CLIMATE SCIENCE REPORT FOR THE CITY OF HAMILTON

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Table of Contents

List of Figures

List of Tables

Glossary

Definitions have been taken from the Intergovernmental Panel on Climate Change (IPCC) (https://www.ipcc.ch/site/assets/uploads/2018/11/sr15_glossary.pdf) and Natural Resources Canada (https://www.nrcan.gc.ca/environment/resources/publications/impacts-adaptation/reports/assessments/2008/glossary/10413#R).

Baseline - A climatological baseline is a reference period, typically three decades (or 30 years), that is used to compare fluctuations of climate between one period and another. Baselines can also be called references or reference periods.

Climate Change - Climate change refers to changes in long-term weather patterns caused by natural phenomena and human activities that alter the chemical composition of the atmosphere through the build-up of greenhouse gases which trap heat and reflect it back to the earth's surface.

Climate Model - A numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes and accounting for some of its known properties. Climate models are applied as a research tool to study and simulate the climate and for operational purposes, including monthly, seasonal and interannual climate predictions.

Climate Projections - A climate projection is the simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases (GHGs) and aerosols, generally derived using climate models.

Coupled Model Intercomparison Project Phase 5 (CMIP5) - The Coupled Model Intercomparison Project (CMIP) is a climate modelling activity from the World Climate Research Programme (WCRP) which coordinates and archives *climate model* simulations based on shared model inputs by modelling groups from around the world. The CMIP3 multimodel data set includes *projections* using SRES *scenarios*. The CMIP5 data set includes projections using the *Representative Concentration Pathways (RCPs)*. The CMIP6 phase involves a suite of common model experiments as well as an ensemble of CMIP-endorsed model intercomparison projects (MIPs).

Emissions Scenarios - An emissions scenario is the difference between a future climate scenario and the current climate. It is a simplified representation of future climate based on comprehensive scientific analyses of the potential consequences of anthropogenic climate change. It is meant to be a plausible representation of the future emission amounts based on a coherent and consistent set of assumptions about driving forces (such as demographic and socioeconomic development, technological change) and their key relationships.

Ensemble Approach - An ensemble approach uses the average of all global climate models (GCMs) for temperature and precipitation. Research has shown that running many models provides the most realistic projection of annual and seasonal temperature and precipitation than using a single model.

Ensemble Mean - The average of the climate projections considered in the study.

Fifth Assessment Report - The Synthesis Report (SYR) of the IPCC Fifth Assessment Report (AR5) provides an overview of the state of knowledge concerning the science of climate change, emphasizing new results since the publication of the IPCC Fourth Assessment Report (AR4) in 2007[i].

Greenhouse Gas (GHG) - Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation, emitted by the Earth's surface, the atmosphere itself, and by clouds. Water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3), and chlorofluorocarbons (CFCs) are the six primary greenhouse gases in the Earth's atmosphere in order of abundance.

Intergovernmental Panel on Climate Change (IPCC) - Created in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), the objective of the IPCC is to provide governments at all levels with scientific information that they can use to develop climate policies. he IPCC currently has 195 members. Thousands of people from all over the world contribute to the work of the IPCC[ii].

Radiative forcing -The change in the value of the net radiative flux (i.e. the incoming flux minus the outgoing flux) at the top of the atmosphere in response to some perturbation, in this case, the presence of greenhouse gases.

RCP2.6 - Lowest projected GHG concentrations, resulting from dramatic climate change mitigation measures implemented globally. It represents an increase of 2.6 W/m^2 in radiative forcing to the climate system.

RCP4.5 - Moderate projected GHG concentrations, resulting from substantial climate change mitigation measures. It represents an increase of 4.5 W/m^2 in radiative forcing to the climate system.

RCP8.5 - Highest projected GHG concentrations, resulting from business-as-usual emissions. It represents an increase of 8.5 W/m^2 in radiative forcing to the climate system.

Representative Concentration Pathway (RCP) - Representative Concentration Pathways (RCPs) are four greenhouse gas concentration (not emissions) trajectories adopted by the IPCC for its fifth Assessment Report (AR5) in 2014. It supersedes Special Report on Emissions Scenarios (SRES) projections published in 2000. RCPs usually refer to the portion of the concentration pathway extending up to 2100.

Introduction

The purpose of the Climate Science Report is to summarize climate data for the City of Hamilton. The City of Hamilton, as defined by the Climate Atlas of Canada, summarizes data from 24 climate models. The purpose of this report is to inform how the climate is projected to change from now until predominantly the 2080s, and to provide direction for the assessment of climate risk and eventual adaptation actions for both municipalities.

Climate Indices

The climate indices included in this report are listed and defined in Table 1 below. The indices represent a broad range of important climate variables that impact the City of Hamilton. Temperature and precipitation data (except freezing rain) were taken from the Climate Atlas of Canada (www.climateatlas.ca), including the description and name of the climate indices.

More details regarding the definitions for the climate variables can be found at: https://climateatlas.ca/variables

Table 1: Summary of Climate Indices

Climatic Driver	Climate Indicator	Description	Units
Hot Temperature	Mean Temperature	The average temperature of the day.	ºC
	Maximum temperature	The highest temperature of the day.	ºC
	Minimum Temperature	The lowest temperature of the day.	ºC
	Very Hot Days (+30ºC)	A Very Hot Day is a day when the temperature rises to at least 30 °C. This is the temperature where a Heat Alert is issues by Environment Canada in Halton Region.	Days
	Tropical Nights	A Tropical Night occurs when the lowest temperature of the day does not go below 20°C.	Days
	Warmest Maximum Temperature	The highest temperature of the year.	ºC
	Cooling Degree Days	Cooling Degree Days (CDD) are equal to the number of degrees Celsius a given day's mean temperature is above 18 °C. It is a measurement designed to quantify the demand for energy needed to cool buildings.	ºC

Climatic Driver	Climate Indicator	Description	Units
	Number of Heat Waves	The average number of heat waves per year. A heat wave occurs when at least three days in a row reach or exceed 30°C.	Number of heatwaves
	Average Length of Heat Waves	The average length of a heat wave. A heat wave occurs when at least three days in a row reach or exceed 30°C.	Days
	Longest Spell of +30°C Days	The longest series of consecutive days with tmax ≥ 30 °C. Here, there is no minimum threshold for number of days in a row that must be reached or exceeded to count as a spell.	Days
	Hot (+30°C) Season	The number of days when +30°C temperatures can be expected.	Days
	Extremely Hot Days (+32°C)	Number of days per year when the temperature rises to at least 32°C.	Days
	Extremely Hot Days (+34°C)	Number of days per year where the temperature rises to at least 34°C.	Days
Cold Temperature	Freeze-Thaw Cycles	This is a simple count of days when the air temperature fluctuates between freezing and non-freezing temperatures.	Days
	Frost Days	A frost day is one on which the coldest temperature of the day is lower than 0°C.	Days
	Icing Days	An Icing Day is a day on which the air temperature does not go above freezing (0°C).	Days
	Coldest Minimum Temperature	The very coldest temperature of the year.	°C
	Heating Degree Days	Heating Degree Days (HDD) are equal to the number of degrees Celsius a given day's mean temperature is below 18 °C. It is a measurement designed to quantify the demand for energy needed to heat a building.	°C
	Freezing Degree Days	Freezing degree days (FDD) are equal to the number of degrees Celsius that each day's mean temperature is below 0°C.	°C
	Mild Winter Days (-5°C)	A Mild Winter Day is a day when the temperature drops to at least -5°C.	Days
	Winter Days (-15°C)	A Winter Day is a day when the temperature drops to at least -15°C.	Days
Precipitation	Total Precipitation	The total amount of rain, drizzle, snow, sleet, etc. Frozen precipitation is measured according to its liquid	mm

Climatic Driver	Climate Indicator	Description	Units
		equivalent: 10 cm of snow is usually about 10 mm of precipitation.	
	Heavy Precipitation Days (10mm)	A Heavy Precipitation Day (10 mm) is a day on which at least a total of 10 mm of rain or frozen precipitation falls.	Days
	Heavy Precipitation Days (20mm)	A Heavy Precipitation Day (20 mm) is a day on which at least a total of 20 mm of rain or frozen precipitation falls.	Days
	Wet Days	The number of days in a year with rain/snow.	Days
	Dry Days	The number of days in a year without rain/snow.	Days
	Max. 1-day Precipitation (mm)	The amount the precipitation that falls on the wettest day of the year.	mm
	Max 5-day Precipitation (mm)	The wettest five-day period.	mm
Agriculture Indices	Frost-Free Season	The Frost-Free Season is the approximate length of the growing season, during which there are no freezing temperatures to kill or damage plants.	Days
	Date of First Fall Frost	The date of the first fall frost, which marks the approximate end of the growing season for frost-sensitive crops and plants.	Date
	Date of Last Spring Frost	The date of the last spring frost, which marks the approximate beginning of the growing season for frost-sensitive crops and plants.	Date
	Corn Heat Units	Corn Heat Units (CHU) is a temperature-based index often used by farmers and agricultural researchers to estimate whether the climate is warm enough (but not too hot) to grow corn.	°C
	Growing Degree Days (Base 5°C)	Growing Degree Days (GDD) provide an index of the amount of heat available for the growth and maturation of plants and insects. Generally, 5 °C GDDs are used for assessing the growth of canola and forage crops.	°C
	Growing Degree Days (Base 10°C)	Growing Degree Days (GDD) provide an index of the amount of heat available for the growth and maturation of plants and insects. 10°C GDDs are more appropriate for assessing the growth of corn and beans.	°C

Climatic Driver	Climate Indicator	Description	Units
	Growing Degree Days (Base 15ºC)	Growing Degree Days (GDD) provide an index of the amount of heat available for the growth and maturation of plants and insects. 15°C GDDs are used to assess the growth and development of insects and pests.	ºC
Extreme Weather	Freezing Rain Events[iii]	Average percentage change in the number of daily freezing rain events (≥1 hr, ≥4 hr and ≥6 hr).	Days
	Wind	Average percentage change in the number of daily wind gust events.	Km/h
	Rainfall IDF Curves	The annual maximum rainfall intensity for specific durations. Common durations for design applications are: 5-min, 10-min, 15-min, 30-min, 1-hr, 2-hr, 6-hr, 12-hr, and 24-hr.	Mm/h
Freshwater Indices[iv]	Lake Levels	Annual changes in water levels as an anomaly relative to the 1981-2010 average	Feet
	Lake temperatures	The change in summer surface water temperatures	ºF
	Ice Cover Duration	Trend in days per year with ice coverage relative to the 1973 to 2018 baseline.	Trend in Days per year

Climate Change Modelling and Downscaling

The majority of the data for this report was collected from the Climate Atlas of Canada (www.climateatlas.ca), produced by the Prairie Climate Centre and supported by Environment and Climate Change Canada. Other data pertaining to freezing rain, wind, and other extreme weather events were taken from various academic literature and have been identified and cited where applicable.

The data presented in this report is based on global climate models (GCMs) and emission scenarios defined by the Intergovernmental Panel on Climate Change (IPCC), drawing from the Fifth Assessment Report (AR5) publications.

Many different methods exist to construct climate change scenarios, however, global climate models (GCMs) are the most conclusive tools available for simulating responses to increasing greenhouse gas (GHG) concentrations, as they are based on mathematical representations of atmosphere, ocean, ice cap, and land surface processes.[v] Wherever possible, this report uses an ensemble approach, which refers to a system that runs multiple climate models at once. Research has shown that this provides a more accurate projection of annual and seasonal temperatures and precipitation than a single model would on its own.

In order to better understand local impacts and vulnerabilities, climate data is often needed at a smaller resolution. In order to get finer resolution data, climate modellers use dynamic or statistically downscaling methods. Dynamically downscaled models are also known as regional climate models (RCMs). RCMs simulate the climate of a smaller region, relying on information provided by GCMs. Statistically downscaled models use statistical relationships between local climate variables (such as precipitation) and large-scale variables (such as atmospheric pressure). The relationship is then applied to projections from GCMs to simulate local climate[vi]. The climate model data presented in the Climate Atlas used a statistically downscaled method - specifically the Bias-Correction/Constructed Analogues with Quantile mapping reordering, Version 2 (BCCAQv2) method[vii]. This work was done by the Pacific Climate Impacts Consortium (PCIC).

Emissions Scenarios

Emissions scenarios are based on models developed by a series of international climate modeling centers. They are socioeconomic storylines used by analysts to make projections about future greenhouse gas emissions and to assess future vulnerability to climate change. Producing scenarios requires estimates of future population levels, economic activity, the structure of governance, social values, and patterns of technological change. In this report, climate change scenarios identified in the Fifth IPCC Assessments are considered.

RCP Scenarios - IPCC Fifth Assessment Report (AR5)

Representative Concentration Pathways (RCPs) are the newest set of climate change scenarios that provide the basis for the Fifth Assessment report from the IPCC.[viii] The new RCPs have replaced the Special Report on Emissions Scenarios (SRES) in order to be more consistent with new data, new models, and updated climate research from around the world. The RCPs contain information regarding emission concentrations and land-use trajectories, and are meant to be representative of the current literature on emissions and concentration of greenhouse gases. The premise is that every radiative forcing pathway can result from a diverse range of socioeconomic and technological development scenarios.[ix] They are identified by their approximate total radiative forcing in the year 2100 relative to 1750, and are labeled as RCP2.6, 4.5, 6.0 and 8.5. These four RCPs include one mitigation scenario leading to a very low forcing level (RCP2.6), two stabilization scenarios (RCP4.5 and RCP6.0), and one scenario with continued rising greenhouse gas concentrations (RCP8.5).[x] The RCPs also consider the presence of 21st century climate policies, as compared with the no-climate policy assumption of the SRESs in the Third and Fourth Assessment Reports.[xi]

For this report, projections will use RCP4.5 representing a moderate increase in projected GHG concentrations and RCP8.5 representing the highest projected GHG concentration, as that data is publicly available for many climate indicators. RCP8.5 is referred to as a ‘business as usual’ pathway, representing a future where regular economic growth continues with emissions continuing to increase. If current emissions trends continue, the higher emissions scenarios and associated temperature increases will likely apply. Additionally, it is important that municipalities are aware of some of the most potentially dramatic effects of climate change should global emissions persist. Table 2 provides a description of each RCP scenario, while Figure 1 illustrates the projected global warming associated with the four scenarios.

Table 2: IPCC Fifth Assessment Report Climate Change Scenario Characteristics

Scenario	Description (all temperature changes are relative to 1850-1900)	Pathway
RCP2.6	Lowest projected GHG concentrations, resulting from dramatic climate change mitigation measures implemented globally. It represents an increase of 2.6 W/m^2 in radiative forcing to the climate system. • RCP2.6 is associated with 430-480ppm of CO_2 and would likely lead to 2°C of warming by the end of the 21st century. • Keeping CO_2 concentrations to 450ppm would require complete decarbonization or greater by 2100. • Retaining 430ppm would require near full decarbonization (75%-95% reduction from 2010 levels) by 2050.	Peak and decline
RCP4.5	Moderate projected GHG concentrations, resulting from substantial climate change mitigation measures. It represents an increase of 4.5 W/m^2 in radiative forcing to the climate system. • RCP 4.5 is associated with 580-720ppm of CO_2 and would more than likely lead to 3°C of warming by the end of the 21st century.	Overshoot*
RCP6.0	Moderate projected GHG concentrations, resulting from some climate change mitigation measures. It represents an increase of 6.0 W/m^2 in radiative forcing to the climate system. • RCP 6.0 is associated with 720-1000ppm of CO_2 and would likely lead to 4°C of warming by the end of the 21st century.	Overshoot*
RCP8.5	Highest projected GHG concentrations, resulting from business-as-usual emissions. It represents an increase of 8.5 W/m^2 in radiative forcing to the climate system. • RCP 8.5 is associated with >1000ppm of CO_2 and would more than likely lead to warming greater than 4°C by the end of the 21st century.	Rising

* The term 'overshoot' refers to scenarios in which the international goal of limiting global warming to 2°C by the end of the century, as set out by the UNFCCC in the Paris Agreement, is not met[xii].

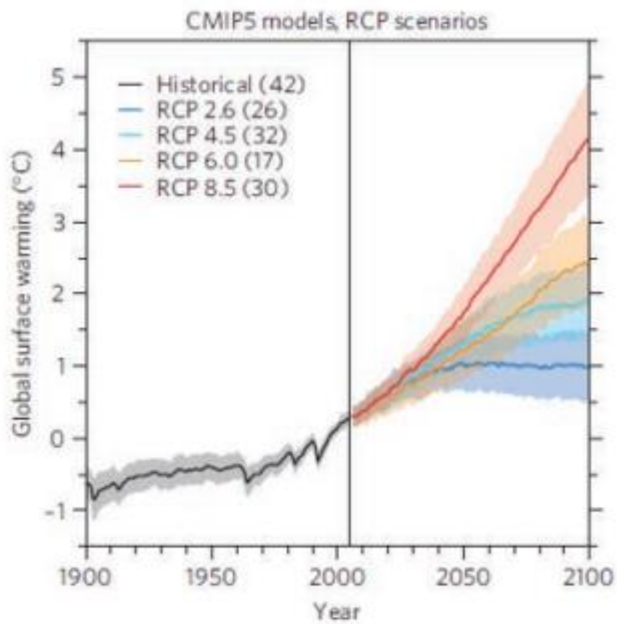


Figure 1: Global temperature change relative to 1986-2005 for the RCP scenarios run by Coupled Model Intercomparison Project (CMIP5). The number of models is given in brackets and the shading (coloured envelopes) represents all model results[xiii]

Time Periods

Climatic projections are typically provided within time periods of 30 years. Additionally, a consistent baseline period is established so that projections can be accurately compared with historical trends. In this report, the time periods of 2021-2050 (immediate future) and 2051-2080 (near future) are used most frequently as well as 1976-2005 for the baseline. Many climate indices are also divided into seasonal periods, defined below.

Table 3: Seasonal timeframes

Season	Months
Winter	December, January, February
Spring	March, April, May
Summer	June, July, August
Fall	September, October, November

Uncertainty

It is important to note that uncertainty in the scientific use of the word does not imply doubt. Uncertainty refers to the idea that data has a range of expected values rather than a singular value. This report thus uses uncertainty as a “quantitative measurement of variability in the data”[xiv]. Value ranges are factored into climate change scenarios, models, and data, and reflect the complex reality of environmental change and the evolving relationship between humans and the planet. Climate change cannot be predicted with absolute certainty in any given case, and all data must be considered with this in mind. While it is not possible to anticipate future climactic changes with absolute certainty, climate change scenarios help to create plausible representations of future climate conditions. These conditions are based on assumptions of future atmospheric composition and on an understanding of the effects of increased atmospheric concentrations of GHG, particulates, and other pollutants.

Hot Weather

All temperature indices for the City of Hamilton are projected to experience significant warming for RCP4.5 and RCP8.5. The minimum, average and maximum monthly temperatures will increase, as will the number of extreme heat days, while the number of extreme cold days will decrease.

Documenting general trends in temperature change can be helpful for understanding the future distribution of vector borne diseases and invasive species migration, temperature-related morbidity and mortality, cooling and heating requirements for buildings, and much more[xv].

Historic Events

The City of Hamilton has recently broken a number of late summer temperature records in 2016 and 2018. 2016 also saw a large spike in the number of days in which a heart alert was made (where daytime temperatures reached at least 31°C or at least 40°C with humidex with nightly temperatures lingering above 20°C[xvi],[xvii]). This number rose to 26 from 17 in 2015[xviii]. More recently, an extended heatwave in July of 2020 triggered the opening of cooling centres and water stations across the City[xix].

Seasonal Mean Temperatures

Seasonal mean temperatures show the average temperature in an area over a given season. Seasonal baseline mean temperatures, averaged over the City of Hamilton are: -3.9, 6.7, 20.1 and 10.1˚C for winter, spring, summer and autumn respectively. This gives a year-round average temperature of 8.3˚C for 1976-2005. According to RCP8.5, Hamilton could experience an increase of 4.2˚C in average annual temperatures in the near future (2051-2080), and 4.7˚C in average winter temperatures.

Table 4: Projected Mean Temperatures for the City of Hamilton (°C) by Season – RCP4.5 and 8.5

Emissions Scenarios	**T Mean (°C)**	**Baseline (1976-2005)**	2021-2050			2051-2080		
			Low	Mean	High	Low	Mean	High
RCP4.5	Spring	6.7	6.3	8.4	10.5	7.2	9.3	11.6
	Summer	20.1	20.4	21.9	23.4	21.1	23	24.9
	Fall	10.1	10.4	12.1	13.7	11.1	12.9	14.7
	Winter	-3.9	-4.4	-1.8	0.8	-3.3	-0.6	2.1
	Annual	8.3	8.9	10.2	11.5	9.7	11.2	12.8
RCP8.5	Spring	6.7	6.3	8.5	10.7	8.2	10.4	12.7

	Summer	20.1	20.8	22.3	23.8	22.6	24.5	26.3
	Fall	10.1	10.7	12.3	14	12.5	14.3	16
	Winter	-3.9	-4.1	-1.6	-1.1	-1.9	0.8	3.4
	Annual	8.3	9.1	10.4	11.7	11	12.5	14.1

Maximum and Minimum Temperatures

Maximum and minimum temperature trends show the average high temperatures and the average low temperatures for a given season.

In terms of minimum temperatures, the baseline mean minimum temperatures across each season were 1.7, 14.4, 5.5 and -7.6°C for spring, summer, fall and winter respectively. Minimum seasonal temperatures are projected to increase substantially, with an increase of 3.6°C in spring, 4.1°C in summer, 3.9°C in fall and 5.2°C in winter 2051-2080.

By 2051-2080 under RCP8.5, the Region will be experiencing close to 20˚C minimum temperatures during the summer months – these are considered "tropical nights". Many people are at risk from suffering heat exhaustion or heat stroke when nighttime temperatures fail to drop below 20 °C[xx]. In the winter months, minimum temperatures are expected to be closer to 0˚C by 2051-2080 under RCP8.5, which could result in an increase in freeze-thaw cycles, and overland flooding due to snowmelt.

Table 5: Projected average seasonal minimum temperatures for the City of Hamilton – RCP4.5 and 8.5

Emissions Scenario	T Mean (°C)	Baseline (1976-2005)	2021-2050			2051-2080		
			Low	Mean	High	Low	Mean	High
RCP4.5	Spring	1.7	1.5	3.3	5.1	2.3	4.2	6.3
	Summer	14.4	14.7	16	17.4	15.3	17	18.8
	Fall	5.5	5.7	7.3	8.8	6.5	8	9.7
	Winter	-7.6	-8.1	-5.3	-2.6	-6.8	-3.9	-1.1
	Annual	3.5	4.2	5.4	6.6	5	6.4	7.9
RCP8.5	Spring	1.7	1.6	3.5	5.5	3.3	5.3	7.5
	Summer	14.4	15.1	16.4	17.8	16.9	18.5	20.2
	Fall	5.5	6	7.5	9.1	7.7	9.4	11
	Winter	-7.6	-7.8	-5	-2.2	-5.3	-2.4	0.3
	Annual	3.5	4.4	5.6	6.9	6.4	7.7	9.2

In terms of maximum temperatures, seasonal average baseline temperatures for Hamilton were 11.7, 25.9, 14.8 and -0.2˚C for spring, summer, fall and winter respectively. Hamilton will experience an increase in all seasonal maximum temperatures, with average summer maximum temperatures reaching over 30˚C in the years 2051-2080 under RCP8.5. Average winter maximum temperatures will reach well into positive digits for the City, with an increase of 4.2˚C (2051 mean) by 2051-2080 according to RCP8.5.

Table 6: Projected average seasonal maximum temperatures for the City of Hamilton – RCP4.5 and 8.5

Emissions Scenarios	**T Mean (℃)**	**Baseline (1976-2005)**	2021-2050			2051-2080		
			Low	Mean	High	Low	Mean	High
RCP4.5	Spring	11.7	11.1	13.5	15.9	11.9	14.4	17.1
	Summer	25.9	26	27.8	29.7	26.8	29	31.2
	Fall	14.8	15	16.9	18.9	15.7	17.7	19.7
	Winter	-0.2	-0.7	1.7	4.2	0.2	2.8	5.4
	Annual	13.1	13.6	15.1	16.5	14.3	16.1	17.7
RCP8.5	Spring	11.7	11.1	13.5	16.1	12.9	15.5	18.1
	Summer	25.9	26.4	28.1	29.9	28.3	30.4	32.6
	Fall	14.8	15.2	17.1	19	17.1	19.2	21.2
	Winter	-0.2	-0.6	1.9	4.5	1.3	4	6.8
	Annual	13.1	13.8	15.2	16.6	15.6	17.3	19

Average annual minimum and maximum temperatures are projected to experience a similar increase as mean temperatures, as shown for the RCP8.5 scenario for Hamilton in Figure 2.

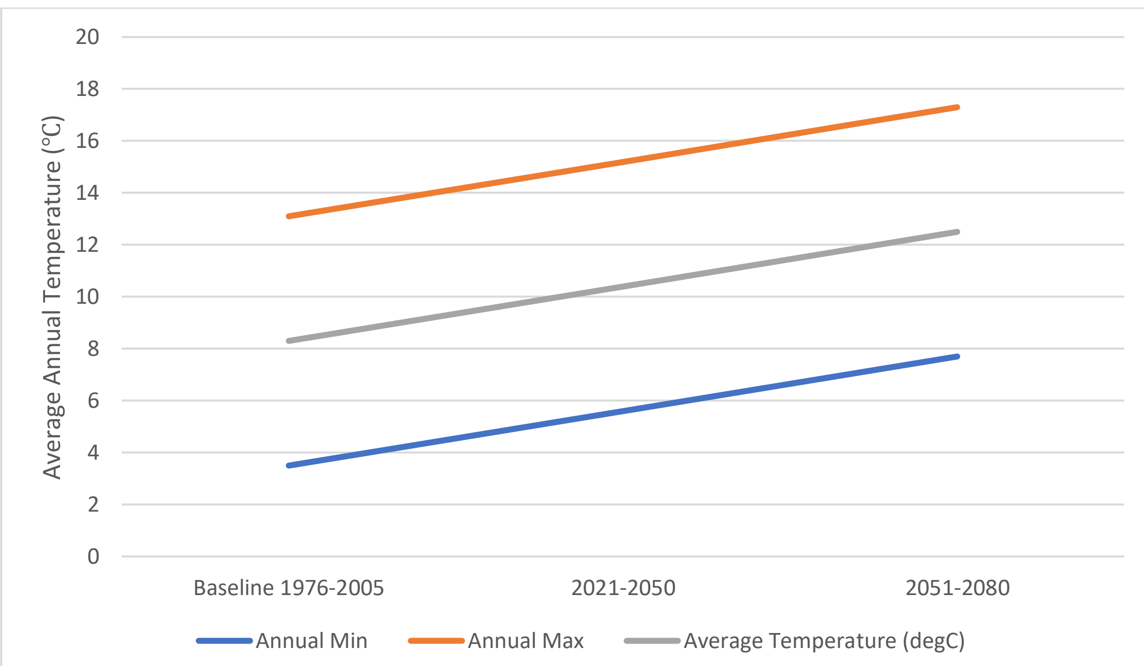


Figure 2: Projected annual mean temperature for the City of Hamilton – monthly minimum (blue), average (grey), and monthly maximum (orange) - RCP8.5

In addition to the average maximum temperatures, the warmest maximum temperature in a given year is also expected to increase (i.e. the single, hottest day of the year). For the City of Hamilton, the baseline average warmest maximum temperature was 34.1°C. According to RCP8.5, the average warmest maximum temperature will increase to 36.4°C in the immediate future (2021-2050), and 38.9°C in the near future (2051-2080) according to the scenario mean. These temperatures do not factor in additional warming due to the humidex which could make it feel 5 to 10°C warmer. These extreme temperatures can cause heat-related illnesses in not only vulnerable populations but also healthy, young adults.

Extreme Heat Days and Tropical Nights

The Climate Atlas presents the number of days where the daily maximum temperature exceeds 30°C, 32°C and 34°C as seen in Table 7. All three of these variables are included in this report as, according to Environment Canada parameters, an extreme heat warning is issued in the City of Hamilton when one or both of the following conditions is met:

- Two consecutive days with the temperature is forecasted to be 31°C or higher during the day and 20°C or higher overnight
- Two consecutive days with a humidex forecasted of 40°C or higher

Days where the daily maximum temperatures exceed 30°C, 32°C and 34°C present the greatest threats to community health due to heat-related illnesses. Examples of these include heat cramps, heat edema, heat exhaustion, or heat stroke. Specific groups, such as those who work outside, infants and young children, older adults (over the age of 65), those with chronic medical conditions, people experiencing homelessness, people planning outdoor sports or activities, and those with limited mobility may be more adversely affected[xxi]. Moreover, while higher summer temperatures increase electricity demand for cooling, at the same time, it also can lower the ability of transmission lines to carry power, possibly leading to electricity reliability issues during heat waves[xxii].

The baseline average number of days when the maximum temperature was greater than or equal to 30°C was 16.1 days for the City of Hamilton. This is expected to increase to an average of 63.3 days in the 2051-2080 period under the RCP8.5 scenario. This means there will be close to four times more days above 30°C by 2080 in the study region.

Table 7: Extreme Heat Days (Tmax ≥30, 32 and 34°C) for the City of Hamilton - RCP4.5 and 8.5

Emissions Scenario	**Tmax (days)**	**Baseline 1976-2005**	2021-2050			2051-2080		
			Low	Mean	High	Low	Mean	High
RCP4.5	30°C or more	16.1	15.1	34.4	55.4	22.1	46.1	70
	32°C or more	5.8	3.9	17	33.7	7.5	26	47.2
	34°C or more	1.5	0.3	6.6	17.4	1.1	12.2	28.6
RCP8.5	30°C or more	16.1	18.1	37.2	56.8	38.2	63.3	87.9

	32°C or more	5.8	5.2	18.8	35.2	18.1	40.3	63.3
	34°C or more	1.5	0.6	7.7	18.9	5.7	22.1	41.2

While the number of days with tmax ≥30°C is expected to increase overall, the length of the Hot Season, or the days from the first day of the year with tmax ≥ 30°C to the last day with tmax ≥ 30°C, is also expected to increase. Table 8 outlines the length of the Hot Season for the City of Hamilton. The baseline average length of the Hot Season was 71.6 days. By 2051-2080, Hamilton can expect an increase to 126.2 days according to RCP8.5 – almost double the length of the Hot Season previously.

Table 8: Length of the Hot Season (Tmax >30 C) for the City of Hamilton - RCP4.5 and 8.5

Emissions Scenarios	**Baseline (1976-2005)**	2021-2050			2051-2080		
		Low	Mean	High	Low	Mean	High
RCP4.5	71.6	63.8	102	136.6	78	111.8	144.7
RCP8.5	71.6	69.3	105	139.1	92.7	126.2	159.2

Traditional patterns of hot weather during the day which then cool off at night can often be enough to mitigate exposure to extreme temperatures[xxiii]. However, during periods of extended heat, it is important to project scenarios where local populations may experience prolonged exposure to heat through the incidence of heat waves with tropical nights (daily minimum temperature above 20°C).

The baseline average number of tropical nights for the City of Hamilton was 6.4. In 2051-2080, according to RCP8.5, Hamilton could experience 33.4 more tropical nights on average. The RCP8.5 scenario predicts an average of over one month of tropical nights by 2080, more than a fivefold increase.

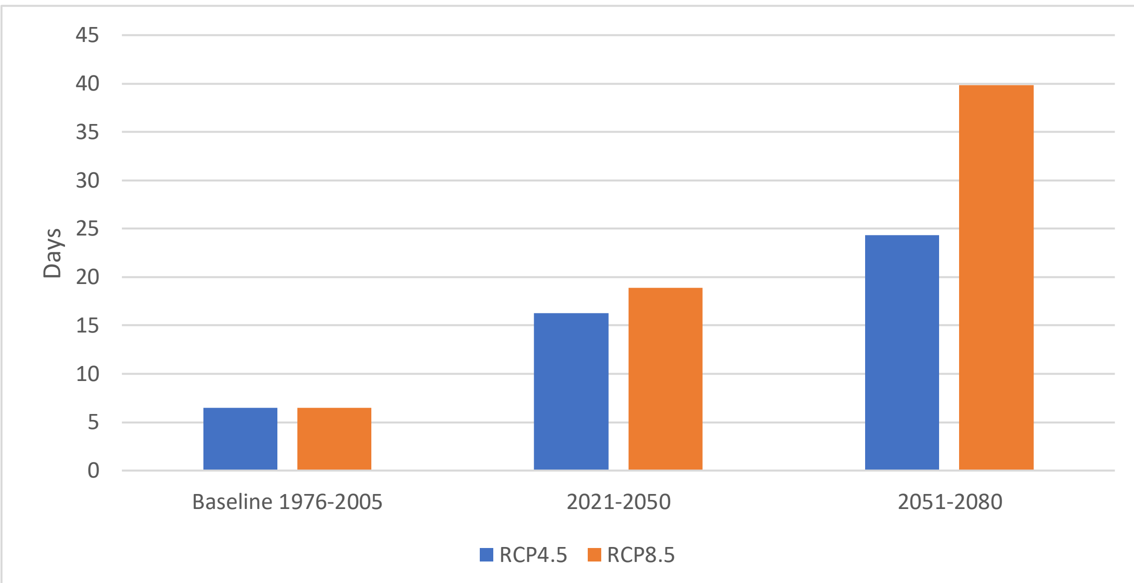
Table 9: Average Annual Tropical Nights for the City of Hamilton - RCP4.5 and 8.5

Emissions Scenarios	**Baseline (1976-2005)**	2021-2050			2051-2080		
		Low	Mean	High	Low	Mean	High
RCP4.5	6.4	5.9	16.3	28.9	9.5	24.3	44
RCP8.5	6.4	8.3	18.9	32.5	21.9	39.8	60.8

Figure 3: Projected Annual Mean Tropical Nights for the City of Hamilton – RCP4.5 and 8.5

Heat Waves

Heat waves are defined as prolonged periods of excessively hot weather, which may be accompanied by high humidity. Heat waves are location-specific; a heat wave is usually measured relative to the usual weather in the area and relative to normal temperatures for the season. Temperatures that people from a hotter climate consider normal can be termed a heat wave in a cooler area. Thus, understanding shifts in local climate can help inform particular strategies to mitigate population exposure in ways that are commensurate with local norms and behaviours. High, persistent temperatures also increase the risk of



drought, which can severely impact food production and increases the risk of wildfire. High temperatures can also lead to more thunderstorms, which means increased risks of flash flooding, lightning, hail and perhaps even tornadoes[xxiv].

In the City of Hamilton, an extended heat warning is issued when the daytime temperatures are expected to reach at least 31°C for three or more days and overnight temperatures above 20°C or when the humidex rises above 40°C for three or more days. Alternatively, the Climate Atlas of Canada defines a heat wave as three days in a row reach or exceed 30°C. Though the parameters slightly differ, the data presented from the Climate Atlas can still illustrate the degree in which heat wave events will become more frequent and prolonged in the City of Hamilton.

The Climate Atlas considers two variables for heatwaves – the annual average length of heat waves, and the annual number of heat waves. The annual number of heatwave events measures the average number of times per year where the temperature reaches or exceeds 30°C. The baseline number of heat waves for the City of Hamilton was 2.1, as presented in Table 10. In the 2051-2080 period according to RCP8.5, Hamilton can expect to experience almost seven heat waves events per year. This is over triple the current number of occurrences.

Table 10: Number of Annual Heat Waves for the City of Hamilton- RCP4.5 and 8.5

Emissions Scenarios	**Baseline (1976-2005)**	2021-2050			2051-2080		
		Low	Mean	High	Low	Mean	High
RCP4.5	2.1	1.8	4.7	7.7	2.7	5.9	9.1
RCP8.5	2.1	2.2	5	7.9	4.1	6.8	9.9

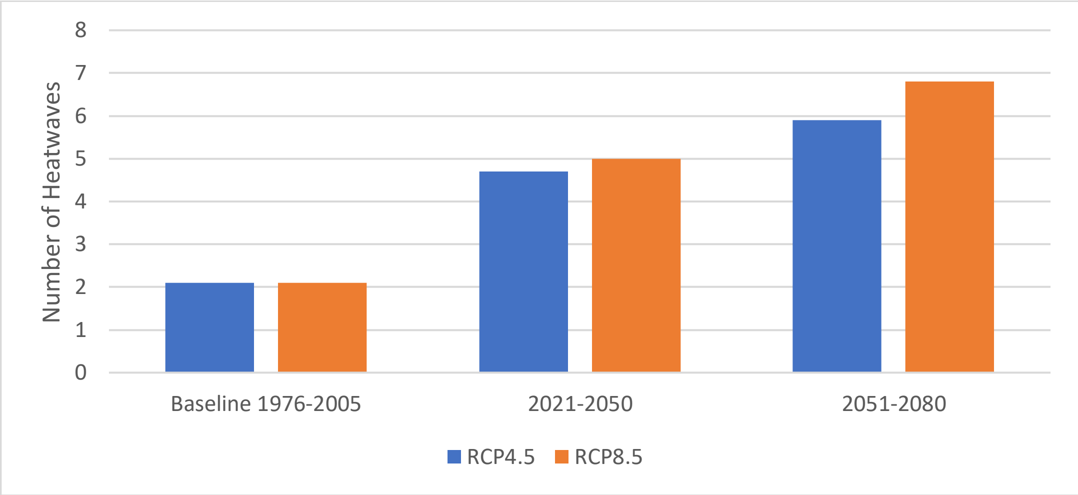


Figure 4: Number of Heatwave Events for the City of Hamilton - RCP4.5 and 8.5

With regards to the average length of heat waves (in days), the City of Hamilton experienced an average of 3.8 days of heatwave conditions in the baseline period as displayed in Table 11. In the 2051-2080 period, according to RCP8.5, Hamilton can expect to see an average heatwave event occurring for 8.4 days – over double the current length.

Table 11: Average Annual Length of Heatwaves for the City of Hamilton - RCP4.5 and 8.5

Emissions Scenarios	**Baseline (1976-2005)**	2021-2050			2051-2080		
		Low	Mean	High	Low	Mean	High
RCP4.5	3.8	3.4	5.3	7.8	3.9	6.3	9.9
RCP8.5	3.8	3.7	5.6	8.5	4.9	8.4	13.5

Overall, heatwave events are projected to occur more frequently and for longer periods of time. These changes become more pronounced as time goes on, and with regards to the higher emissions scenarios. While Table 11 outlines the average annual lengths of heatwave events, Table 12 outlines the longest series of consecutive days with tmax ≥ 30°C. The baseline average of consecutive length of 30°C Days for the City of Hamilton was 4. By 2051-2080 according to RCP8.5, Hamilton could experience 19.2 consecutive days where temperatures exceed 30°C. This potentially would signify an Extended Heat Warning for the City for more than two and a half weeks.

Table 12: Longest Spell of +30°C Days for the City of Hamilton - RCP4.5 and 8.5

Emissions Scenarios	Baseline (1976-2005)	2021-2050			2051-2080		
		Low	Mean	High	Low	Mean	High
RCP4.5	4	3	7.9	15	4.3	11.4	21.6
RCP8.5	4	3.6	8.9	16.5	7	19.2	36.1

These extreme temperatures that are sustained over several days will have significant impacts on the health of individuals in the City of Hamilton – heat illnesses can manifest quickly, and lead to long-term health problems and even death. Overexposure to extreme heat is especially dangerous for children and elderly adults, and those who work outside or are physically active in the outdoors[xxv].

Cooling Degree Days

Cooling Degree Days (CDD) is an indicator of energy consumption due to air conditioner usage during summer. If a location shows an increase in projected CDD values, this implies that it will experience hotter or longer summers.

18 °C is the temperature at which air conditioning is required to maintain a comfortable temperature inside buildings. A place that gets many days with average temperatures above 18°C or that gets mean temperatures much higher than 18°C will require a relatively large amount of energy (and thus money) to cool buildings for comfort and safety. This will have significant impacts as well for those who do not have access to air conditioning in their homes or apartments.

CDD are projected to increase significantly in the City of Hamilton, more than doubling across the City in the 2051-2080 period according to RCP8.5.

Table 13: Cooling Degree Days for the City of Hamilton – RCP4.5 and 8.5

Emissions Scenarios	Baseline (1976-2005)	2021-2050			2051-2080		
		Low	Mean	High	Low	Mean	High
RCP4.5	303.6	332.9	485.3	643.2	407	601.9	821.9
RCP8.5	303.6	369.4	520.4	677	563.1	779.5	1013

Cold Weather

Cold weather is an important aspect of life in Canada, and many places in Canada are well adapted to very cold winters. Overall, the frequency and severity of cold days are decreasing across Canada, and in the City of Hamilton, while the number of hot days is increasing. However, it is important to know how our winters will change in the future, because cold temperatures affect health and safety, determine what plants and animals can live in the area, limit or enable outdoor activities, define how we design our buildings and vehicles, and shape our transportation and energy use.

Mild Winter Days and Winter Days

A Mild Winter Day is a day when the temperature drops to at least -5°C. Mild Winter Days indicate how much a location experiences moderately cold temperatures. The baseline number of Mild Winter Days was 71.6 – by 2051-2080 according to RCP8.5, that number could decrease to 32.1 days. This means there will less than half the amount of mild winter days.

Table 14: Mild Winter Days (Tmin ≤5 °C) for the City of Hamilton - RCP4.5 and 8.5

Emissions Scenarios	Baseline (1976-2005)	2021-2050			2051-2080		
		Low	Mean	High	Low	Mean	High
RCP4.5	71.6	31.1	52.8	73.4	19.5	42.8	66
RCP8.5	71.6	29.6	51.6	73.8	12	32.1	54.6

Winter days, defined as a day where the temperature drops to at least -15°C, are also projected to decrease in the City of Hamilton. In fact, by the end of the century Hamilton can expect to see only about one day a year where temperatures dip below -15°C.

Table 15: Winter Days (Tmin ≤15 °C) for the City of Hamilton - RCP4.5 and 8.5

Emissions Scenarios	Baseline (1976-2005)	2021-2050			2051-2080		
		Low	Mean	High	Low	Mean	High
RCP4.5	13.8	0.3	6	14.6	0	3.1	9.2
RCP8.5	13.8	0.4	5.3	13.8	0	1.3	4.7

In addition to an overall decrease in winter days and mild winter days, the City of Hamilton is also expected to see a decrease in the Coldest Minimum Temperature – i.e. the temperature of the coldest day of the year. In the baseline period, Hamilton's average coldest minimum temperature was -21.9°C. According to RCP8.5, Hamilton's average coldest temperature will increase to -18.0°C in 2021-2050, and -14.1°C in 2051-2080.

Frost Days and Icing Days

Other indicator of cold temperatures are Frost Days and Icing Days - frost and ice days can help to understand freeze and thaw patterns throughout the region, and document risks relating to morbidity and mortality from traffic accidents, damage to roads and infrastructure, facility closures and more.

A frost day is a day with frost potential – meaning the **minimum** temperature is below 0°C. Frost days are predicted to decrease an average of 52 days by the 2080s in RCP8.5.

Table 16: Projected Frost Days for the City of Hamilton - RCP4.5 and 8.5

Emissions Scenarios	Baseline 1976-2005	2021-2050			2051-2080		
		Low	Mean	High	Low	Mean	High

RCP4.5	133.4	87.6	110.1	131.4	71.4	97.5	121.8
RCP8.5	133.4	85.6	107.8	131.8	53.5	81.3	106.4

Similarly, the number of ice days are projected to decrease. Ice days are the total number of days when the when daily **maximum** temperature is at or below 0 °C. A reduction in days below 0°C could have an impact on the survival and spread of ticks and Lyme disease, as ticks can be active in temperatures above 4°C[xxvi]. While deer ticks are most active in spring and fall, warmer winters could extend their window of activity.

Table 17: Projected Icing Days for the City of Hamilton - RCP4.5 and 8.5

Emissions Scenarios	Baseline 1976-2005	2021-2050			2051-2080		
		Low	Mean	High	Low	Mean	High
RCP4.5	52.2	17.1	35.7	53.6	10.8	28.5	49
RCP8.5	52.2	17.5	35.2	54.4	5.4	20.4	39.5

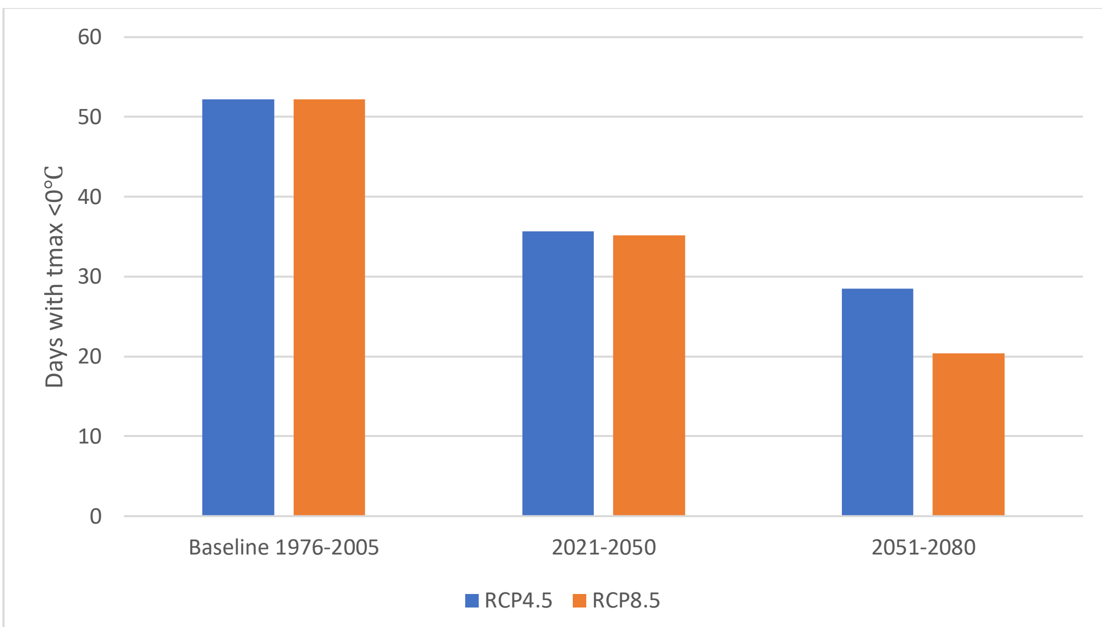


Figure 5: Projected Annual Mean Icing Days for the City of Hamilton - RCP4.5 and 8.5

Freeze-Thaw Cycles

Freeze-thaw cycles are the number of days when the air temperature fluctuates between freezing and non-freezing temperatures. Under these conditions, it is likely that some water at the surface was both liquid and ice at some point during the 24-hour period.

Freeze-thaw cycles can have major impacts on infrastructure. Water expands when it freezes, so the freezing, melting and re-freezing of water can over time cause significant damage to roadways, sidewalks, and other outdoor structures. Potholes that form during the spring, or during mid-winter melts, are good examples of the damage caused by this process.

In recent years, the City of Hamilton has seen an increased need to repair roads as abrupt winter temperature changes have increased freeze-thaw cycles. Based on the future freeze-thaw cycle projections outlined in table 18 below, Hamilton may be currently experiencing the peak of this phenomena[xxvii]. In fact, freeze-thaw cycles are projected to decrease slightly this century – from 66.4 days in the baseline, to 58.2 days in the immediate future, to 48.9 days in the near future according to RCP8.5 as depicted in Figure 6. This is likely due to the fact that overall, the days are getting warmer, and Hamilton is likely to experience a decrease in the number of days that reach a minimum temperature below 0°C.

Table 18: Average Annual Freeze-Thaw Cycles for the City of Hamilton - RCP4.5 and 8.5

Emissions Scenarios	Baseline 1976-2005	2021-2050			2051-2080		
		Low	Mean	High	Low	Mean	High
RCP4.5	66.4	44.6	59.6	74.1	41.5	55.4	69.4
RCP8.5	66.4	43.9	58.2	73.7	32.4	48.9	65

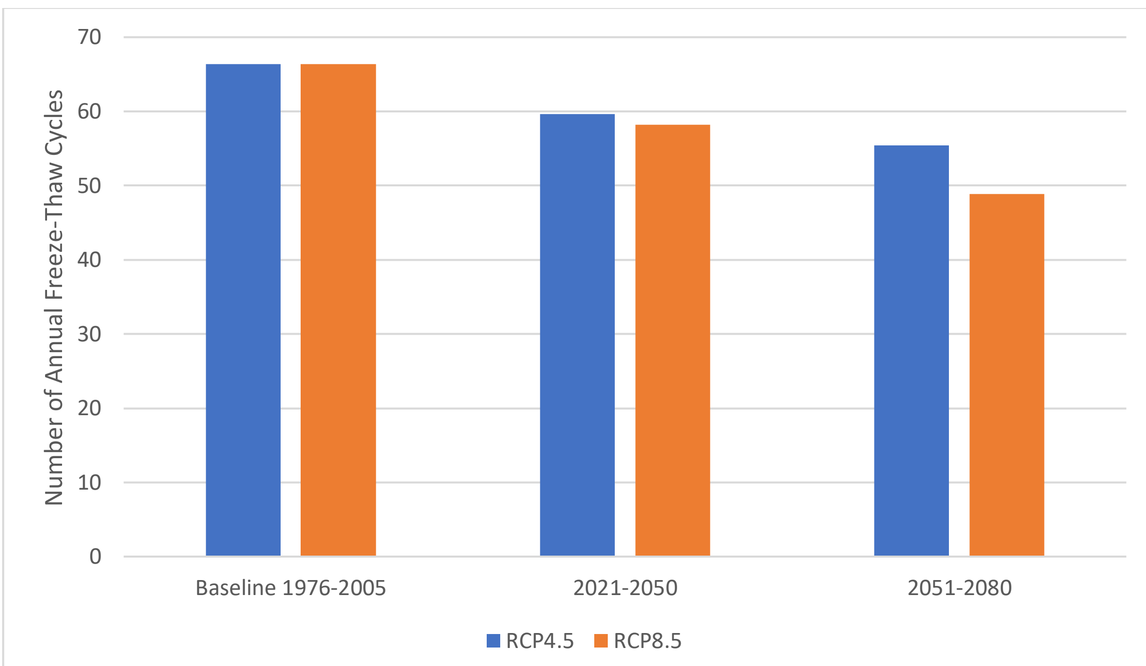


Figure 6: Average Annual Freeze-Thaw Cycles for the City of Hamilton - RCP4.5 and 8.5

Heating Degree Days and Freezing Degree Days

Similar to Cooling Degree Days, Heating Degree Days (HDD) are equal to the number of degrees Celsius a given day's mean temperature is below 18 °C. For example, if the daily mean temperature is 12 °C, the

HDD value for that day is equal to 6 °C. If the daily mean temperature is above 18 °C, the HDD value for that day is set to zero.

Heating Degree Days are a measure of how much heating is required in a year. An average temperature below 18 °C is heating is required to maintain a comfortable temperature inside buildings. A place that gets many days with average temperatures below 18 °C will require a relatively large amount of energy (and thus money) to heat buildings for comfort and safety.

As shown in the figure below, HDD is expected to decrease, implying that the City of Hamilton will be experiencing less severe cold events in the future. This could mean a reduction in heating costs and greenhouse gas (GHG) emissions for heating during the winter months.

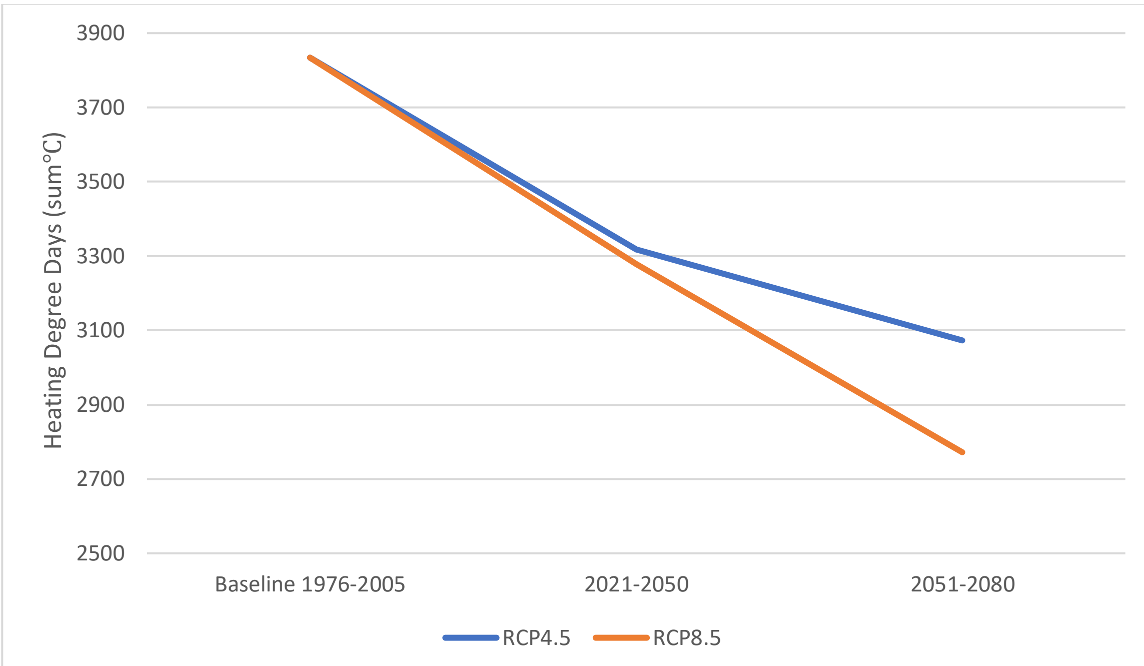


Figure 7: Average Annual Heating Degree Days for the City of Hamilton - RCP4.5 and 8.5

Similarly, Freezing Degree Days (FDD) begin to accumulate when the daily mean temperature drops below freezing: if a day's mean temperature is -21 °C, for example, it increases the annual FDD value by 21. Days when the mean temperature is 0 °C or warmer do not contribute to the annual sum. High FDD values are associated with relatively cold conditions: places with high FDD values likely get many days with temperatures significantly below freezing. If projections show a decrease in FDDs, then that location is likely to experience shorter or less severe winters.

Areas with high FDD indicate higher levels of snow and ice accumulation, which is an important consideration for corporate and community snow clearance and removal[xxviii]. These areas would also likely require larger amounts of energy for heating buildings and homes.

As shown in the figure below, FDD are expected to decrease significantly until the end of the century – this implies that Hamilton will experience less days where the temperature is significantly below freezing.

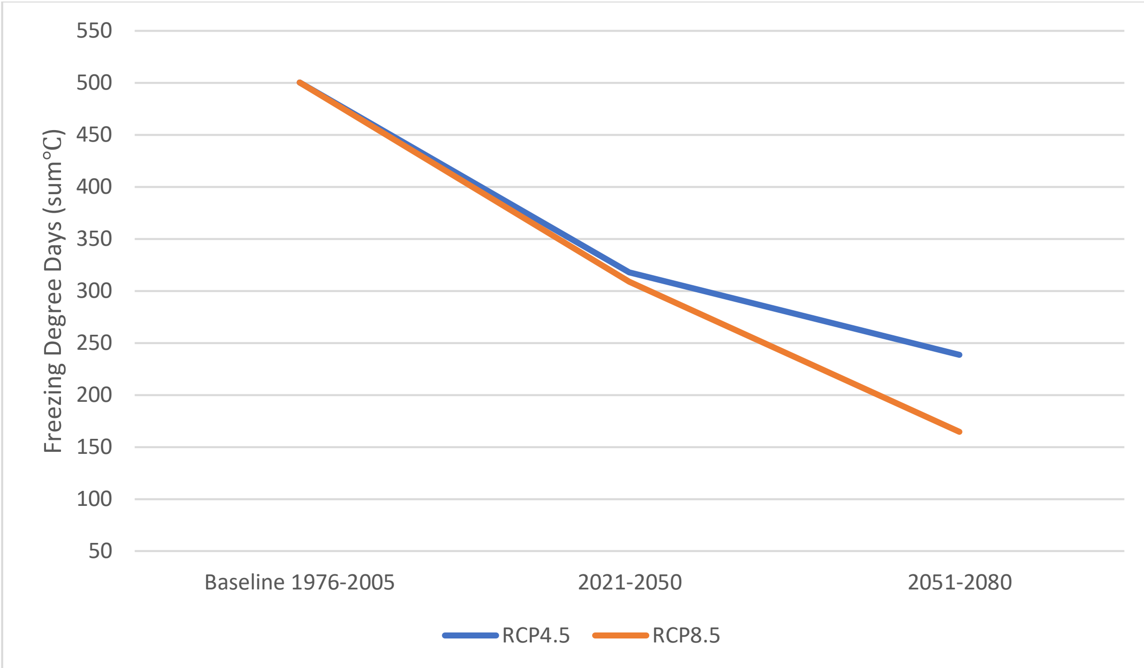


Figure 8: Freezing Degree Days for the City of Hamilton - RCP4.5 and 8.5

Precipitation

In this section, projections of total precipitation accumulation as well as extreme precipitation indices are presented.

Total Precipitation

The total annual average precipitation is projected to slightly increase over the coming decades. For the City of Hamilton, this increase will be from a baseline of 844 mm to approximately 898 mm in the 2021-2050 period, and to 923 mm by the 2051-2080 period.

Historic Events

A series of rainfall events in April and May of 2017 damaged an array of public and private assets including homes, parks, roadways and trails in the City of Hamilton[xxix]. The storms created slope instability, washouts and flooding of roadways, making conditions hazardous for motorists and forcing the closure of various road segments[xxx]. Active transportation infrastructure was also damaged substantially as earth shifted beneath the asphalt paths of both the rail and waterfront trails creating large shelves and gaps between previously continuous surfaces[xxxi].

The spring storms also had unanticipated consequences on local fish populations. As the City's overflow tanks were operating beyond capacity, residual overflow containing aquatic animals made its way into the sewer system[xxxii]. The fish were later removed as they were identified by staff at wastewater treatment facilities[xxxiii].

The City of Hamilton had taken a number of steps to prepare for major rainfall events including the clearing of debris in catchment areas at the site of a mudslide which occurred near the Kenilworth

Access at the base of the escarpment[xxxiv]. The City has also invested in 9 combined sewer overflow tanks which aid in regulating the flow of water during heavy precipitation events[xxxv]. Despite this foresight, the damage caused by intense and frequent precipitation in the spring of 2017 required anywhere between $1.8 and $2.5 million to address[xxxvi].

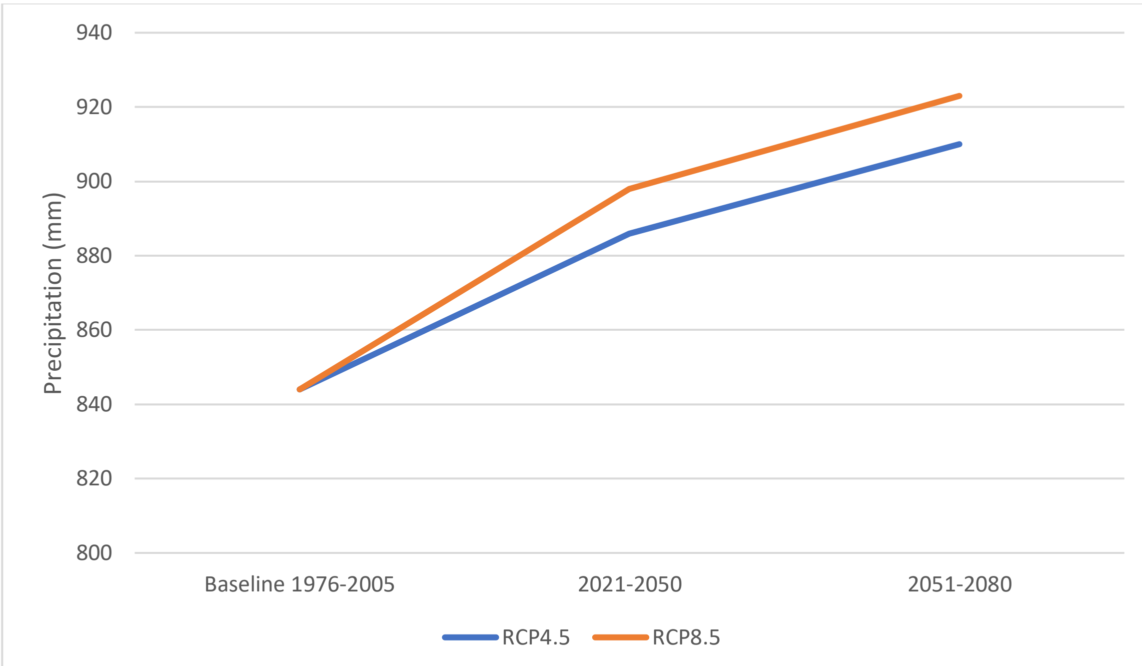


Figure 9: Projected Total Annual Precipitation Accumulation for the City of Hamilton (mm) (RCP4.5 and 8.5)

On a seasonal basis, in Hamilton, spring, winter and autumn precipitation accumulations are projected to increase by the end of the century with spring and winter experiencing the greatest increases. Summer will experience a slight increase and then a slight decrease, though not substantially. These seasonal trends, including relatively stable summer rainfall amounts paired with the projected increases in summer temperatures and heatwave lengths may lead to increased instances of drought. Table 19 presents the precipitation accumulation projections for Hamilton according to seasons under RCP4.5 and 8.5. Figure 10 presents the precipitation accumulation projections for Hamilton according to RCP8.5.

Table 19: Projected Total Precipitation (mm) by Season for the City of Hamilton – RCP. 4.5 and 8.5

Emissions Scenario	**Tmean (˚C)**	**Baseline 1976-2005**	2021-2050			2051-2080		
			Low	Mean	High	Low	Mean	High
RCP4.5	Spring	217	154	233	320	161	241	329
	Summer	217	134	221	322	127	220	327
	Fall	223	143	229	330	148	239	341
	Winter	187	132	204	281	139	211	286
	Annual	844	714	886	1065	721	910	1113
RCP8.5	Spring	217	161	240	330	171	254	348

	Summer	217	128	219	320	125	217	325
	Fall	223	144	232	332	142	232	337
	Winter	187	138	207	284	147	221	304
	Annual	844	715	898	1087	742	923	1120

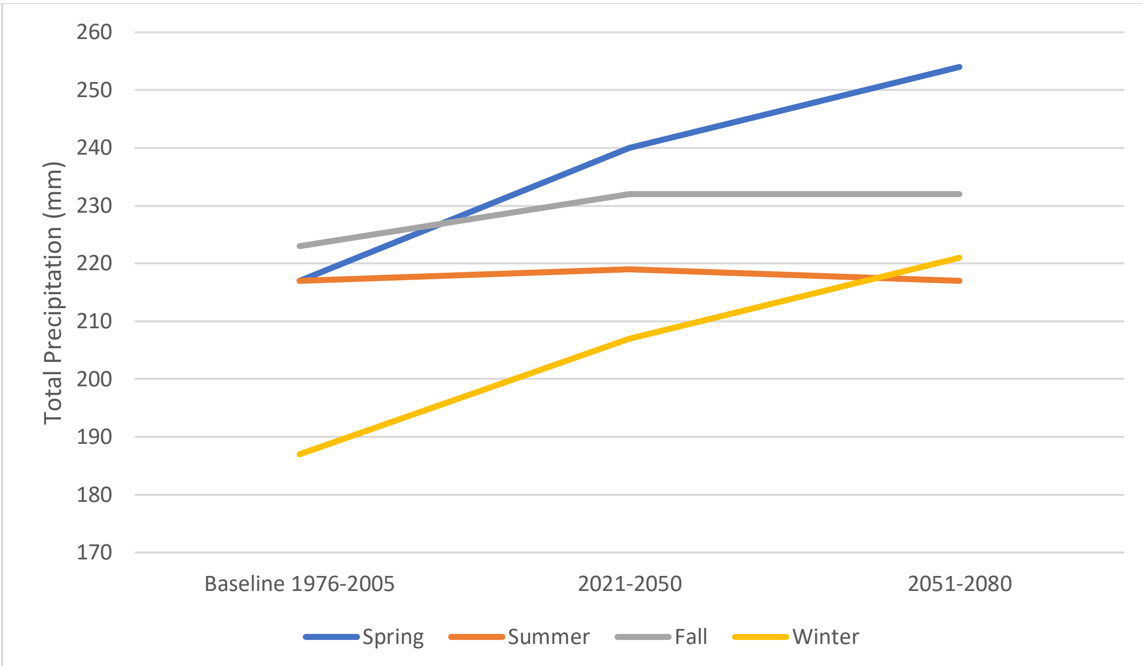


Figure 10: Projected Seasonal Precipitation Accumulation for Hamilton (RCP 8.5)

Dry Days and Wet Days

Precipitation patterns are critical for many important issues, including water availability, crop production, electricity generation, wildfire suppression, snow accumulation, seasonal and flash-flooding, and short- and long-term drought risk[xxxvii]. Two indicators that measure the frequency of rain events are the number of Wet Days and the number of Dry Days. The number of wet days measures the number of days in a year with more than 0.2 mm of rain/snow, while the number of dry days measure the number of days with less than 0.2 mm of rain/snow which is consistent with the Meteorological Service of Canada. Table 21 and Table 22 depict the number of annual projected Wet Days and Dry Days for the City of Hamilton, respectively. The tables show very little change in terms of the number of Dry Days and Wet Days for the City of Hamilton overall. However, when exactly these Wet and Dry Days occur and exactly how much rain falls on a particular day will have implications for both flooding and drought scenarios. The preceding section regarding seasonal changes to precipitation as well as the information in sections to follow which relate to extreme precipitation events should be considered together with Wet and Dry Days.

Table 20: Number of annual Wet Days for the City of Hamilton (RCP4.5 and 8.5)

Emissions Scenarios	**Baseline 1976-2005**	2021-2050	2051-2080

		Low	Mean	High	Low	Mean	High
RCP4.5	155.6	138.6	155.5	171.6	138.8	155.6	172.3
RCP8.5	155.6	140.2	156.5	173.3	138.3	155	171

Table 21: Number of annual Dry Days for the City of Hamilton (RCP4.5 and 8.5).

Emissions Scenarios	**Baseline 1976-2005**	2021-2050			2051-2080		
		Low	Mean	High	Low	Mean	High
RCP4.5	209	192.8	209.1	226.3	192.5	209.1	225.7
RCP8.5	209	191.4	208.1	224.4	193.7	209.7	226.4

Heavy Precipitation

The projections of several extreme precipitation indices are presented in this section.

Heavy Precipitation Days (both 10 mm and 20 mm) are days on which at least a total of 10 mm (or 20 mm) of rain or frozen precipitation falls. Frozen precipitation is measured according to its liquid equivalent: 10 cm of snow is usually about 10 mm of precipitation[xxxviii].

Max 1-Day precipitation and Max-5 Day precipitation indicate the amount of precipitation that falls on the wettest day of the year, and the five wettest days of the year respectively. The Max 1-Day precipitation amount could be the result of a short but intense precipitation event such as a storm or because a moderate amount of snow/rain falls continuously all day, rather than all at once.

Table 23 shows the projected Heavy Precipitation Days (both 10 mm and 20 mm), as well as the Max 1-Day and 5-Day Precipitation for the City of Hamilton.

Table 22: Extreme Precipitation Indices for the City of Hamilton - RCP4.5 and 8.5

Variable	**Emissions Scenario**	**Baseline 1976-2005**	2021-2050			2051-2080		
			Low	Mean	High	Low	Mean	High
Heavy precipitation Day (10 mm)	RCP4.5	25.8	19.6	27.6	36	20.3	28.5	37.3
	RCP8.5	25.8	20.1	28.2	36.7	20.8	28.8	37
Heavy precipitation Day (20 mm)	RCP4.5	6.7	3.8	7.7	11.8	4.3	8.4	12.9
	RCP8.5	6.7	4	8	12.2	4.6	8.9	13.2
Max 1-Day Precipitation	RCP4.5	42	30	46	71	30	46	70
	RCP8.5	42	29	46	69	31	48	73
Max 5-Day Precipitation	RCP4.5	65	48	70	104	49	72	105
	RCP8.5	65	47	69	99	51	74	107

Across the City, heavy precipitation days are expected to increase by approximately 3 days for 10 mm days and 2 days for 20 mm days. Maximum 1-Day and 5-day events are also expected to increase across the City, with the greatest increase in five-day events. For example, Max 5-Day events are projected to increase from a baseline of 65 mm to 74 mm by 2051-2080 for RCP8.5.

Changes in the above extreme precipitation indices are visually presented in Figures 10 and 11 for the City of Hamilton under RCP8.5.

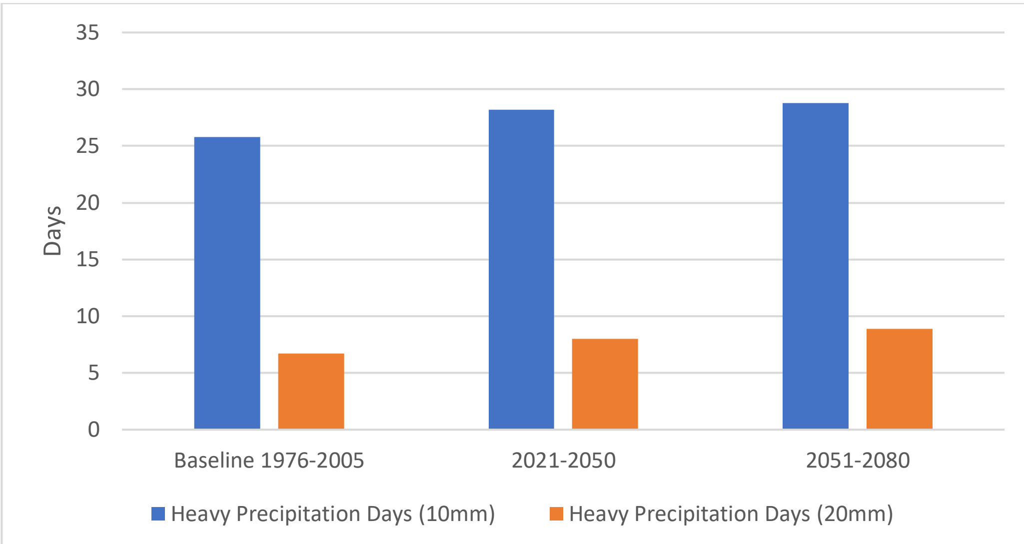


Figure 11: Heavy Precipitation Days (10 mm and 20 mm) for the City of Hamilton (RCP8.5)

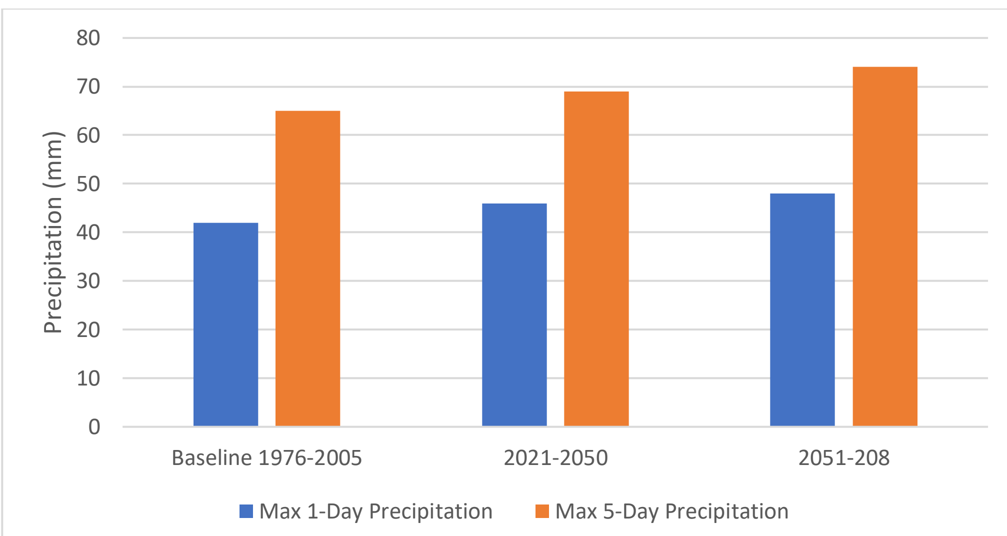


Figure 12: Max 1-Day and 5-Day Precipitation for the City of Hamilton (RCP8.5)

It's important to understand projections for heavy rainfall events, as they can create many challenges. In cities and towns, heavy rainfalls can overwhelm storm drains and cause flash flooding. Overwhelmed storm drains can lead to a host of consequences to local ecology and public safety as excess water, including untreated sewage overflow, courses into nearby waterways and aquatic life finds its way into water treatment facilities. Flooding can also cause erosion and slope instability, damaging important natural features and creating hazardous conditions[xxxix]. Finally, heavy rainfalls can also cause problems in rural areas by drowning crops, eroding topsoil, and damaging roads. Those areas which are most at risk of flooding are those which are low-lying, or which sit atop former wetlands[xl].

Agricultural Indices

Climate change creates both risks and opportunities for Ontario agriculture. Changes in seasonal temperatures, precipitation events, the length of growing seasons, and the timing of extreme heat and cold days all determine the types of crops that can be grown now and in the future[xli]. While increased temperatures will extend the growing season of some crops, it will bring with it a series of deleterious factors which may negate any benefit. For instance, increased temperatures may also increase the likelihood of drought conditions, reduce the water supply for crop irrigation, improve conditions for some pests, and disrupt pollination patterns[xlii]. Managing for increased agricultural productivity and working to reduce risks under climate change will require careful consideration of changing weather and climate conditions, as well as key landscape and soil characteristics, crop suitability, farm management options, and policy and program support[xliii].

Frost Indices

Changes in the length and timing of the frost-free season affect plant and animal life, but also our social, psychological, and physical experience of the changing seasons.

The Frost-Free Season is the approximate length of the growing season, during which there are no freezing temperatures to kill or damage plants. Table 24 and Figure 13 depict that the length of the frost-free season is expected to increase, from a baseline of 174 days per year, to 220.1 days per year in 2051-2080 according to RCP8.5 for the City of Hamilton. This lengthening of the frost-free seasons means plants and crops have a longer window to grow and mature.

Table 23: Length of Frost-Free Season for the City of Hamilton (RCP4.5 and 8.5)

Emissions Scenarios	**Baseline 1976-2005**	2021-2050			2051-2080		
		Low	Mean	High	Low	Mean	High
RCP4.5	174	167.7	194.7	223	171.6	201.9	233.4
RCP8.5	174	170.7	197.5	227.5	189.6	220.1	253

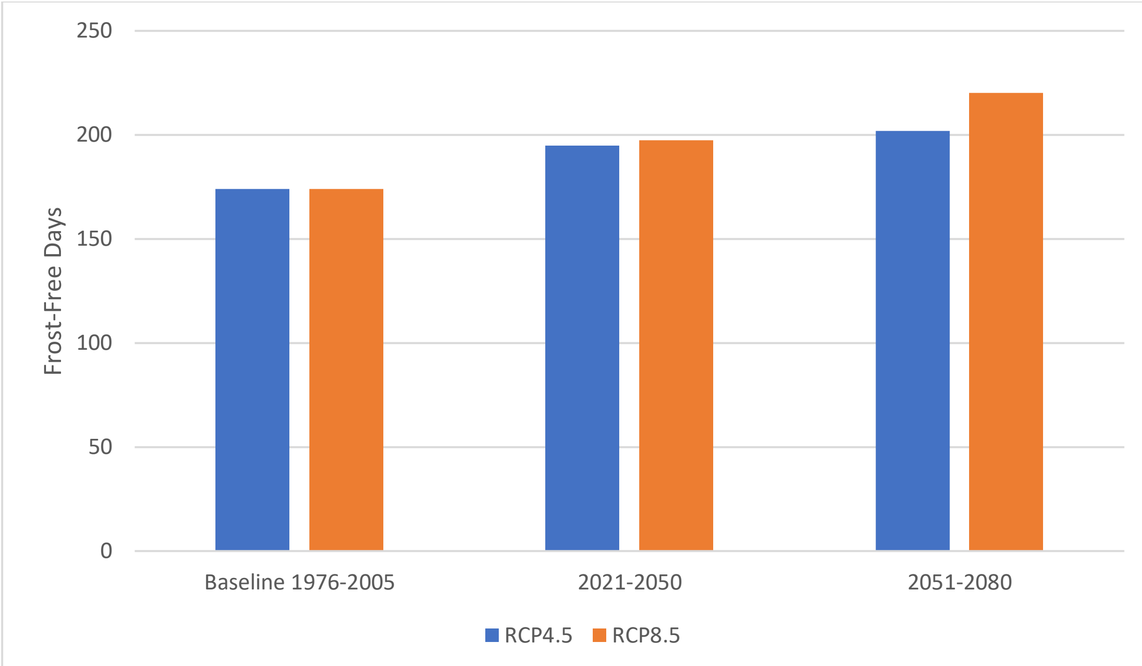


Figure 13: Length of Frost-Free Season for the City of Hamilton (RCP4.5 and 8.5)

Not only is the overall frost-free season becoming longer, the dates of first and last frosts of the year are also changing. The arrival of frost marks the end of the growing season and announces the imminent return of winter. Projections for Hamilton indicate a later date of First Fall Frost, meaning the seasonal transition from warmer to colder weather is happening later in the year. Table 25 outlines the expected changes to first and last frost for the City of Hamilton. According to RCP8.5, this date could shift from a baseline of October 20th to potentially November 15th in the 2051-2080 period.

Similarly, the date of Last Spring Frost is expected to occur earlier – a change from a baseline of April 26th to April 6th by the 2051-2080 period according to RCP8.5.

Table 24: Date of First and Last Frost for the City of Hamilton (RCP4.5 and 8.5)

Variable	**Emissions Scenario**	**Baseline 1976-2005**	2021-2050			2051-2080		
			Low	Mean	High	Low	Mean	High
Date of First Fall frost	RCP4.5	Oct. 20	Oct. 12	Oct. 31	Nov. 20	Oct. 16	Nov. 4	Nov. 26
	RCP8.5	20-Oct	14-Oct	02-Nov	24-Nov	23-Oct	15-Nov	11-Dec
Date of Last Spring Frost	RCP4.5	26-Apr	31-Mar	16-Apr	May	25-Mar	13-Apr	03-May
	RCP8.5	26-Apr	30-Mar	15-Apr	02-May	16-Mar	06-Apr	24-Apr

Corn Heat Units

Corn Heat Units (CHU) is a temperature-based index often used by farmers and agricultural researchers to estimate whether the climate is warm enough (but not too hot) to grow corn. One of the common climate indices used to assess the viability of growing a crop in a region is average annual CHUs. The CHUs expected in a region's growing season are used to assess whether corn, or a particular variety of corn, is likely to fully mature in that region[xliv]. Generally, at least 2200 CHUs are required to mature most varieties of corn[xlv]. Table 26 outlines the annual projected CHUs for the City of Hamilton.

Table 25: Corn Heat Units for the City of Hamilton (RCP4.5 and 8.5)

Emissions Scenarios	Baseline 1976-2005	2021-2050			2051-2080		
		Low	Mean	High	Low	Mean	High
RCP4.5	3442	3551	4008	4428	3794	4297	4764
RCP8.5	3442	3644	4091	4539	4253	4723	5211

Overall, CHUs are projected to increase from now until the end of the century. According to RCP8.5, CHUs are projected to increase from a baseline of 3442 to 4723 by the 2051-2080 period.

Growing Degree Days

Growing Degree Days (GDD) provide an index of the amount of heat available for the growth and maturation of plants and insects. Different base temperatures (5, 10 and 15 °C) are used to capture results for organisms that demand different amounts of heat.

GDDs accumulate whenever the daily mean temperature is above a specified threshold temperature. Generally, 5 °C GDDs are used for assessing the growth of canola and forage crops; 10 °C GDDs are more appropriate for assessing the growth of corn and beans; and 15 °C GDDs are used to assess the growth and development of insects and pests[xlvi]. Table 27 outlines the GDDs for the City of Hamilton across 5, 10, and 15-degree thresholds respectively.

Table 26: Growing Degree Days for the City of Hamilton (RCP4.5 and 8.5)

Variable	Emissions Scenario	Baseline 1976-2005	2021-2050			2051-2080		
			Low	Mean	High	Low	Mean	High
Growing Degree Days (Base 5oC)	RCP4.5	2300	2407	2717	3001	2579	2946	3296
	RCP8.5	2300	2481	2774	3065	2900	3280	3669
Growing Degree Days (Base 10oC)	RCP4.5	1331	1410	1661	1895	1543	1847	2141
	RCP8.5	1331	1472	1712	1950	1804	2118	2436
Growing Degree Days (Base 15oC)	RCP4.5	611.1	659.6	852.8	1042	755.4	997.3	1252
	RCP8.5	611.1	708.4	895.5	1085	956.5	1211	1480

All GDDs are expected to increase across all emission scenarios and time periods. This indicates that there will be more days per year that meet these temperature thresholds. While this presents some opportunities for agriculture (e.g. longer growing seasons), it also could signal an increase in the survival of pests and other invasive species due to warmer temperatures in the winter months.

Extreme Weather Events

Canada has seen more frequent and intense extreme events over the last 50-60 years than ever before. These events come in the form of extreme heat days, more instances of extreme precipitation and flooding, wind storms, and ice storms. In Canada, models show shorter return periods of extreme events – that is, the estimated interval of time between occurrences – in the future[xlvii].

Historic Events

The City of Hamilton has been confronted with a range of extreme weather events over the past several years including multiple ice storms and heavy winds. 2013's ice storm which affected a wide swath of North America caused destruction locally as downed trees weighed down by accumulating ice damaged vehicles and homes and left many residents without power for multiple days[xlviii]. A rare April ice storm in 2018, though less severe, had similar consequences for residents of Hamilton as power was lost in areas and some roads and trails were closed due to hazardous conditions[xlix]. This storm, which was accompanied itself by high winds and was followed by heavy rainfall, created concerns of erosion in areas with high slope and overwhelmed water treatment facilities sending untreated sewage and runoff into the lake[l].

A separate windstorm incident mere weeks after the April 2018 ice storm once again left many without power in Hamilton and across southern Ontario. Downed power lines posed a threat to the safety of citizens and took the life of a Hamilton man attempting to clear a line from a roadway[li].

Rainfall IDF Curves

Extreme and heavy rain events are expected to become more intense and more frequent[lii]. As Southern Ontario is the most intensely urbanized area of the province, the magnitude and costs associated with flooding is significantly higher than elsewhere in the province.

Storm water management systems depend on Intensity–Duration–Frequency (IDF) curves as a standard design tool. However, due to climate change, the extreme precipitation data represented by IDF curves will be subject to change over time. The City of Hamilton has developed IDF curves for the municipality using Western University's Computerized Tool for the Development of Intensity-Duration-Frequency Curves under Climate Change – version 4.5 (www.idf-cc-uwo.ca), integrating climate change considerations over time. Available precipitation data from existing Environment Canada stations, is integrated with predictions obtained from Global Climate Models to assess the impacts of climate change on IDF curves. GCM models developed for IPCC Assessment Report AR5 are used to provide future climate scenarios for the various RCPs.

The table below outlines the historical IDF curves for the City of Hamilton using data from the Royal Botanical Gardens station. Appendix A outlines the projected IDF curves under RCP4.5 and RCP8.5 for the immediate future (2021 – 2050) and the near future (2051 – 2080).

Table 27: Historical Precipitation Intensity Rates for the City of Hamilton (mm/h) (1962-2017)

T (years)	2	5	10	20	25	50	100
5 min	96.51	123.91	141.02	156.71	161.54	176.01	189.76
10 min	68.56	87.67	100.49	112.90	116.86	129.13	141.43
15 min	54.68	69.72	80.84	92.48	96.38	109.09	122.79
30 min	35.63	45.46	52.11	58.60	60.68	67.15	73.67
1 h	22.10	27.67	30.92	33.73	34.56	36.98	39.16
2 h	13.76	17.64	20.09	22.35	23.04	25.15	27.16
6 h	5.70	7.81	9.41	11.13	11.71	13.65	15.79
12 h	3.39	4.55	5.48	6.53	6.89	8.14	9.57
24 h	2.00	2.58	3.05	3.58	3.76	4.40	5.14

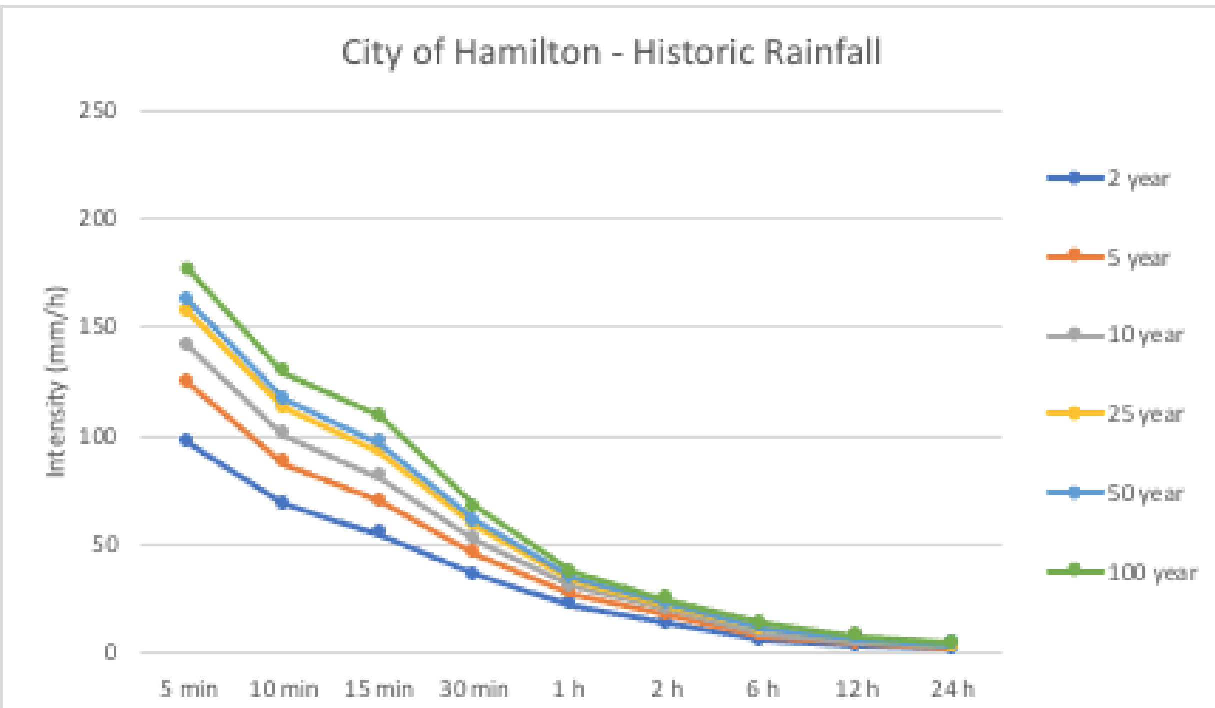


Table 28: Historical IDF Curve for the City of Hamilton (mm/h) 1962-2016

Overall, the curves indicate that the intensity of rainfall events are expected to increase. Increases in the intensity of rainfall events as a result of climate change are a major threat to infrastructure systems, especially stormwater infrastructure systems and the transportations systems they protect. Higher rainfall intensities lead to more severe storms, with expected increases in damages related to residential, street, and flash flooding.

Freezing Rain

A study conducted by the Meteorological Service of Canada and the Science and Technology branch of Environment Canada observed the possible impacts of climate change on freezing rain using downscaled future climate scenarios for Eastern Canada. This study used climate scenarios from the IPCC AR4 report.

Region I of the study encompasses a portion of Southwestern Ontario, including the City of Hamilton. The study conducted analysis on the projected average percentage change in the number of daily freezing rain events. Figure 11 presents the averaged percentage change in the number of daily freezing rain events for ≥1 h, ≥4 h and ≥6 h events per day. For Region I, the percentage increase is most pronounced in the months of January, with slight changes in the months of December and February, and an overall decrease in the months of November, March and April. Severe freezing rain events (>6 h per day) are projected to increase up to 30% by 2100[liii].

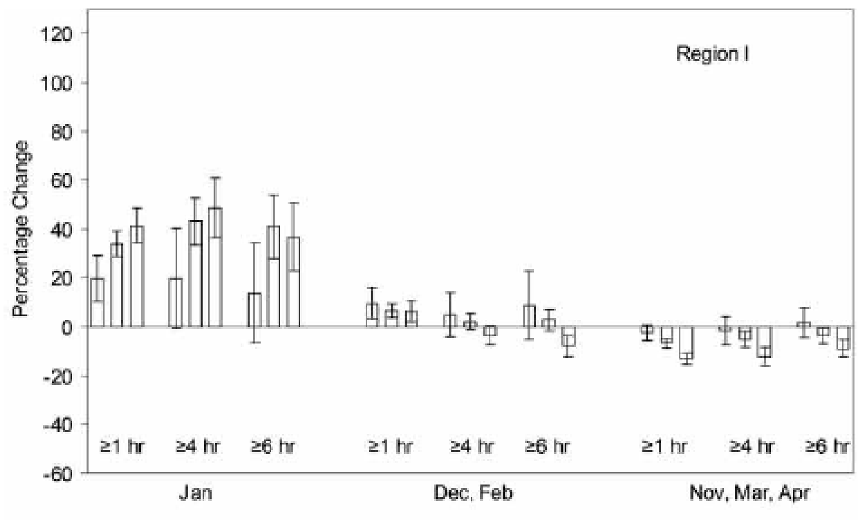


Figure 14: The average percentage change in the number of daily freezing rain events (%) for Region I relative to 1957-2007 baseline conditions[liv]

Wind

A recent 2012 study by Cheng et al. observed the possible impacts of climate change on future daily and hourly wind gust events in the province of Ontario. This study used climate scenarios from the IPCC AR4 report. Overall, the results show that Canada could possibly receive more wind gust events late this century than has been historically experienced. The magnitude of the projected percentage increases in the frequency of future wind gust events would be generally greater for more severe wind gust events.

Region C3 of the study includes the City of Hamilton. Figure 15 outlines the projected percentage changes in annual-mean frequency of future hourly wind gust events across all study regions (including C3). Overall, the study found that the magnitude of the percentage increases in the frequency of future hourly and daily wind gust events would be greater for more severe wind gust events[lv]. For example, the percentage increases in the frequency of future hourly and daily wind gust events ≥28 km/h are projected to be less than 10%, generally for most of the regions. The corresponding increases for future hourly wind gust events ≥90 km/h are projected to be more than double for all regions[lvi].

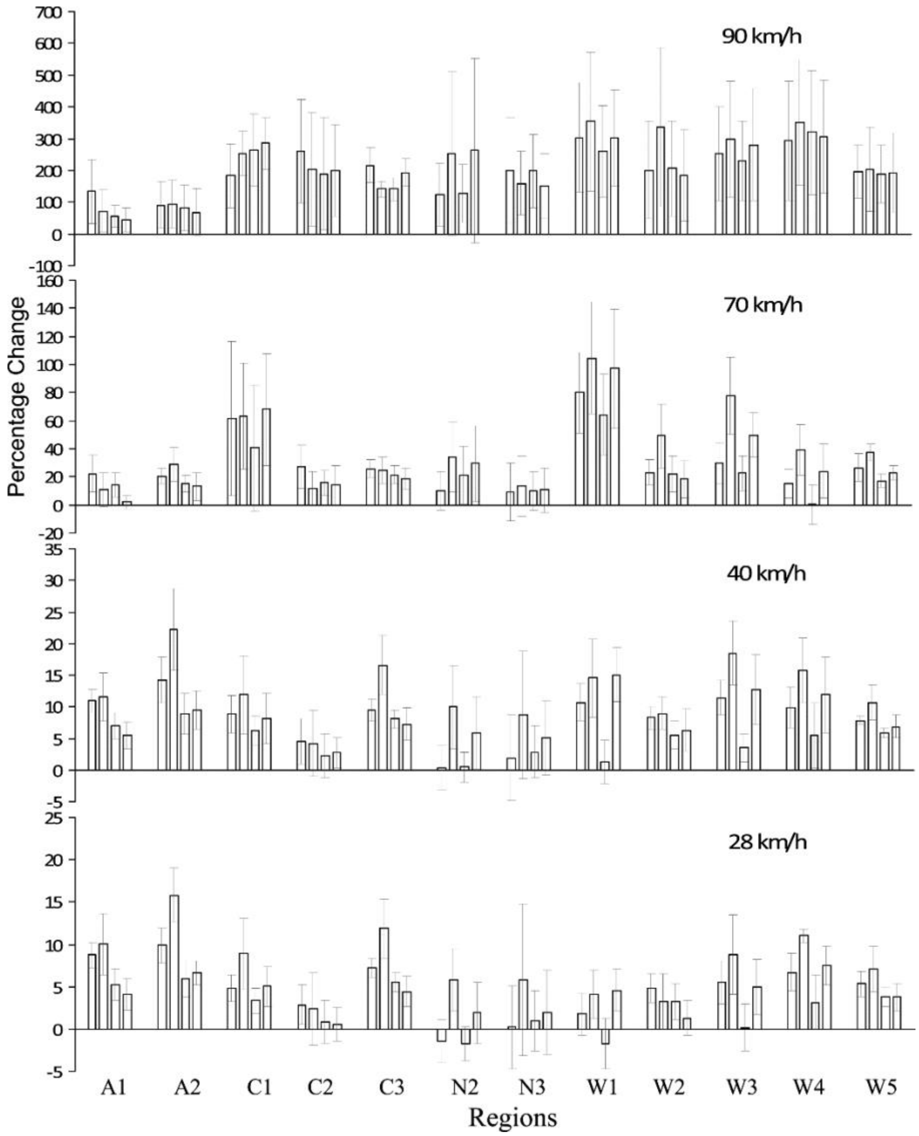


Figure 15: Projected percentage changes in annual-mean frequency of future hourly wind gust events (A2 and B1)[lvii]*

* Four bars in each of the panels: the first two for scenario A2 over the periods 2046–65 and 2081–2100; the last two for scenario B1 over the periods 2046–65 and 2081–2100). The 95% confidence interval is indicated.

The study also analyzed the increase in the number of daily mean gust events. Similar to the annual mean-frequency numbers, daily mean gust events are expected to increase most significantly for extreme wind gust events – i.e. those ≥ 70 km/h and 90 km/h[lviii].

Lake Temperature and Water Levels

Lake Ontario Water Levels

Water levels in the Great Lakes have fluctuated considerably over multi-decadal time scales. Figure 16 shows annual changes in the water levels for the Great Lakes from 1860 to 2015[lix]. Water levels across all of the Great Lakes have risen over the past several years following a period of record low levels. In 2017, Lake Ontario experiences extremely high-water levels. Record breaking heavy precipitation in the basin appears to have largely driven the increases in lake levels and may have exceeded the capacity of the regulatory system to respond[lx]. Records of lake level over several decades show that trends are small and variability is high. Newer model-based projections of lake level (since 2011) foresee a central tendency toward small drops in lake levels to the end of the 21st century, with appreciable probability of small rises in lake levels, in contrast to the large drops projected using the older, now-defunct methodology[lxi]. Highly variable water levels in Lake Ontario may create hazardous conditions for residents as well as having the potential to degrade important shorelines and natural areas.

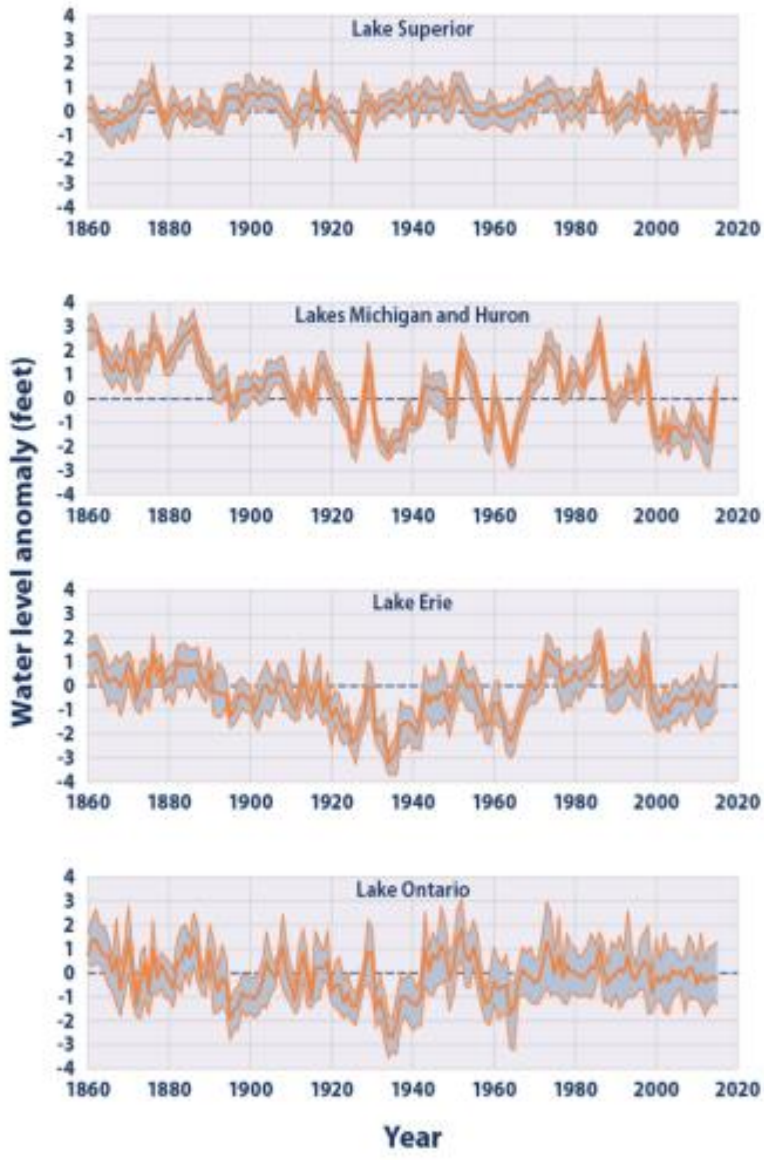


Figure 16: Great Lake Water Levels (1860-2020)

Water Temperatures and Ice Coverage

Climate change in the Great Lakes involves both direct input of heat to the Lakes by increased downward longwave emissions by GHGs, and inhibited loss of heat to the air by turbulent heat fluxes associated with the effects of the lakes[lxii]. Figure 17b shows the change in summer temperatures in the Great Lakes from 1994 to 2013[lxiii] – all of the Great Lakes show a significant increase over the 20-year period. Increases in water temperature are currently disrupting aquatic food webs to unknown effect. This disruption is occurring as local fish species alter their territory and diets in pursuit of suitable temperatures[lxiv].

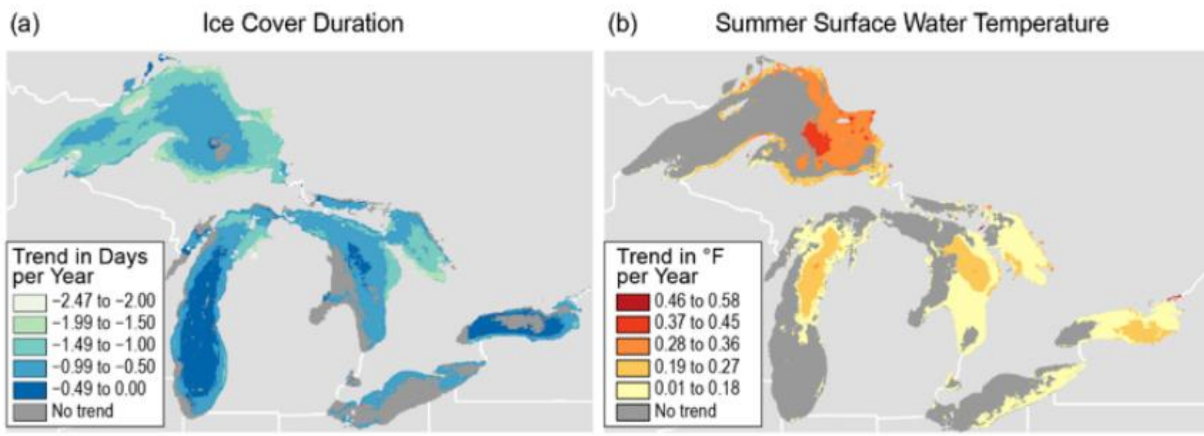


Figure 17: Ice Cover Duration and Summer Surface Water Temperature in the Great Lakes

Ice cover on the Great Lakes has seen a slight decreasing trend between the time when systematic observations began in 1973 and 2018 based on data from NOAA GLERL[lxv]. As seen in Figure 17a, the greatest rate of decrease in seasonal ice cover duration occurs near shorelines, with smaller rates occurring in the deeper central parts of Lake Ontario, which rarely have ice cover.

Conclusion

The information provided in this report provides a clear indication that climate change is affecting Canada, and specifically the City of Hamilton. Rising annual temperatures as well as increases in precipitation and extreme events are major climate impacts that can have tremendous ecological, infrastructural, economic, and sociological effects for the community. This report is meant to act as a background and an introduction to climate change in this area. The information in this report will be used to inform proactive adaptation planning across the community and corporation, and may be integrated into asset management practices, emergency management planning, outreach and communications, as well as other community-based adaptation programs.

Projected Impacts

The significant impacts the City of Hamilton and its residents will face are informed by past events as well as by projected increases in temperature and precipitation and increasingly frequent extreme weather events all of which have been detailed in the above report. While temperatures are expected to increase across all seasons, their effects will be experienced most acutely in the summer as maximum yearly temperatures and the length of heatwaves are pushed to new highs. Precipitation will also increase across most seasons, with the exception of summer, with the greatest additional precipitation arriving in the winter and spring seasons. In addition to overall increases in precipitation, rainfall events in Hamilton are also expected to increase in intensity, duration and frequency by the 2050s. Finally, instances of extreme weather in the form of extreme heat days and extreme precipitation as well as flooding, windstorms, and ice storms have been increasing across Canada for the past half-century and are expected to continue to become more frequent[lxvi]. The above trends will continue to present unique challenges to the health of the City of Hamilton's citizens, as well as to its infrastructure and economy.

Human Health

Increasing heat in the Hamilton area will have widespread implications on human health. Summer temperature increases and extended periods of warm weather can raise the likelihood of heat stroke and heat exhaustion, especially among the City's vulnerable populations. Among vulnerable groups in Hamilton are older adults (≥ 65 years old) whose population currently exceeds provincial averages[lxvii]. Similar population groups (≥ 55 years old) are expected to increase substantially in Hamilton by 2041[lxviii]. Increased heat also has negative implications for the City's air quality. Smog, which is exacerbated by extreme summer heat, can worsen existing respiratory issues and promote asthma development among young people[lxix]. Finally, increased summer temperature and its consequences may also be felt more acutely in built up urban cores such as Hamilton's downtown. This is thanks to the urban heat island effect, a phenomenon in which the presence of many impermeable surfaces and tall buildings work to absorb and trap summer heat [lxx].

Rising annual temperatures in Hamilton may also have the effect of extending the breeding season and geographical range of disease vectors such as mosquitoes and black-legged ticks. In fact, existing trends in Ontario suggests that the boundary in which ticks have been reported is currently expanding[lxxi]. General temperature increases will also see the extension of allergy season which can cause aggravation to respiratory systems[lxxii]. While winter temperatures are also set to rise, the Hamilton region will still experience significant cold periods and snow fall, creating hazardous conditions for pedestrians and drivers alike.

Along with temperatures and precipitation increases in Hamilton, extreme weather events are likely to become more frequent occurrences[lxxiii]. These events can have direct effects on human health through potential injury or mortality related to infrastructure failure[lxxiv]. Health impacts can also come in the form of food and water borne illness brought about by extreme precipitation events which can increase water turbidity and introduce disease to drinking sources[lxxv].

Stormwater Management and Sewage

The total amount of annual precipitation in Hamilton is expected to increase by as much as about 79 millimetres in the 2051-2080 period, the largest of these increases associated with the spring and winter seasons. The severity of rainstorms is also expected to worsen in the 2021-2050 period. These paired dynamics can restrict the ability of natural and human-made systems to manage rainwater, leading to flooding. Among areas most susceptible to flooding are those which are low lying or which were former wetlands which have been filled and built upon[lxxvi]. While flooding can lead to property and infrastructure damage, it can also promote erosion and slope instability, damaging or destroying significant natural features and creating hazardous conditions[lxxvii]. Aside from physical damages, flooding which overwhelms sewer systems can also allow sewage to enter waterways[lxxviii]. The impacts of rainfall events on the natural environment are explored in subsequent sections below.

Tourism and Recreation

Changes in the climate will have varied implications for tourism in the City of Hamilton. Increased annual temperatures may at once extend the summer tourism season while limiting opportunities for snow-based recreation in the winter season. Hamilton's combination of stabilizing summer precipitation projections paired with the anticipated significant increases to temperature may lead to hot and dry conditions. Such conditions can trigger fire bans, impacting outdoor activities[lxxix]. Extreme precipitation events can also erode beaches and other natural features as well as leading to slope instability, forcing closure of natural areas to tourists and reducing the health of habitats[lxxx]. Finally, unpredictable lake levels, which are set to persist to the end of the 21st century, may also create unsafe conditions or degrade popular natural areas[lxxxi].

Transportation Network

Extreme weather and general warming in the Hamilton area will have a range of consequences for Hamilton's transportation network. In the near to mid-term, freeze-thaw cycles are likely to continue to damage major infrastructure and pose hazards to travellers. Conversely, in the long-term, freeze-thaw cycles are anticipated to wane and so may demand less in terms of infrastructure repair[lxxxii]. Milder winters will also allow for the viability of year-round active transportation which may necessitate greater investments in pedestrian and cyclist focused infrastructure[lxxxiii]. However, extreme precipitation and heat events may negate the increasing popularity of these modes of travel. All modes, including automobile travel, may be challenged as storms and extreme heat increases hazardous conditions and places stress on the integrity of infrastructure such as roads and bridges[lxxxiv].

Ecosystems and Species

The effects of Hamilton's changing climate on local ecosystems and species is markedly complex. Temperature increase alone could be positive for some plant and animal species as growing seasons are extended, as well as to the process of decomposition which is suppressed during cold weather[lxxxv],[lxxxvi]. Despite these potential benefits, warmer temperatures could also confuse vital relationships between and among organisms[lxxxvii]. For instance, pollinators may be triggered to begin pollinating at inopportune points in time, reducing their effectiveness[lxxxviii]. Warmer air temperatures can translate to higher water temperatures in Lake Ontario and can have the effect of disrupting food webs, potentially to the detriment of the aquatic ecosystem[lxxxix]. Changes in temperature can also invite invasive species to new territories and may increase the instances of vector borne diseases[xc]. In cases where rising temperatures lead to drought conditions, the growth of fungi and other bacteria may be impeded[xci]. In times of reduced water levels there will also be negative impacts to the wider array of species in the area, increasing vulnerability to competition[xcii].

Precipitation events, which are set to intensify in the near and medium-term, can also cause damage to both flora and fauna. Rain events may increase erosion and concentrations of sediment in key spawning areas, disrupting the birth cycles and survival rates of aquatic animals[xciii]. Flooding and storm events may also inundate the roots of trees and other vegetation and leave them unable to withstand high winds[xciv].

Buildings and Energy Systems/ Power Grid

Increasing temperatures in the summer season will place greater demand on Hamilton's electricity grid as is implied by the projected more than doubling of Cooling Degree Days displayed in this report. Cooling Degree Days (CDD) are equal to the number of degrees Celsius a given day's mean temperature is above 18 °C (consider putting this in a side bar). High temperatures themselves can also lower the ability of transmission lines to carry power, possibly leading to electricity reliability issues during heat waves[xcv]. Extreme weather such as rain and ice storms, which are anticipated to become more frequent, can also down power lines, creating hazards for pedestrians and increasing the uncertainty of electricity delivery. Extreme heat and storm events place stresses on the power grid which can ultimately lead to more frequent brownout and blackout conditions and leave residents vulnerable by reducing access to essential services.

Food and Agriculture

Food and agriculture in the Hamilton area may experience some benefits as climate change progresses in the future, however there are also many negative implications related to the anticipated changes in temperature, precipitation and extreme weather events. As outlined in the report above, the number of growing degree days (measured as the total amount of heat available annually to enable the growth of various crops) will increase, allowing for longer growing seasons[xcvi]. Consistently warmer temperatures and mild winters can also enable the survival of pests and other invasive species. Increased heat and drier summer conditions may also reduce the amount of available water and restrict irrigation capacity during longer growing seasons[xcvii]. The survival of crops will be further challenged by extreme weather events and flooding. Finally, as mentioned above, changing pollination patterns brought on by temperature increases may come at the detriment of reliant crops[xcviii].

APPENDIX A

Table 30: Precipitation Intensity Rates (mm/h) (Baseline: 1962-2017, projection: 2021 - 2050) for Royal Botanical Garden – Hamilton. RCP4.5.

T (years)	2	5	10	20	25	50	100
5 min	102.45	134.49	153.12	168.49	173.66	189.54	205.43
10 min	72.73	95.05	109.24	121.45	125.76	139.03	153.36
15 min	57.96	75.46	87.81	99.26	103.43	116.99	133.1
30 min	37.79	49.28	56.65	63.04	65.3	72.29	79.84
1 h	23.48	30.07	33.54	36.21	37.08	39.84	42.39
2 h	14.6	19.14	21.81	24.03	24.78	27.07	29.39
6 h	6.05	8.43	10.2	11.93	12.55	14.62	17.11
12 h	3.59	4.91	5.93	7.04	7.42	8.76	10.62
24 h	2.12	2.79	3.3	3.86	4.06	4.74	5.71

Figure 18: Precipitation Intensity Rates (mm/h) (Baseline: 1962-2017, projection: 2021 - 2050) for Royal Botanical Garden – Hamilton. RCP4.5.

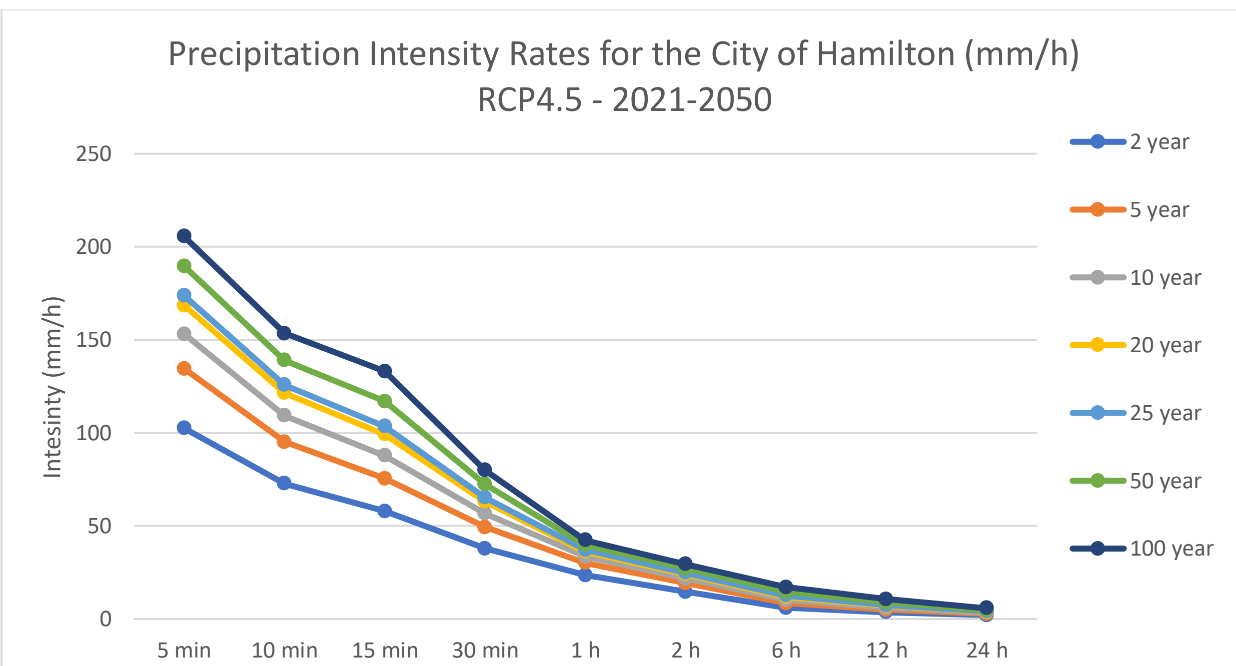


Table 31: Precipitation Intensity Rates (mm/h) (Baseline: 1962-2017, projection: 2021 - 2050) for Royal Botanical Garden – Hamilton. RCP8.5.

T (years)	2	5	10	20	25	50	100
5 min	103.67	133.31	153.05	171.68	178.22	197.26	214.53
10 min	73.66	93.94	108.87	123.43	128.39	143.97	158.53
15 min	58.86	74.39	87.21	100.87	105.53	120.18	135.89
30 min	38.28	48.68	56.44	64.06	66.62	74.8	82.35
1 h	23.77	29.82	33.55	37.02	38.2	41.55	44.39
2 h	14.77	18.97	21.8	24.47	25.41	28.17	30.69
6 h	6.15	8.33	10.15	12.12	12.78	14.92	17.3
12 h	3.66	4.85	5.88	7.06	7.46	8.79	10.32
24 h	2.16	2.75	3.27	3.88	4.08	4.76	5.54

Figure 19: Precipitation Intensity Rates (mm/h) (Baseline: 1962-2017, projection: 2021 - 2050) for Royal Botanical Garden – Hamilton. RCP8.5.

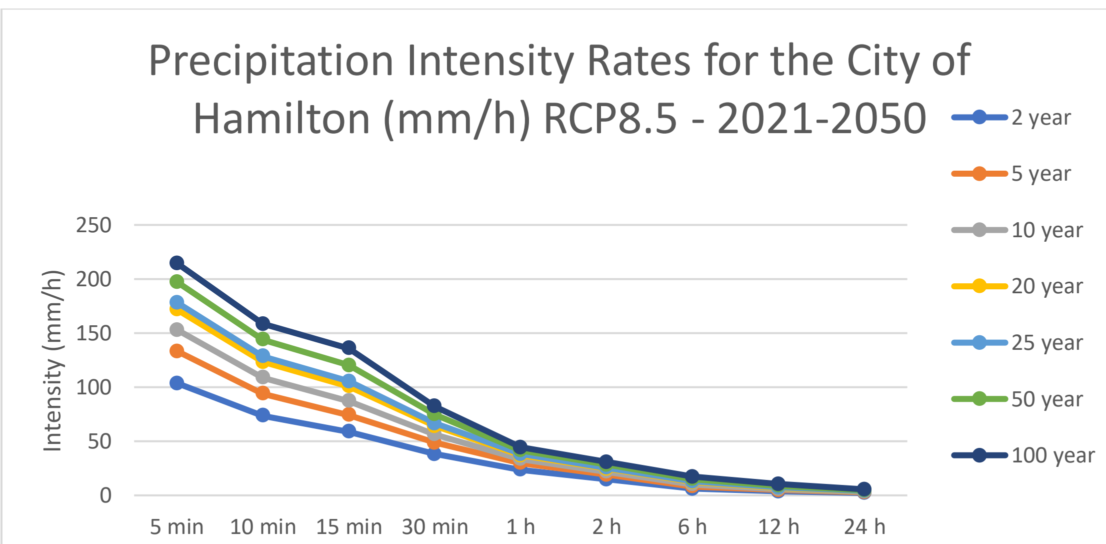


Table 32: Precipitation Intensity Rates (mm/h) (Baseline: 1962-2017, projection: 2051 - 2080) for Royal Botanical Garden – Hamilton. RCP4.5.

T (years)	2	5	10	20	25	50	100
5 min	106.02	134.83	155.12	171.66	176.95	192.75	207.83
10 min	75.13	95.52	110.1	123.48	127.82	141.26	154.43
15 min	59.66	76.02	88.06	100.84	104.99	118.82	132.6
30 min	39.03	49.54	57.06	64.08	66.35	73.44	80.38
1 h	24.28	30.1	33.99	36.97	37.88	40.52	43.07
2 h	15.11	19.2	22.08	24.47	25.24	27.54	29.75
6 h	6.21	8.5	10.29	12.13	12.73	14.81	17.05
12 h	3.68	4.95	5.94	7.11	7.48	8.78	10.24
24 h	2.17	2.81	3.31	3.9	4.09	4.75	5.48

Figure 20: Precipitation Intensity Rates (mm/h) (Baseline: 1962-2017, projection: 2051 - 2080) for Royal Botanical Garden – Hamilton. RCP4.5.

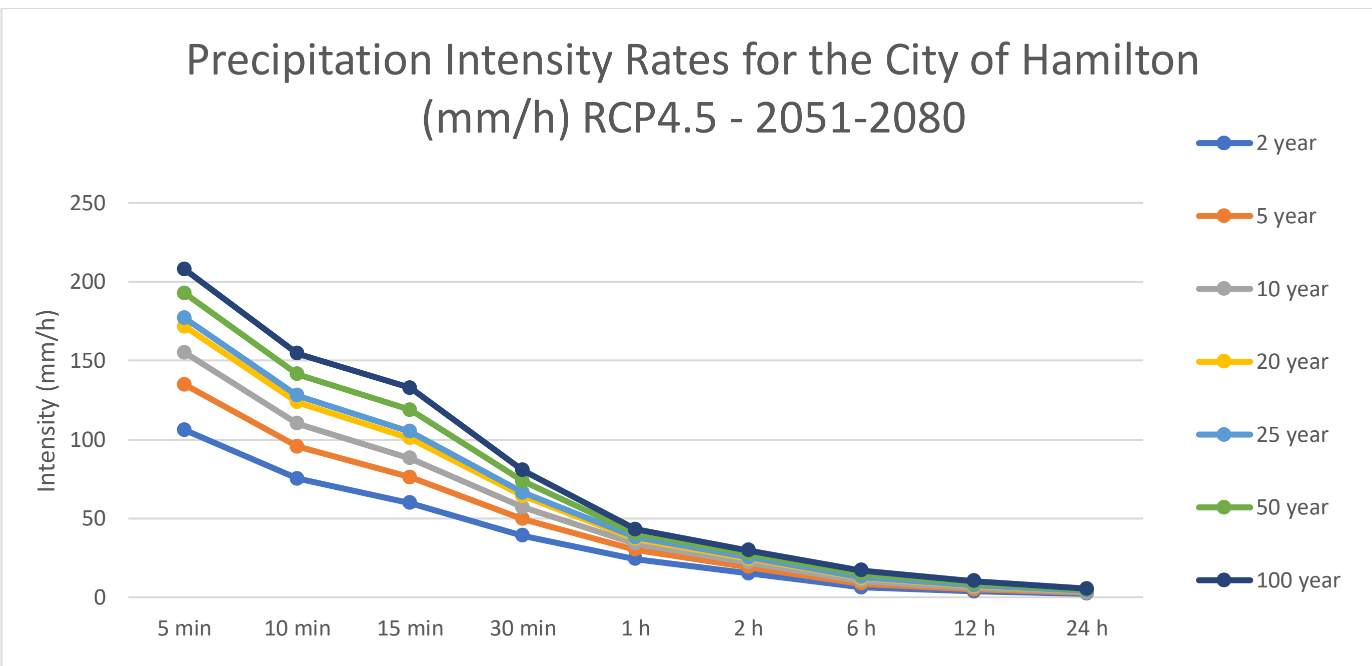
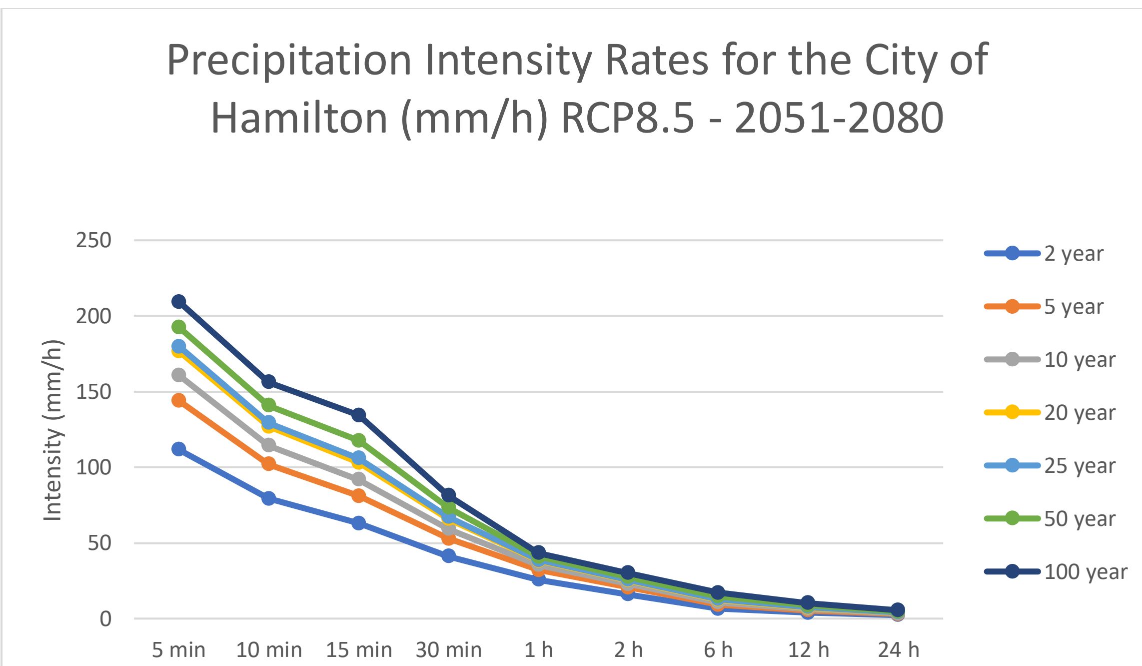


Table 33: Precipitation Intensity Rates (mm/h) (Baseline: 1962-2017, projection: 2051 - 2080) for Royal Botanical Garden – Hamilton. RCP8.5.

T (years)	2	5	10	20	25	50	100
5 min	111.56	143.89	160.7	176.62	179.85	192.46	209.35
10 min	79.13	101.88	114.3	126.74	129.33	140.81	156.05
15 min	63	81.09	91.69	103.14	105.79	117.65	134.43
30 min	41.11	52.84	59.26	65.75	67.1	73.19	81.3
1 h	25.58	32.12	35.26	38.13	38.66	40.8	43.26
2 h	15.9	20.49	22.88	25.17	25.64	27.49	29.97
6 h	6.57	9.06	10.65	12.36	12.87	14.65	16.97
12 h	3.9	5.3	6.19	7.2	7.51	8.66	10.18
24 h	2.3	3.02	3.45	3.95	4.09	4.67	5.49

Figure 21: Precipitation Intensity Rates (mm/h) (Baseline: 1962-2017, projection: 2051 - 2080) for Royal Botanical Garden – Hamilton. RCP8.5.



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