°C	Proportion of Season's days	Fall Days < 30°C	Proportion of Season's days
1970s	4	0%	39	1%	3	0%
2020s	12	0%	164	6%	13	0%
2050s	24	1%	419	15%	32	1%
2080s	72	3%	965	35%	101	4%

Extremely Cold Days

Append 7. Goderich's days falling below -14°C (10th percentile minimum temperatures)

Climate Period	Extremely cold Days (below -14° C)	Season	Proportion Season's Nights	Extremely cold Days (below -14° C)	Season	Proportion Season's Nights
1970s	274	Winter RCP 4.5	10%	274	Winter RCP 8.5	10%
2020s	130	Winter RCP 4.5	5%	119	Winter RCP 8.5	4%
2050s	67	Winter RCP 4.5	2%	44	Winter RCP 8.5	2%
2080s	63	Winter RCP 4.5	2%	15	Winter RCP 8.5	1%

Append 8. Wawa's days falling below -27.4°C (10th percentile minimum temperatures)

Climate Period	Extremely cold Days (below -27.4° C)	Season	Proportion Season's Nights	Extremely cold Days (below -27.4° C)	Season	Proportion Season's Nights
1970s	280	Winter RCP 4.5	10%	280	Winter RCP 8.5	10%

2020s	161	Winter RCP 4.5	6%	152	Winter RCP 8.5	6%
2050s	87	Winter RCP 4.5	3%	65	Winter RCP 8.5	2%
2080s	63	Winter RCP 4.5	2%	18	Winter RCP 8.5	1%

NUMBER OF DAYS WITH EXTREME PRECIPITATION

Append 9. Number of days with precipitation greater than or equal to 20mm

Goderich RCP 8.5	Spring	Summer	Fall	Winter
1970s	31	64	62	19
2020s	41	61	63	27
2050s	53	72	69	33
2080s	57	59	72	36
Change				
2020s	35%	-6%	3%	41%
2050s	75%	12%	11%	70%
2080s	86%	-8%	17%	87%

Goderich RCP 4.5	Spring	Summer	Fall	Winter
1970s	31	64	62	19
2020s	44	60	71	22
2050s	52	69	74	29
2080s	51	65	70	27
Change				
2020s	45%	-7%	15%	9%
2050s	72%	7%	19%	32%
2080s	66%	1%	13%	26%

Wawa RCP 8.5	Spring	Summer	Fall	Winter
1970s	40	77	69	11
2020s	56	73	82	23
2050s	65	62	88	24
2080s	74	68	92	33
Change				
2020s	42%	-5%	20%	109%
2050s	63%	-19%	28%	121%
2080s	87%	-11%	34%	206%

Wawa RCP 4.5	Spring	Summer	Fall	Winter
1970s	40	77	69	11
2020s	55	70	86	21
2050s	53	69	92	23
2080s	57	69	89	22
Change				
2020s	38%	-9%	24%	26%
2050s	35%	-10%	34%	32%
2080s	44%	-10%	30%	28%

Append 10. The 95th percentile of precipitation for Wawa and Goderich from the 1960-1990 climate period

Precipitation 95th Percentile (mm)		
Season (1960-1990)	Wawa	Goderich
Winter	12	14
Spring	19	17

Summer	25	23
Fall	21	20

Append 11. The average number of days per season for Goderich and Wawa with extreme precipitation (over 95th percentile)

Goderich RCP 8.5	Spring	Summer	Fall	Winter
1960-1990	47	46	59	71
2011-2040	60	41	60	80
2041-2070	73	56	66	100
2071-2100	80	43	69	106
Change				
2011-2040	28%	-11%	2%	13%
2041-2070	55%	22%	12%	41%
2071-2100	70%	-7%	17%	49%

Goderich RCP 4.5	Spring	Summer	Fall	Winter
1960-1990	47	46	59	71
2011-2040	62	41	67	78
2041-2070	70	52	70	95
2071-2100	72	47	66	88
Change				
2011-2040	32%	-11%	14%	16%
2041-2070	56%	13%	19%	53%
2071-2100	60%	2%	12%	38%

Wawa RCP 8.5	Spring	Summer	Fall	Winter
1960-1990	48	47	61	63
2011-2040	66	42	75	93
2041-2070	76	37	79	104
2071-2100	85	43	84	122
Change				
2011-2040	38%	-11%	23%	48%
2041-2070	58%	-21%	30%	65%
2071-2100	77%	-9%	38%	94%

Wawa RCP 4.5	Spring	Summer	Fall	Winter
1960-1990	48	47	61	63
2011-2040	63	41	77	91
2041-2070	63	41	85	96
2071-2100	67	42	81	98
Change				
2011-2040	31%	-13%	26%	58%
2041-2070	31%	-13%	39%	69%
2071-2100	40%	-11%	33%	73%

Append 12. Occurrences of precipitation events exceeding the 95th percentile threshold amounts for Goderich and Wawa

Goderich	Spring (RCP 4.5)	Spring (RCP 8.5)	Summer (RCP 4.5)	Summer (RCP 8.5)	Fall (RCP 4.5)	Fall (RCP 8.5)	Winter (RCP 4.5)	Winter (RCP 8.5)
1960-1990	2%	2%	2%	2%	2%	2%	3%	3%
2011-2040	2%	2%	1%	1%	2%	2%	3%	3%
2041-2070	3%	3%	2%	2%	3%	2%	4%	4%
2071-2100	3%	3%	2%	2%	2%	3%	3%	4%

Wawa	Spring (RCP 4.5)	Spring (RCP 8.5)	Summer (RCP 4.5)	Summer (RCP 8.5)	Fall (RCP 4.5)	Fall (RCP 8.5)	Winter (RCP 4.5)	Winter (RCP 8.5)
1960-1990	2%	2%	2%	2%	2%	2%	2%	2%
2011-2040	2%	2%	1%	2%	3%	3%	3%	3%
2041-2070	2%	3%	1%	1%	3%	3%	4%	4%
2071-2100	2%	3%	2%	2%	3%	4%	4%	5%

DRY SPELLS

Append 13. Summary of RCP 4.5 Projections for Goderich

#dry days	1960-1990	2011-2040	2041-2070	2071-2100	Diff	2020s	2050s	2080s	Percent difference	2020s	2050s	2080s
Spring					**Spring**				**Spring**			
min	15	21	16	14	min	6	1	-1	min	40%	7%	-7%
max	21	28	33	33	max	7	12	12	max	33%	57%	57%
average	17	22	22	19	average	5	5	2	average	30%	30%	12%
Summer					**Summer**				**Summer**			
min	21	19	22	20	min	-2	1	-1	min	-10%	5%	-5%
max	21	28	26	41	max	7	5	20	max	33%	24%	95%
average	21	21	23	24	average	0	2	3	average	-2%	9%	13%
Fall					**Fall**				**Fall**			
min	22	19	16	21	min	-3	-6	-1	min	-14%	-27%	-5%
max	22	23	21	25	max	1	-1	3	max	5%	-5%	14%
average	22	20	18	23	average	-2	-4	1	average	-11%	-20%	3%
Winter					**Winter**				**Winter**			
min	13	13	12	20	min	0	-1	7	min	0%	-8%	54%
max	18	15	14	21	max	-3	-4	3	max	-17%	-22%	17%
average	16	13	12	21	average	-3	-4	5	average	-16%	-23%	29%
#5-day periods	1970	2020	2050	2080	Diff	2020	2050	2080	Percent difference	2020	2050	2080
Spring					**Spring**				**Spring**			
min	83	81	84	82	min	-2	1	-1	min	-2%	1%	-1%
max	92	88	93	90	max	-4	1	-2	max	-4%	1%	-2%
average	88	84	88	85	average	-4	0	-2	average	-5%	0%	-3%
Summer					**Summer**				**Summer**			
min	114	97	107	112	min	-17	-7	-2	min	-15%	-6%	-2%
max	123	109	119	124	max	-14	-4	1	max	-11%	-3%	1%

average	118	104	114	117	average	-14	-3	-1	average	-11%	-3%	-1%
Fall					**Fall**				**Fall**			
min	82	82	84	80	min	0	2	-2	min	0%	2%	-2%
max	89	89	93	93	max	0	4	4	max	0%	4%	4%
average	86	87	88	88	average	1	2	2	average	1%	3%	2%
Winter					**Winter**				**Winter**			
min	36	31	32	42	min	-5	-4	6	min	-14%	-11%	17%
max	46	40	42	47	max	-6	-4	1	max	-13%	-9%	2%
average	41	35	37	45	average	-6	-5	3	average	-15%	-11%	8%

Append 14. Summary of RCP 8.5 Projections for Goderich

#dry days	1960-1990	2011-2040	2041-2070	2071-2100	2020s	2050s	2080s	Percent difference	2020s	2050s	2080s	2080
Spring					**Spring**				**Spring**			
min	15	21	17	14	min	6	2	-1	min	40%	13%	-7%
max	21	28	32	24	max	7	11	3	max	33%	52%	14%
average	17	22	23	17	average	5	6	0	average	30%	35%	0%
Summer					**Summer**				**Summer**			
min	21	19	22	14	min	-2	1	-7	min	-10%	5%	-33%
max	21	21	30	52	max	0	9	31	max	0%	43%	148%
average	21	19	24	21	average	-2	3	0	average	-8%	14%	2%
Fall					**Fall**				**Fall**			
min	22	19	16	20	min	-3	-6	-2	min	-14%	-27%	-9%
max	22	21	27	28	max	-1	5	6	max	-5%	23%	27%
average	22	19	18	22	average	-3	-4	0	average	-13%	-19%	-2%
Winter					**Winter**				**Winter**			
min	13	13	12	21	min	0	-1	8	min	0%	-8%	62%
max	18	20	14	34	max	2	-4	16	max	11%	-22%	89%
average	16	14	12	20	average	-2	-4	4	average	-13%	-25%	25%
#5-day	1970	2020	2050	2080	Diff	2020	2050	2080	Percent	2020	2050	2080

periods									difference			
Spring					**Spring**				**Spring**			
min	83	79	81	77	min	-4	-2	-6	min	-5%	-2%	-7%
max	92	89	92	91	max	-3	0	-1	max	-3%	0%	-1%
average	88	84	86	85	average	-4	-2	-3	average	-4%	-2%	-4%
Summer					**Summer**				**Summer**			
min	114	100	108	82	min	-14	-6	-32	min	-12%	-5%	-28%
max	123	116	123	127	max	-7	0	4	max	-6%	0%	3%
average	118	106	117	96	average	-12	-1	-22	average	-10%	0%	-19%
Fall					**Fall**				**Fall**			
min	82	83	85	80	min	1	3	-2	min	1%	4%	-2%
max	89	91	94	94	max	2	5	5	max	2%	6%	6%
average	86	87	90	87	average	2	4	1	average	2%	4%	1%
Winter					**Winter**				**Winter**			
min	36	31	32	40	min	-5	-4	4	min	-14%	-11%	11%
max	46	44	40	48	max	-2	-6	2	max	-4%	-13%	4%
average	41	36	37	44	average	-5	-5	3	average	-13%	-11%	7%

Append 15. Summary of RCP 4.5 Projections for Wawa

#dry days	1960-1990	2011-2040	2041-2070	2071-2100	Diff	2020s	2050s	2080s	Percent difference	2020s	2050s	2080s
Spring					**Spring**				**Spring**			
min	22	28	22	26	min	6	0	4	min	27%	0%	18%
max	28	39	23	26	max	11	-5	-2	max	39%	-18%	-7%
average	25	29	22	26	average	4	-3	1	average	16%	-12%	4%
Summer					**Summer**				**Summer**			
min	17	17	17	17	min	0	0	0	min	0%	0%	0%
max	17	20	30	24	max	3	13	7	max	18%	76%	41%
average	17	18	19	20	average	1	2	3	average	6%	12%	18%
Fall					**Fall**				**Fall**			
min	20	20	16	13	min	0	-4	-7	min	0%	-20%	-35%
max	20	33	23	19	max	13	3	-1	max	65%	15%	-5%

average	20	22	17	17	average	2	-3	-3	average	10%	-15%	-15%
Winter					**Winter**				**Winter**			
min	15	13	14	13	min	-2	-1	-2	min	-13%	-7%	-13%
max	16	26	27	21	max	10	11	5	max	63%	69%	31%
average	15	16	16	18	average	1	1	3	average	7%	7%	20%
#5-day periods	1970	2020	2050	2080	Diff	2020	2050	2080	Percent difference	2020	2050	2080
Spring					**Spring**				**Spring**			
min	105	101	82	95	min	-4	-23	-10	min	-4%	-22%	-10%
max	114	115	98	108	max	1	-16	-6	max	1%	-14%	-5%
average	109	110	91	101	average	1	-18	-8	average	1%	-16%	-7%
Summer					**Summer**				**Summer**			
min	96	92	89	69	min	-4	-7	-27	min	-4%	-7%	-28%
max	105	103	112	103	max	-2	7	-2	max	-2%	7%	-2%
average	101	96	99	86	average	-4	-2	-15	average	-4%	-2%	-15%
Fall					**Fall**				**Fall**			
min	75	70	72	67	min	-5	-3	-8	min	-7%	-4%	-11%
max	81	77	86	78	max	-4	5	-3	max	-5%	6%	-4%
average	77	73	78	72	average	-4	1	-5	average	-6%	1%	-7%
Winter					**Winter**				**Winter**			
min	59	50	62	66	min	-9	3	7	min	-15%	5%	12%
max	69	70	74	72	max	1	5	3	max	1%	7%	4%
average	64	60	66	70	average	-5	2	5	average	-8%	3%	8%

Append 16 Summary of RCP 8.5 Projections for Wawa

#dry days	1960-1990	2011-2040	2041-2070	2071-2100	Diff	2020s	2050s	2080s	Percent difference	2020s	2050s	2080s
Spring					**Spring**				**Spring**			
min	22	28	22	26	min	6	0	4	min	27%	0%	18%

max	28	28	27	26	max	0	-1	-2	max	0%	-4%	-7%
average	25	28	23	26	average	3	-2	1	average	12%	-8%	4%
Summer					**Summer**				**Summer**			
min	17	17	17	17	min	0	0	0	min	0%	0%	0%
max	17	20	30	26	max	3	13	9	max	18%	76%	53%
average	17	17	19	20	average	0	2	3	average	0%	12%	18%
Fall					**Fall**				**Fall**			
min	20	20	16	15	min	0	-4	-5	min	0%	-20%	-25%
max	20	27	25	20	max	7	5	0	max	35%	25%	0%
average	20	21	17	18	average	1	-3	-2	average	5%	-15%	-10%
Winter					**Winter**				**Winter**			
min	15	13	14	15	min	-2	-1	0	min	-13%	-7%	0%
max	16	19	27	20	max	3	11	4	max	19%	69%	25%
average	15	15	18	17	average	0	3	2	average	0%	20%	13%
#5-day periods	1970	2020	2050	2080	Diff	2020	2050	2080	Percent difference	2020	2050	2080
Spring					**Spring**				**Spring**			
min	105	104	86	97	min	-1	-19	-8	min	-1%	-18%	-8%
max	114	115	102	106	max	1	-12	-8	max	1%	-11%	-7%
average	109	110	95	101	average	1	-14	-8	average	1%	-13%	-7%
Summer					**Summer**				**Summer**			
min	96	89	94	72	min	-7	-2	-24	min	-7%	-2%	-25%
max	105	104	102	106	max	-1	-3	1	max	-1%	-3%	1%
average	101	96	98	101	average	-5	-3	1	average	-5%	-2%	1%
Fall					**Fall**				**Fall**			
min	75	66	72	62	min	-9	-3	-13	min	-12%	-4%	-17%
max	81	80	83	77	max	-1	2	-4	max	-1%	2%	-5%
average	77	72	78	70	average	-6	1	-8	average	-7%	1%	-10%
Winter					**Winter**				**Winter**			

min	59	52	56	68	min	-7	-3	9	min	-12%	-5%	15%
max	69	65	73	77	max	-4	4	8	max	-6%	6%	12%
average	64	58	65	72	average	-7	0	7	average	-10%	0%	11%