Climate Science Report

for the Climate Change and Health Vulnerability Assessment

for Waterloo Region, Wellington County, Dufferin County, and the City of Guelph

Region of Waterloo
PUBLIC HEALTH AND EMERGENCY SERVICES

PublicHealth
WELLINGTON-DUFFERIN-GUELPH
Stay Well.

About This Report

This report was prepared by ICLEI Canada in partnership with Region of Waterloo Public Health and Wellington-Dufferin-Guelph Public Health to support the development of the Climate Change and Health Vulnerability Assessment for Waterloo Region, Wellington County, Dufferin County, and the City of Guelph.

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Designed by artsum.

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Glossary

Definitions from the Intergovernmental Panel on Climate Change (IPCC) (https://www.ipcc.ch/site/assets/uploads/2018/11/sr15_glossary.pdf), and Environment and Climate Change Canada (https://www.canada.ca/en/environment-climate-change/services/weather-general-tools-resources/glossary.html).

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 Projections
Climate projections are a projection of the response of the climate system to emissions or concentration scenarios of greenhouse gases and aerosols. These projections depend upon the climate change (or emission) scenario used, which are based on assumptions concerning future socioeconomic and technological developments that may or may not be realized and are therefore subject to uncertainty.

CMIP5
Climate Model Intercomparison Project Phase 5.

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.

Extreme Weather Event
A meteorological event that is rare at a place and time of year, such as an intense storm, tornado, hailstorm, flood or heat wave, and is beyond the normal range of activity. An extreme weather event would normally occur very rarely or fall into the tenth percentile of probability.

General Circulation Models (GCM)
General Circulation Models are based on physical laws and physically-based empirical relationships and are mathematical representations of the atmosphere, ocean, ice caps, and land surface processes. They are therefore the only tools that estimate changes in climate due to increased greenhouse gases for a large number of climate variables in a physically-consistent manner.

Greenhouse Gas (GHG) Emissions
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.

IPCC
Intergovernmental Panel on Climate Change.

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.

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.

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.

UV Index
Invisible electromagnetic radiation with a frequency between that of visible violet light and x-rays. Most of the ultraviolet component of sunlight is absorbed by the ozone layer of the atmosphere, however UV-B radiation can cause sunburn and skin cancer, and UV-A radiation can cause photosensitivity reactions and possibly skin cancer.

W/m^2
Watts per square meter. The rate of heat energy of one watt transferred through the area of one square meter - used to calculate radiative forcing.

Introduction

The purpose of this Climate Science Report is to summarize climate data for jurisdictions of Wellington-Dufferin-Guelph Public Health (WDGPH) and Region of Waterloo Public Health (ROWPH). The report presents climate change projections to support the Climate Change and Health Vulnerability Assessment for Waterloo Region, Wellington County, Dufferin County, and the City of Guelph. It is intended to help inform what risks and vulnerabilities may affect the areas of Wellington-Dufferin-Guelph (WDG) and Waterloo Region as a result of climate change and inform how the Public Health and community stakeholders can prepare for projected health impacts over time.

Climate Indices

The climate indices included in this report are listed and defined in the table below. The indices represent a broad range of important climate variables that impact the study area. Temperature and precipitation data (except freezing rain) were taken from the Ontario Climate Data Portal and climatedata.ca, including the description and name of the climate indices.

Table 1: Climate Indices Definitions

Climatic Driver	Climate Indicator	Description	Units
Temperature	Mean Monthly Temperature	The average temperature for a given month	°C
	Mean Monthly Maximum Temperature	The average monthly maximum temperature	°C
	Mean Monthly Minimum Temperature	The average monthly minimum temperature	°C
	Extreme Heat Days	The number of days where the daily maximum temperature (Tmax) is >30°C and 32°C respectively.	Days
	Tropical Nights	Annual count of days when the daily minimum temperature is above 20°C	Days
	Extreme Cold Days	The number of days where the daily minimum temperature is <-15°C	Days
	Ice Days	Total number of days on which ice can form (i.e., when daily maximum temperature is below 0°C)	Days
	Frost Days	Total number of days with frost potentials (i.e., minimum temperature below 0°C)	Days
	Extended Heat Wave Frequency	The total number of extended heat wave events during a year. An extended heat wave is defined as three consecutive days with Tmax >31°C and Tmin >20°C	Times/ year

Climatic Driver	Climate Indicator	Description	Units
Precipitation	Total Precipitation	Total accumulated precipitation	mm
	Maximum Length of Dry Spell	Longest dry period in a year defined as the greatest number of consecutive days with daily precipitation less than 1mm	Days
	Specific Day Intensity Index	Average daily precipitation rate on days with precipitation	mm/day
	1-Day Maximum Precipitation	Annual 1-day maximum precipitation accumulation	mm
	5-Day Maximum Precipitation	Annual 5-day maximum precipitation accumulation	mm
	Very Wet Days Total Precipitation	Amount of annual precipitation that falls during events that respectively produce more precipitation than 95% of all events in a year (e.g., if there are 100 precipitation events in a given year, the total accumulation from the five (5) heaviest storms is captured by this indicator)	mm
	Extremely Wet Days Total Precipitation	Amount of annual precipitation that falls during events that produce more precipitation than 99% of all events in a year (similar to 95th percentile above)	mm
	Freezing Rain Events	Average percentage change in the number of daily freezing rain events (≥1 hour, ≥4 hours, and ≥6 hours)	Days

Climatic Driver	Climate Indicator	Description	Units
Air Quality	Ground Level Ozone	The amount of ground level ozone in the air at a given location. Ozone is a gas that is formed when nitrogen oxides react with a group of air pollutants known as 'reactive organic substances' in the presence of sunlight	Ppm or as indicated
	Particulate Matter	The amount of particulate matter (both $PM_{2.5}$ and PM_{10} depending on the size of the matter) suspended in the air. Particulate matter includes aerosols, smoke, fumes, dust, fly ash, and pollen	Ppm or as indicated
UV Radiation	UV Index	Strength of sunburn-producing ultraviolet (UV) radiation at a particular place and time	UV Index

Data Collection

The majority of the data for this report was collected through the Ontario Climate Data Portal (OCDP), produced by the Laboratory of Mathematical Parallel Systems (LAMPS), York University. Data was also collected from the Canadian Centre for Climate Services (CCCS) tool – specifically for extreme heat days and heat wave analysis. Additional qualitative data pertaining to freezing rain, air quality, and UV index were taken from various reports, as these indices were not available on the OCDP platform or climatedata.ca. These are identified and cited where applicable. All data were downloaded from the corresponding links above in October 2019.

Climate Modelling and Downscaling

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 (Taylor et al., 2012). Data projecting temperature and precipitation changes have been summarized using the OCDP and climateData.ca.

Many different methods exist to construct climate change scenarios, however, GCMs are the most conclusive tools available for simulating responses to increasing greenhouse gas concentrations, as they are based on mathematical representations of atmosphere, ocean, ice cap, and land surface processes. The OCDP tool uses an ensemble approach, which refers to a system that runs multiple climate models at once. climatedata.ca also uses an ensemble approach of 24 climate models for the historical period, 1950-2005, and for plausible futures, 2006-2100. 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 (Tebaldi & Knutti, 2007).

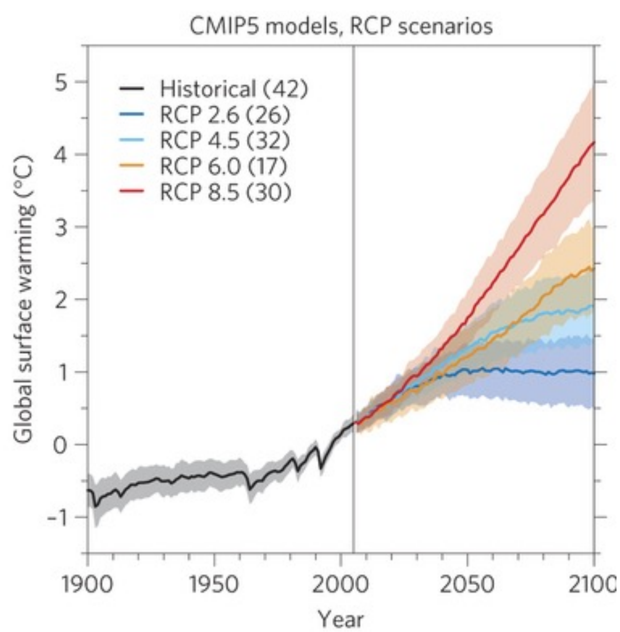
Greenhouse Gas Emissions Scenarios

It is unknown what future greenhouse gas (GHG) emissions will be. In order to account for multiple possible future emissions scenarios, the IPCC developed four Representative Concentration Pathways (RCP) as part of a new initiative for the Fifth Assessment Reports (Taylor et al., 2012). RCP2.6, 4.5, 6.0, and 8.5 reflect various levels of climate change mitigation efforts and business-as-usual GHG emissions scenarios. This report includes projections for RCP2.6, RCP4.5, and RCP8.5. RCP6.0 was not included as it has been found to be very similar to RCP4.5, which is deemed sufficient to represent the "medium" GHG scenario. Table 2 provides a description of each RCP scenario while Figure 1 (IPCC, 2014) illustrates the projected global warming associated with the four scenarios.

Table 2: RCP Scenario Descriptions

Scenario	Description
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.

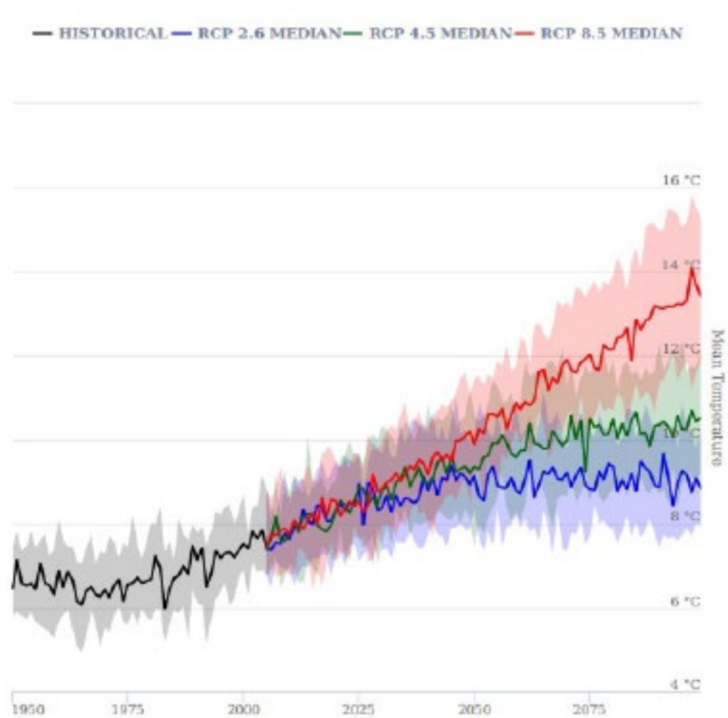
Figure 1: RCP Greenhouse Gas Emissions Scenarios



While RCP2.6 and RCP4.5 results are presented and discussed, the primary focus is on RCP8.5 as it represents the business-as-usual scenario, which is the current path that global emissions trends follow. Another reason for this focus is that the impacts of climate change under this more 'extreme' scenario will be the most pronounced for most variables of interest and any adaptation measures developed for RCP8.5 would be, at the very least, adequate for RCP4.5 and RCP2.6. Therefore, the principle focus on this scenario is to highlight that health risks undoubtedly become magnified and will affect larger populations under higher emissions scenarios.

Example Mean Annual Temperature Projections for Waterloo Region are shown in Figure 2. It is uncertain which emissions path society will follow. The difference between RCP2.6, RCP4.5, and RCP8.5 projections illustrates why multiple emissions scenarios should be considered: to ensure a range of possible future climates are captured in the analysis. The difference between future projections for different climate indices (variables) will not always be as pronounced as mean annual temperature (though in some cases it may be more pronounced).

Figure 2: RCP2.6, 4.5, and 8.5 Mean Annual Temperature Projections for Waterloo Region



Timeframes

Climatic projections are typically provided within time periods of 20-30 years. Additionally, a consistent baseline period is established so that projections can be accurately compared with historical trends. For the LAMPS data, future projected time periods include 2040-2069 (referred to as the 2050s) and 2070-2099 (referred to as the 2080s). Baseline data from LAMPS is from 1986-2005. For data from climatedata.ca, each climate model simulates the climate for the historical period, 1950-2005, and for plausible futures, 2006-2100. 30-year averages are currently not available from climatedata.ca. For other qualitative data retrieved from various literature, different time periods and baselines are identified.

Some of the climate indices are divided into seasons (defined below) along with annual totals or averages (e.g., temperatures, total precipitation), however, others only have a single annual value (e.g., temperature extremes, etc.).

Table 3: Season and Months

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

Uncertainty

It is important to note that uncertainty is an integral part of the study of climate change. Uncertainty is factored into climate change scenarios, models, and data, and reflects 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.

The primary constraint on quantifying the impacts of climate change is typically GCM projection uncertainty. It is good practice that multiple GCMs be selected for use in future climate projection studies. Using different models for the same greenhouse gas scenarios is one way to evaluate uncertainty, although various greenhouse gas scenarios are required for a more complete assessment of uncertainty.

There is no established method to evaluate which models best simulate the future. However, there are many ways through which uncertainty of future projections can be accounted for. In this report, the results focus on the ensemble mean projections – e.g., 50^{th} percentile.

Temperature Indices

All temperature indices for the study area are projected to experience significant warming for RCP2.6, 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 (e.g., mosquito transmission of West Nile virus), zoonotic disease (e.g., water contamination from *E. coli* bacteria or harmful algal blooms), and temperature-related morbidity and mortality.

Seasonal Mean Temperatures

Seasonal baseline mean temperatures for Wellington County are: -4.5, 6.0, 19.6, and 9.5˚C for winter, spring, summer, and autumn respectively. This gives a year-round average temperature of 7.7˚C for 1986-2005.

Table 4: Baseline and Projected Mean Temperatures for Wellington County (°C) by Season, RCP2.6, 4.5, and 8.5

Mean Temperatures (°C)	Baseline 1986-2005	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Winter	-4.5°C	-2.4°C	-2.0°C	-1.3°C	-2.5°C	-1.2°C	0.8°C
Spring	6.0°C	8.0°C	8.3°C	9.0°C	7.8°C	9°C	10.9°C
Summer	19.6°C	21.3°C	21.9°C	22.7°C	21.2°C	22.5°C	24.6°C
Autumn	9.5°C	11.3°C	11.9°C	12.5°C	11.2°C	12.2°C	14.6°C
Annual	7.7°C	9.6°C	10.1°C	10.7°C	9.5°C	10.7°C	12.8°C

Seasonal baseline mean temperatures for Dufferin County are: -5.1, 5.8, 19.5, and 9.2˚C for winter, spring, summer, and autumn respectively. This gives a year-round average temperature of 7.4˚C for 1986-2005.

Table 5: Baseline and Project Mean Temperatures for Dufferin County (°C) by Season – RCP2.6, 4.5, and 8.5

Mean Temperatures (˚C)	Baseline 1986-2005	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Winter	-5.1°C	-2.9°C	-2.5°C	-1.9°C	-3.0°C	-1.7°C	0.4°C
Spring	5.8°C	7.8°C	8.1°C	8.8°C	7.7°C	8.8°C	10.7°C
Summer	19.5°C	21.2°C	21.8°C	22.6°C	21.1°C	22.5°C	24.8°C
Autumn	9.2°C	11°C	11.6°C	12.2°C	10.9°C	12.2°C	14.3°C
Annual	7.4°C	9.3°C	9.8°C	10.5°C	9.2°C	10.4°C	12.6°C

Seasonal baseline mean temperatures for Waterloo Region are: -3.5, 6.4, 20 and 10.2˚C for winter, spring, summer and autumn respectively. This gives a year-round average temperature of 8.2˚C for 1986-2005. Overall, mean temperatures in Waterloo Region are slightly higher than those in Wellington County or Dufferin County due to its more urbanized landscape and geographic location.

Table 6: Baseline and Projected Mean Temperatures for Waterloo Region (°C) by Season – RCP2.6, 4.5, and 8.5

Mean Temperatures (˚C)	Baseline 1986-2005	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Winter	-3.5°C	-1.5°C	-1.1°C	0.5°C	-1.6°C	-0.4°C	1.6°C
Spring	6.4°C	8.3°C	8.7°C	9.3°C	8.1°C	9.3°C	11.1°C
Summer	20°C	21.7°C	22.3°C	23°C	21.6°C	22.8°C	25.1°C
Autumn	10.2°C	11.9°C	12.5°C	13.2°C	11.8°C	13°C	15.1°C
Annual	8.2°C	10.0°C	10.5°C	11.2°C	9.9°C	11.2°C	13.3°C

Maximum and Minimum Temperatures

Extreme temperatures can have an impact on a variety of health outcomes including heat-related illness and cold-related injuries. Extreme heat can lead to dehydration, heat exhaustion, heat stroke, heat edema, loss of coordination, nausea, fatigue and the exacerbation of respiratory illness. High temperatures are also correlated with worsening mental health problems and can lead to increased incidences of violence. Extreme cold can lead to frostbite and hypothermia and may aggravate pre-existing conditions. Flash freezing and winter storms can also create unsafe travel conditions leading to increased morbidity and mortality (Mills and Andrey, 2002).

Projected minimum and maximum temperatures for each season by RCP2.6, 4.5 and 8.5 are presented for Wellington County, Dufferin County, and Waterloo Region below.

In terms of minimum temperatures, annual averages across the areas were 3.2, 2.7, and 3.8°C for Wellington County, Dufferin County, and Waterloo Region respectively. Minimum seasonal temperatures are projected to increase substantially for all three areas, with an increase anywhere from 4.4 to 5.4°C in the 2080s across all areas in various seasons.

By the 2080s under RCP8.5, all three areas will be experiencing approximately 20˚C minimum temperatures during the summer months. When temperatures do not decrease lower than 20˚C at night, it is considered a “Tropical Night.” Tropical nights make it difficult for our bodies to cool down after a hot day, which can increase the risk of heat related illness (Canadian Climate Atlas, 2019). In the winter months, minimum temperatures are expected to be closer to 0˚C by the 2080s under RCP8.5, which could result in an increase in freeze-thaw cycles, and overland flooding due to snowmelt and ice jams in waterways.

Table 7: Baseline and Projected Average Seasonal Minimum Temperatures for Wellington County – RCP2.6, 4.5, and 8.5

Seasonal Minimum Temperature (˚C)	Baseline 1986-2005	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Winter	-7°C	-5.5°C	-4.8°C	-4.2°C	-5.6°C	4.1°C	-1.8°C
Spring	2.4°C	3.9°C	4.3°C	5°C	3.7°C	4.9°C	7°C
Summer	15.8°C	16.1°C	17°C	18°C	16°C	17.1°C	20.2°C
Autumn	6.1°C	6.7°C	7.6°C	8.3°C	6.7°C	8.1°C	10.4°C
Annual	3.2°C	5.1°C	5.6°C	6.4°C	5°C	6.3°C	8.6°C

Table 8: Baseline and Projected Average Seasonal Minimum Temperatures for Dufferin County – RCP2.6, 4.5, and 8.5

Seasonal Minimum Temperature (°C)	Baseline 1986-2005	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Winter	-8.4°C	-6.9°C	-6.1°C	-5.4°C	-7°C	-5.4°C	-3°C
Spring	1.5°C	3°C	3.4°C	4.2°C	2.8°C	4.1°C	6.2°C
Summer	15.1°C	15.3°C	16.3°C	17.3°C	15.3°C	17°C	19.5°C
Autumn	5.6°C	6.3°C	7.1°C	7.9°C	6.2°C	7.6°C	10°C
Annual	2.7°C	4.6°C	5.1°C	5.9°C	4.5°C	5.8°C	8.1°C

Table 9: Baseline and Projected Average Seasonal Minimum Temperatures for Waterloo Region – RCP2.6, 4.5, and 8.5

Seasonal Minimum Temperature (°C)	Baseline 1986-2005	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Winter	-6.5°C	-5°C	-4.4°C	-3.7°C	-5.1°C	-3.7°C	-1.4°C
Spring	2.6°C	4.1°C	4.5°C	5.3°C	4°C	4.2°C	7.2°C
Summer	16°C	16.4°C	17.3°C	18.2°C	16.3°C	17.9°C	20.4°C
Autumn	6.9°C	7.5°C	7.4°C	8.1°C	7.5°C	8.9°C	11.2°C
Annual	3.8°C	5.6°C	6.9°C	6.9°C	5.6°C	6.8°C	9.1°C

In terms of maximum temperatures, annual average baseline for Wellington County, Dufferin County, and Waterloo Region was 12.1, 11.8, and 12.5°C respectively. All three areas will experience an increase in seasonal maximum temperatures, with average summer maximum temperatures reaching over 30°C in all three areas. Average winter maximum temperatures will reach well into positive digits for all three areas, with Wellington County, Dufferin County, and Waterloo Region experiencing an increase between 4.1 to 4.3°C by the 2080s according to RCP8.5.

Table 10: Baseline and Projected Average Seasonal Maximum Temperatures for Wellington County – RCP2.6, 4.5 and 8.5

Average Seasonal Maximum Temperatures (˚C)	Baseline 1986-2005	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Winter	-0.4°C	0.5°C	1.1°C	1.7°C	0.6°C	1.9°C	3.7°C
Spring	12.1°C	13.7°C	14.1°C	14.8°C	13.5°C	14.8°C	16.7°C
Summer	24.9°C	26.2°C	27.1°C	27.8°C	26.1°C	27.7°C	30.2°C
Autumn	13.3°C	14.8°C	15.4°C	16.3°C	14.7°C	16.2°C	18.5°C
Annual	12.1°C	14°C	14.6°C	15.2°C	13.9°C	15.2°C	17.4°C

Table 11: Baseline and Projected Average Seasonal Maximum Temperatures for Dufferin County – RCP2.6, 4.5 and 8.5

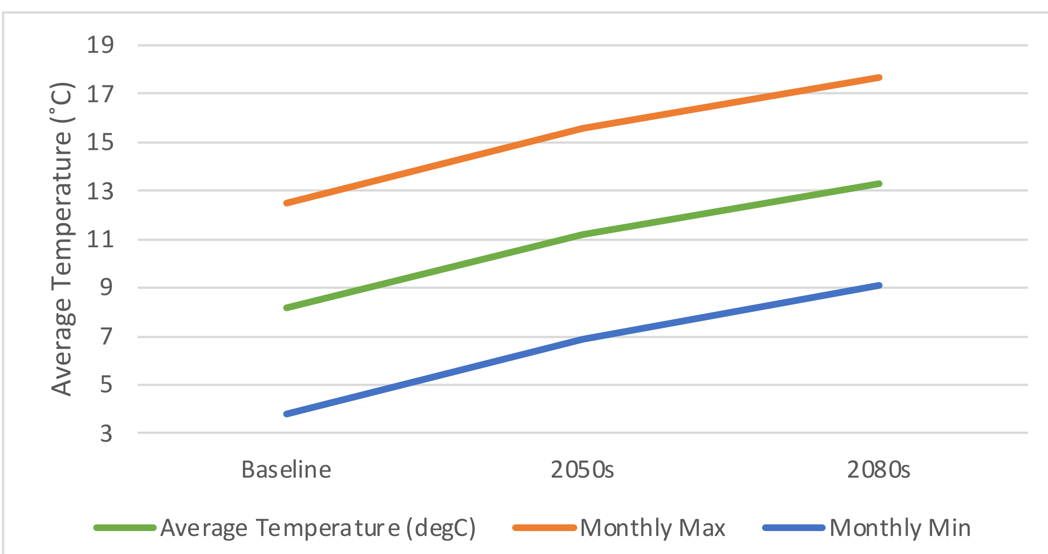
Average Seasonal Maximum Temperatures (˚C)	Baseline 1986-2005	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Winter	-0.7°C	0.2°C	0.8°C	1.4°C	0.2°C	1.5°C	3.4°C
Spring	12.1°C	13.6°C	14.1°C	14.8°C	13.5°C	14.8°C	16.7°C
Summer	24.7°C	26.0°C	26.9°C	27.6°C	25.9°C	27.5°C	30.0°C
Autumn	13.1°C	14.5°C	15.2°C	16°C	14.4°C	16.0°C	18.3°C
Annual	11.8°C	13.7°C	14.3°C	14.9°C	13.6°C	15°C	17.1°C

Table 12: Baseline and Projected Average Seasonal Maximum Temperatures for Waterloo Region – RCP2.6, 4.5 and 8.5

Average Seasonal Maximum Temperatures (˚C)	Baseline 1986-2005	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Winter	0.2°C	1.3°C	2.0°C	2.5°C	1.4°C	2.7°C	4.5°C
Spring	12.3°C	14.0°C	14.4°C	15.1°C	13.8°C	15.1°C	17.0°C
Summer	25.0°C	26.8°C	27.5°C	28.3°C	26.7°C	28.1°C	30.5°C
Autumn	13.6°C	15.3°C	16.0°C	16.8°C	15.3°C	16.7°C	18.9°C
Annual	12.5°C	14.4°C	14.9°C	15.6°C	14.3°C	15.6°C	17.7°C

Minimum and maximum temperatures are projected to experience a similar increase as mean temperatures, as shown for the annual values of the RCP8.5 scenario for Waterloo Region in Figure 3.

Figure 3: Baseline and Projected Annual Mean Temperature for Waterloo Region – Monthly Minimum, Annual Average, and Monthly Maximum – RCP8.5



Extreme Heat Days and Tropical Nights

For both Waterloo Region and WDG, a Heat Warning is issued by Environment Canada and Climate Change Canada 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

A Heat Warning is issued when heat and humidity present the greatest threats to public health due to heat-related illness. Examples 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 participating in outdoor sports or activities, and those with limited mobility may be more adversely affected (Health Canada, 2011).

climatedata.ca presents the number of days where the daily maximum temperature exceeds 30°C and 32°C, but does not share this data specifically for 31°C. For the purposes of this report, daily maximum temperature exceeding both 30°C and 32°C are included to illustrate the impact of extreme heat locally now and into the future.

According to RCP8.5, by the 2080s, WDG is projected to see 60 days above 30°C, which is an increase of 53 days from the current baseline of 7 days. Waterloo Region is projected to see 72 days above 30°C by the 2080s, 62 days above the current baseline of 10 days (Table 13). This means there will be almost seven to eight times more days above 30°C by the 2080s in the study area.

Table 13: Baseline and Projected Annual Days above 30°C for WDG and Waterloo Region – RCP2.6, 4.5, and 8.5

Annual Days above 30°C	Baseline 1981-2010	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
WDG	7	18	24	35	17	31	60
Waterloo Region	10	25	33	45	24	39	72

Days where maximum temperatures exceed 32°C are also expected to rise. According to RCP8.5, by the 2080s, WDG is projected to see 37 days above 32°C, which is an increase of 35 days above the current baseline of 2 days per year. Waterloo Region is projected to see 47 days above 32°C, 44 days more than the baseline of 3 days per year (Table 14). This means that the study area will need to prepare for a future where days above 32°C are the norm across the summer season.

Table 14: Baseline and Projected Annual Days above 32°C for WDG and Waterloo Region – RCP2.6, 4.5, and 8.5

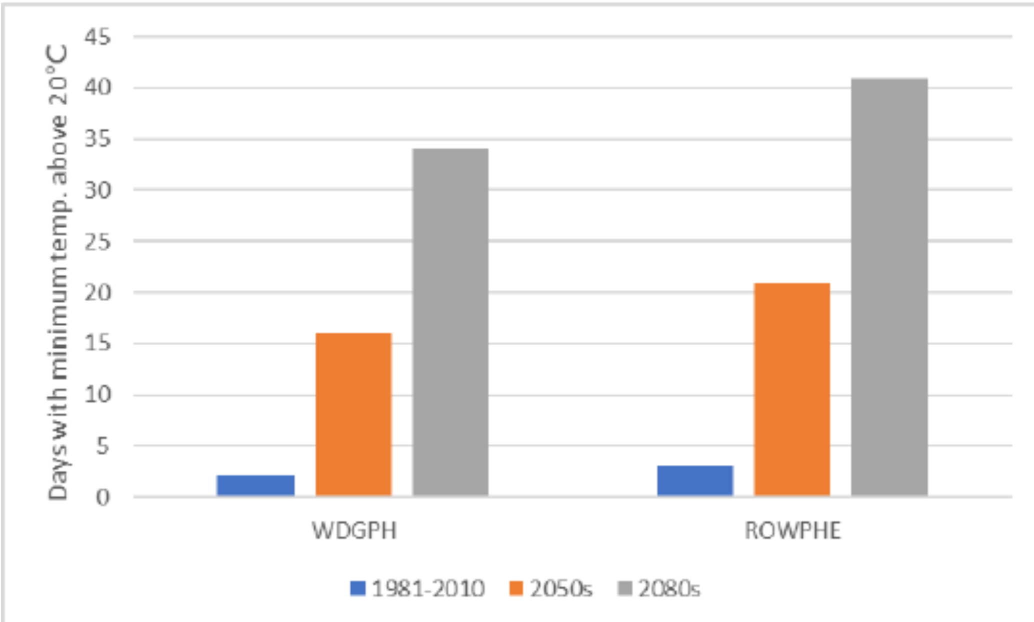
Annual Days above 32°C	Baseline 1981-2010	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
WDG	2	6	9	17	6	14	37
Waterloo Region	3	10	14	24	10	19	47

Traditional patterns of hot weather during the day which then cool off at night can often be enough to mitigate exposure to extreme temperatures (Health Canada, 2011). 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 Tropical Nights for WDG was two days, and three days for Waterloo Region from 1981-2010. In the 2080s, according to RCP8.5, WDG is projected to see 34 Tropical Nights annually (an increase of 32 from baseline), and Waterloo Region is projected to see 41 Tropical Nights per year (an increase of 38 from baseline) (Table 15 and Figure 4). The RCP8.5 scenario predicts over one month of Tropical Nights by the 2080s.

Table 15: Baseline and Projected Annual Mean Tropical Nights for WDG and Waterloo Region – RCP2.6, 4.5, and 8.5

Tropical Nights (days)	Baseline 1981-2010	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
WDG	2	6	8	16	6	12	34
Waterloo Region	3	9	11	21	9	16	41

Figure 4: Projected Annual Mean Tropical Nights for WDG and Waterloo Region – RCP 8.5

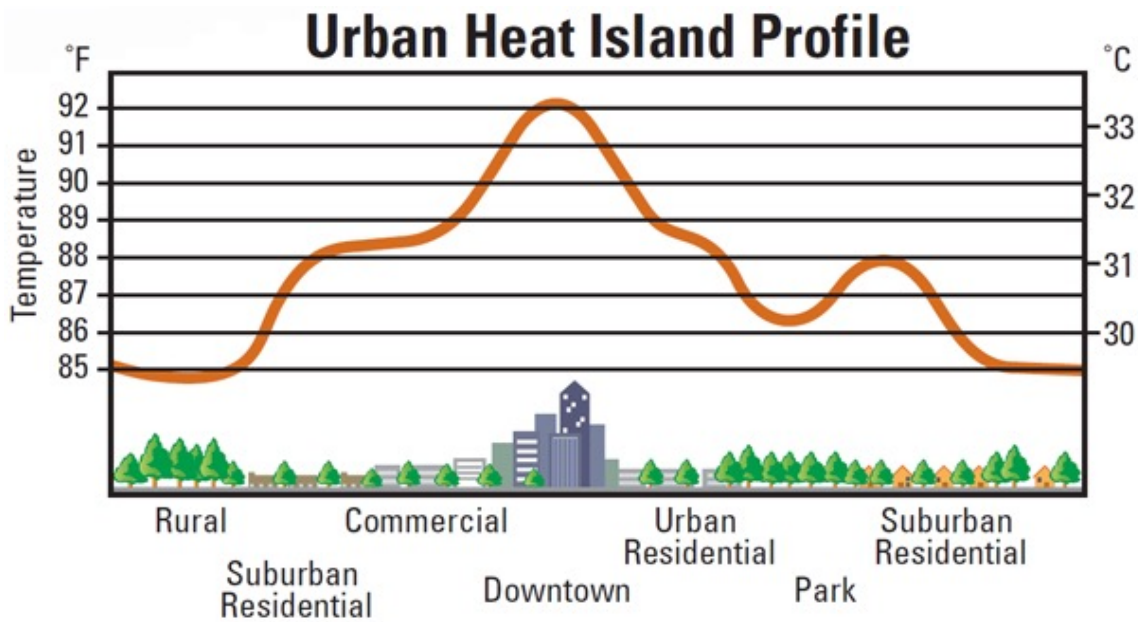


Urban vs. Rural Temperatures

The study area covers a large geography and contains a diverse array of urban and rural landscapes. The climate data from OCDP and climatedata.ca present spatial averages over the study area, as temperatures vary due to a variety of factors (e.g., topography, the Great Lakes, etc.). One important factor in variability of temperatures is the Urban Heat Island (UHI) effect. UHI happens because the thermal and radiative properties of materials that cover the land in urban environments differ from the materials found in rural areas. The materials in urban environments have higher heat capacity (i.e., higher quantity of heat added to raise temperature) and a lower albedo (i.e., percentage of reflectivity, which can lower temperatures) (Claus, 2011). Moreover, the lack of vegetation found in cities reduces transpiration, and subsequent heat loss through transpiration is reduced (Claus, 2011). Also, the higher percent of impervious surface areas found in cities transports water quickly from the streets through sewer systems further reducing the latent heat loss through evaporation (Claus, 2011).

On a sunny day, paved surfaces can be anywhere from 27-50°C hotter than the air (Berdahl & Bretz, 1997). On average, the difference in daytime surface temperatures (e.g., surfaces like roofs and pavement) between developed and rural areas is 10 to 15°C; the difference in nighttime surface temperatures is typically smaller, 5 to 10°C (Berdahl & Bretz, 1997). Atmospheric heat islands (i.e., air temperatures) on the other hand vary much less in intensity than surface heat islands. On an annual mean basis, air temperatures in large cities might be 1 to 3°C warmer than those of their rural surroundings (Berdahl & Bretz, 1997). Higher temperatures can cause enhanced air quality problems and related respiratory illnesses, as well as other adverse health impacts. Figure 5 demonstrates the differences in temperatures for various areas of development (Karl et al., 2009).

Figure 5: Urban Heat Island Profile



The magnitude of urban heat islands varies with seasons, due to changes in the sun's intensity as well as ground cover and weather. As a result of such variation, urban heat islands are typically largest in the summer. To illustrate the differences in projected daytime temperatures between urban and rural municipalities in the study area, Table 16 shows the average annual maximum temperatures for four urban municipalities, and four rural municipalities in the study area. In WDG and Waterloo Region, the largest urban municipalities include the cities of Kitchener, Guelph, Cambridge, and Waterloo. Four other randomly selected smaller municipalities (that are less urban and more rural) include the Town of Orangeville, the Township of Center Wellington, the Township of Wellesley, and the Township of Wilmot.

Table 16: Annual Maximum Temperatures for Urban vs. Rural Municipalities - RCP 8.5

Urban vs. Rural	Municipality	Population Size	Historical (2005)	2050	2080
Urban	Kitchener	242,368	12.5˚C	15.3˚C	17.3˚C
	Guelph	135,474	12.7˚C	15.1˚C	17.1˚C
	Cambridge	129,920	12.8˚C	15.6˚C	17.6˚C
	Waterloo	113,520	12.5˚C	15.3˚C	17.3˚C

Urban vs. Rural	Municipality	Population Size	Historical (2005)	2050	2080
Rural	Orangeville	30,734	11.6˚C	14.3˚C	16.3˚C
	Centre Wellington	20,767	11.6˚C	14.4˚C	16.4˚C
	Wellesley	11,260	11.9˚C	14.7˚C	16.7˚C
	Wilmot	20,545	12.4˚C	15.2˚C	17.2˚C

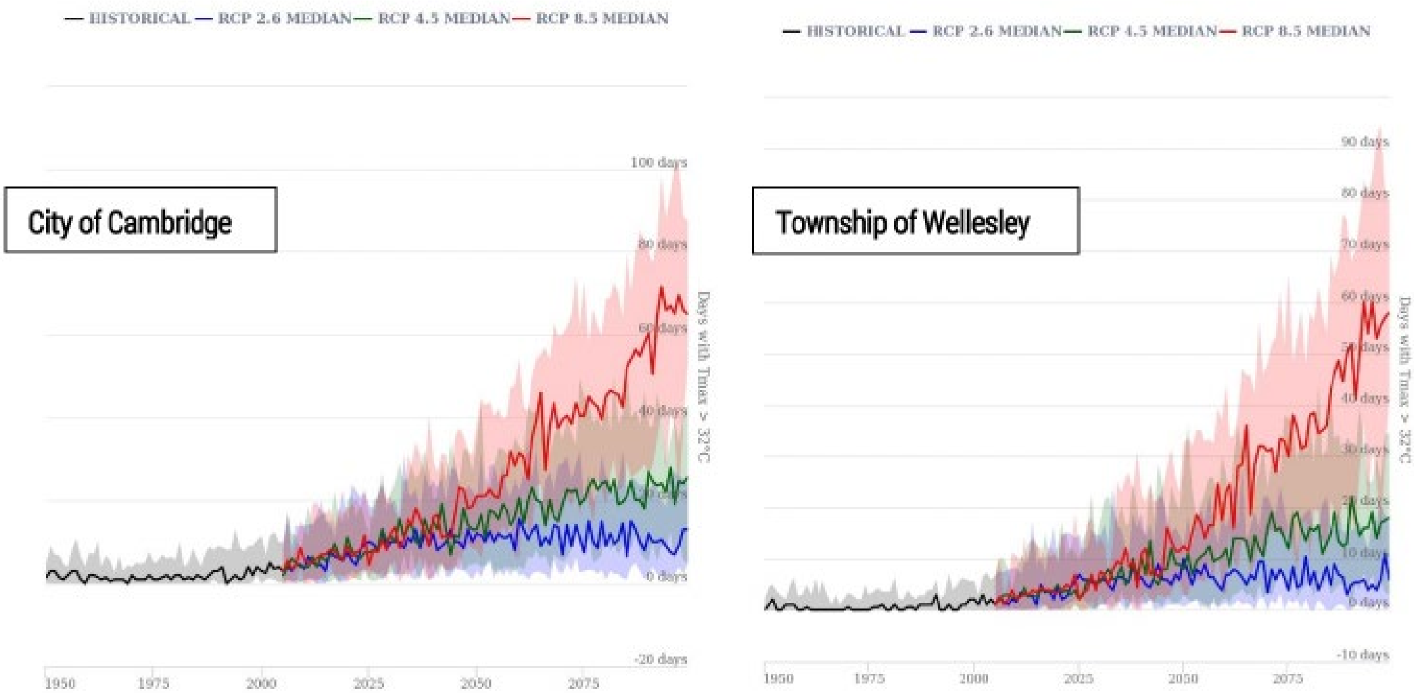
As shown in Table 16, on average, the urban municipalities have an annual maximum temperature average that is one degree Celsius warmer than the smaller, rural municipalities in the study area. Exceptions exist however, such as the Township of Wilmot, which has very similar temperature trends to the larger, urban municipalities (most likely due to its proximity to both Waterloo and Kitchener).

Other temperature variables show more pronounced differences in urban versus rural temperatures. For example, for temperature extremes such as average annual days above 32˚C differences can range from up to 10 days from urban versus rural municipalities. These results are presented in Table 17 and Figure 6.

Table 17: Days Above 32˚C for Urban vs. Rural Municipalities - RCP8.5

Urban vs. Rural	Municipality	Population Size	Historical (2005)	2050	2080
Urban	Kitchener	242,368	2	18	45
	Guelph	135,474	2	17	42
	Cambridge	129,920	3	21	45
	Waterloo	113,520	2	18	45
Rural	Orangeville	30,734	1	8	35
	Centre Wellington	20,767	1	11	35
	Wellesley	11,260	1	13	38
	Wilmot	20,545	2	16	43

Figure 6: Days with TMax >32˚C for City of Cambridge and Township of Wellesley – RCP2.6, 4.5, and 8.5



Increased daytime temperatures, reduced nighttime cooling, and higher air pollution levels associated with urban heat islands can affect population health by contributing to general discomfort, respiratory difficulties, heat cramps and exhaustion, non-fatal heat stroke, and heat-related mortality (Health Canada 2011). Urban heat islands also raise demand for electrical energy in summer. Companies that supply electricity typically rely on fossil fuel power plants to meet much of this demand, which in turn leads to an increase in air pollutant and greenhouse gas emissions, such as sulphur dioxide, nitrogen oxides, particulate matter, carbon monoxide, and mercury. These pollutants are discussed in further detail under the Air Quality section of this report.

It should be noted that UHI is not the only factor that determines elevated temperatures in a specific municipality – geographic location, topography, and the Great Lakes all play a role in determining temperatures in the identified municipalities.

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 correspond with local norms and behaviours.

As described above, Environment and Climate Change Canada will issue a public Heat Warning when one of the following conditions is met:

1. Two consecutive days where the temperature is forecasted to be at or over 31˚C during the day and at or over 20˚C over night, and/or
2. Two consecutive days where the humidex is forecasted to be 40˚C or more

climatedata.ca has a heat wave analysis tool, which allows users to input local heat wave event thresholds to generate tailored heat wave event indicators for various geographic locations across Canada. The tool presents heat wave frequency more specifically, the total number of heatwave events in a given year.

The heatwave analysis tool does not output ensemble information such as the medium of the model ensemble, but rather outputs each model individually. This results in data for each of the three emission scenarios across 24 climate models for study area. The heat wave analysis tool also does not spatially average the data across regions or Health Units, therefore a grid cell in each of Wellington County, Dufferin County, and Waterloo Region were selected. The table below shows the number of extended heat events (3+ days) for the Wellington County, Dufferin County, and Waterloo Region.

Table 18: Baseline and Projected Annual Frequency of Extended Heat Warning Events for Wellington County, Dufferin County, and Waterloo Region – RCP2.6, 4.5, and 8.5

Heat Wave Frequency	Baseline 1986-2005	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Wellington County	0.03	0.33	0.61	1.32	0.30	1.04	3.55
Dufferin County	0.02	0.22	0.46	1	0.23	0.82	3.04
Waterloo Region	0.07	0.56	0.46	1.85	0.54	0.82	4.14

Extended heat wave events are projected to occur more frequently. These changes become more pronounced as time goes on, and emissions increase according to the RCP scenario. These extreme temperatures that are sustained over several days will have significant impacts on the health of individuals in the study area – heat illnesses can manifest quickly, and lead to long-term health problems and even death. Over-exposure to extreme heat is especially dangerous for children and older adults, and those who work outside or are physically active in the outdoors.

Extreme Cold Days, Frost Days, and Ice Days

While Extreme Heat Days and Tropical Nights are increasing, the number of Extreme Cold Days, Frost Days, and Ice Days are decreasing. An Extreme Cold Day is a day with minimum temperatures of less than -15°C. The total number of Extreme Cold Days are decreasing across both WDG and Waterloo Region into the 2080s across all three emissions scenarios (Table 19). While Extreme Cold Days are expected to become more infrequent, it is still prudent to adequately prepare and manage the health impacts of extreme cold.

Table 19: Baseline and Projected Extreme Cold Days (<-15°C) for WDG and Waterloo Region

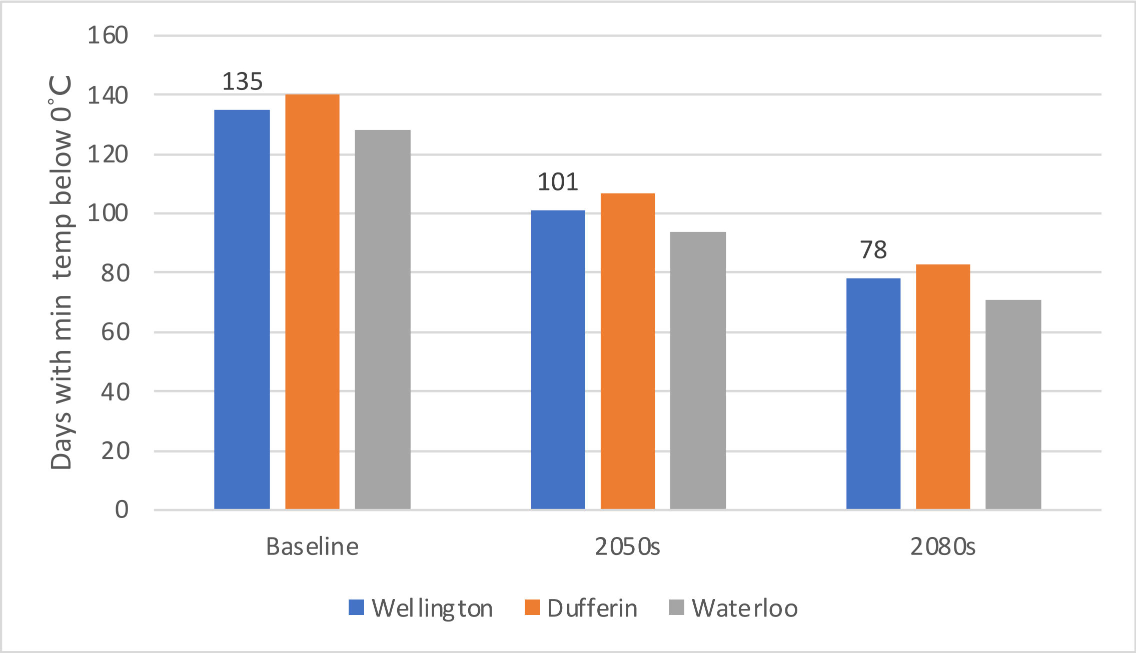
Extreme Cold Days (<-15˚C)	Baseline 1986-2005	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
WDG	19	17	11	9	17	8	0
Waterloo Region	21	10	8	3	12	5	0

A Frost Day is a day with frost potential, when the minimum temperature is below 0°C. Frost Days are projected to decrease up to 57 days by the 2080s across the study area in RCP8.5 (Table 20 and Figure 7). Frost and Ice Days can help to understand freeze and thaw patterns throughout each area, and risks related to accidental morbidity and mortality from traffic collisions due to icy conditions, for example.

Table 20: Baseline and Projected Frost Days for Wellington County, Dufferin County, and Waterloo Region – RCP2.6, 4.5, and 8.5

Frost Days	Baseline 1986-2005	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Wellington County	135	114	108	101	114	101	78
Dufferin County	140	119	114	107	120	106	83
Waterloo Region	128	107	101	94	107	93	71

Figure 7: Baseline and Projected Annual Mean Frost Days for Wellington County, Dufferin County, and Waterloo Region – RCP8.5

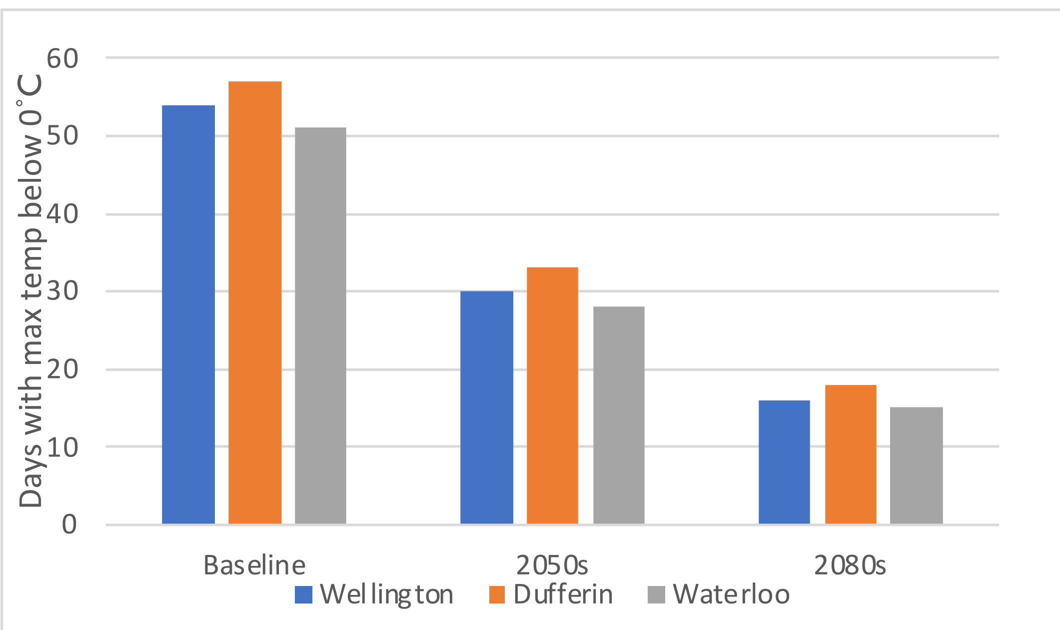


Similarly, the number of Ice Days are projected to decrease (Table 21 and Figure 8). Ice Days are the total number of days when the daily maximum temperature is below 0°C. A reduction in days below 0°C could have an impact on the survival and spread of ticks and Lyme disease, as ticks can be active in temperatures above 4°C (Alberta Health, 2019). While blacklegged ticks (the ticks capable of spreading the bacteria that causes Lyme disease) are most active in spring and fall, warmer winters could extend their window of activity.

Table 21: Baseline and Projected Ice Days for Wellington County, Dufferin County, and Waterloo Region – RCP2.6, 4.5, and 8.5

Ice Days	Baseline 1986-2005	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Wellington County	54	38	33	30	39	29	16
Dufferin County	57	41	36	33	42	32	18
Waterloo Region	51	36	31	28	36	27	15

Figure 8: Baseline and Projected Annual Mean Ice Days for Wellington County, Dufferin County, and Waterloo Region – RCP8.5



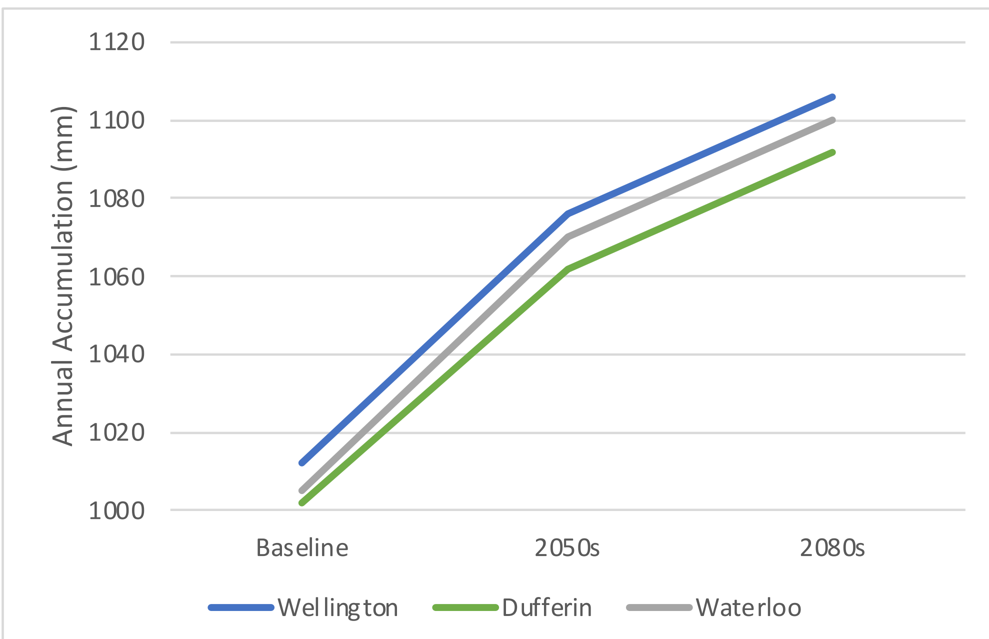
Precipitation Indices

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(Figure 9). Changes are relatively similar across the study area. For Wellington County, this increase will be from a baseline of 1012 mm to approximately 1070 mm (RCP4.5) or 1106 mm (RCP8.5) by the 2080s. For Dufferin County, the increase is similar, from a baseline of 1002 mm to approximately 1060 mm (RCP4.5) or 1093 mm (RCP8.5) by the 2080s. Finally, Waterloo Region is projected to see an increase from 1005 mm at baseline, to 1060 mm (RCP4.5) or 1100 mm (RCP8.5) by the 2080s.

Figure 9: Baseline and Projected Total Annual Precipitation Accumulation for Wellington County, Dufferin County, and Waterloo Region (mm) (RCP8.5)

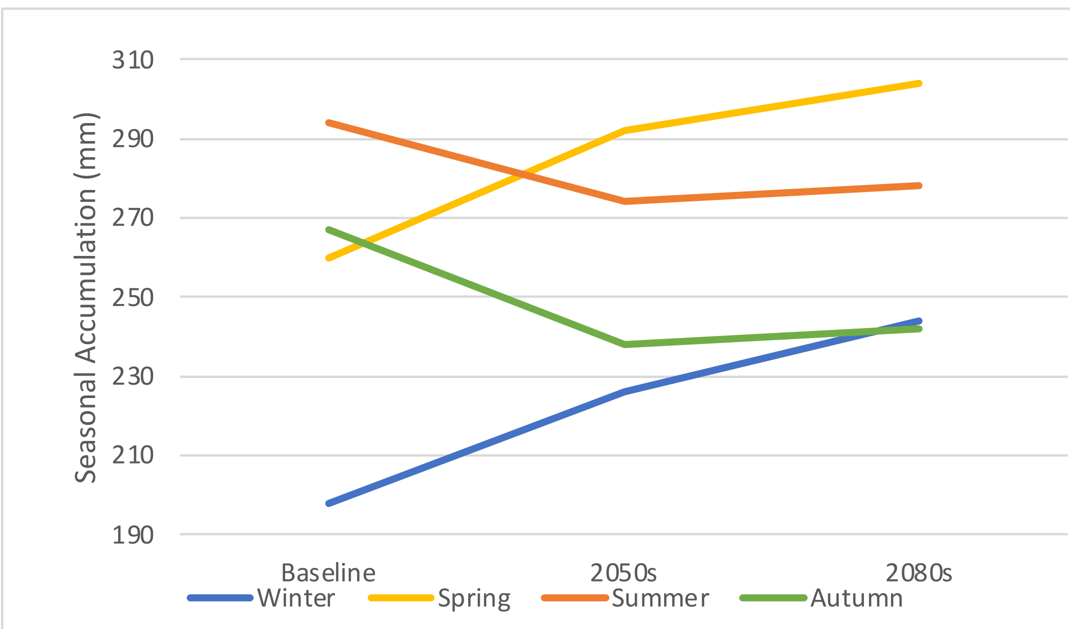


On a seasonal basis, in Wellington County, spring and winter precipitation accumulations are projected to increase by the 2080s. Summer and autumn will experience a slight decrease, though not substantially. Table 22 and Figure 10 present the precipitation accumulation projections for Wellington County in each season and according to RCP2.6, 4.5, and 8.5.

Table 22: Baseline and Projected Total Precipitation (mm) by Season for Wellington County – RCP2.6, 4.5, and 8.5

Total Precipitation (mm)	Baseline 1986-2005	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Winter	198	209	218	226	211	225	244
Spring	260	275	282	292	276	283	304
Summer	294	267	267	274	278	270	278
Autumn	267	243	239	238	237	237	242
Annual	1012	1063	1044	1076	1071	1070	1106

Figure 10: Baseline and Projected Total Precipitation (mm) by Season for Wellington County (RCP8.5)



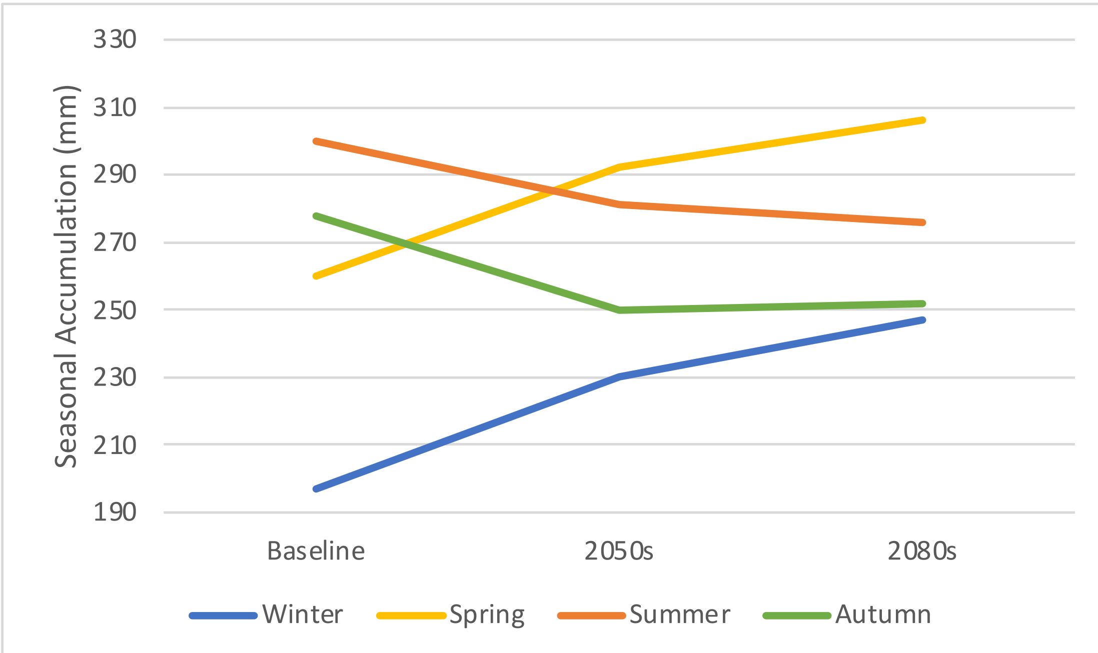
Similar seasonal trends will be experienced in Dufferin County, with an increase in spring and winter precipitation accumulations. The greatest precipitation increase will occur in winter, from a baseline of 197mm to 247mm in 2080 according to RCP8.5. Summer and autumn will experience a slight decrease in precipitation, though not substantially.

Table 23 and Figure 11 present the precipitation accumulation projections for Dufferin County, in each season and according to RCP2.6, 4.5, and 8.5. The annual total precipitation does not change substantially from the baseline, as it accounts for increases in precipitation for spring and winter months, and slight decreases in summer and autumn months.

Table 23: Baseline and Projected Total Precipitation (mm) by Season for Dufferin County – RCP2.6, 4.5, and 8.5

Total Precipitation (mm)	Baseline 1986-2005	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Winter	197	215	224	230	217	231	247
Spring	260	273	283	292	278	283	306
Summer	300	279	277	281	287	276	276
Autumn	278	256	252	250	249	249	252
Annual	1002	1052	1062	1062	1059	1060	1092

Figure 11: Baseline and Projected Total Precipitation (mm) by Season for Dufferin County (RCP8.5)

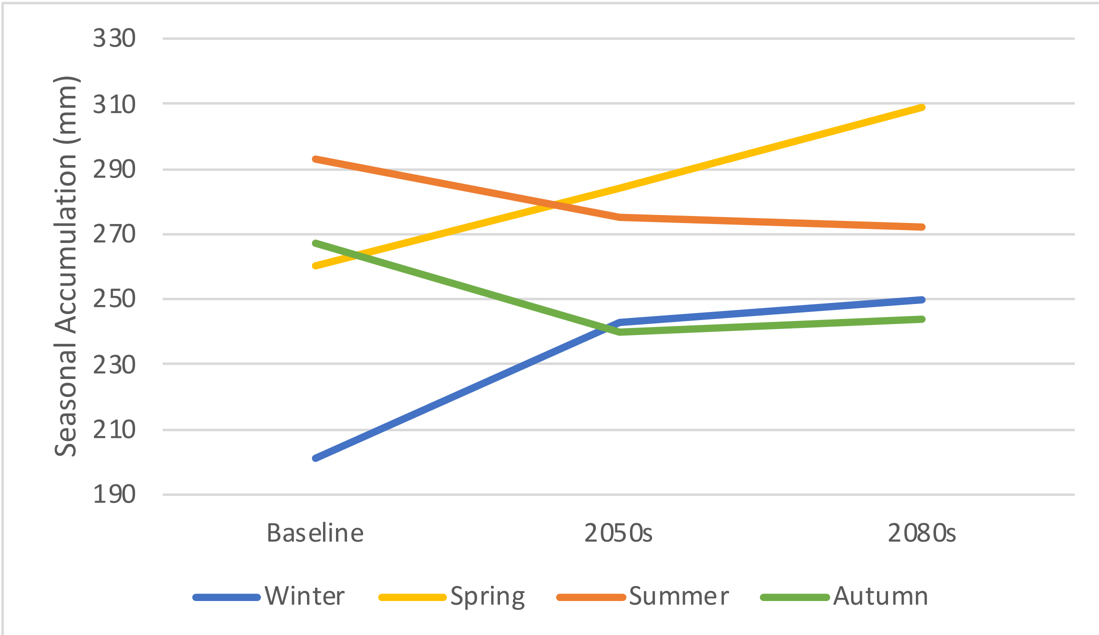


In Waterloo Region, spring and winter precipitation accumulations are projected to increase by the 2080s, both with an increase of 49mm from the baseline for RCP8.5. Summer and autumn will experience a slight decrease, though not substantially. Table 24 and Figure 12 present the precipitation accumulation projections for Waterloo Region, in each season and according to RCP2.6, 4.5, and 8.5.

Table 24: Baseline and Projected Total Precipitation (mm) by Season for Waterloo Region – RCP2.6, 4.5, and 8.5

Total Precipitation (mm)	Baseline 1986-2005	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Winter	201	217	225	243	219	233	250
Spring	260	278	285	284	280	286	309
Summer	293	270	272	275	282	272	272
Autumn	267	246	241	240	240	239	244
Annual	1005	1056	1067	1070	1063	1062	1100

Figure 12: Projected Total Precipitation (mm) by Season for Waterloo Region – RCP8.5



Dry Spells

Dry spells are the longest dry period in a year, defined as the greatest number of consecutive days with daily precipitation less than 1mm. The bigger the value, the longer the dry spell. There is no significant projected change in the expected longest dry period for the study area. One day increases are shown in Table 25 into the 2050s and 2080s.

Table 25: Longest Dry Period in a Year (days) for Wellington County, Dufferin County, and Waterloo Region – RCP2.6, 4.5, and 8.5

Longest Dry Period in a Year (days)	Baseline 1986-2005	2050s			2080s		
			RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Wellington County	14	14	14	15	14	15	15
Dufferin County	13	13	13	13	13	13	14
Waterloo Region	14	14	14	15	14	15	15

Extreme Precipitation

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

Maximum One-Day and Five-Day are a measure of rain and/or snow that fall over single or consecutive days. The Maximum One-Day includes both intense precipitation events, as well as continuous all day precipitation. The Maximum 5-Day precipitation total provides a metric of the total volume of precipitation a region should expect to receive at one time. The Simple Day Intensity Index is the typical accumulation seen during a day that receives precipitation. Very Wet Days and Extreme Wet Days define the annual total precipitation amount during the defined very wet or extreme wet days. A Very Wet Day is a day during which the total precipitation amount is more than the daily precipitation amount of the 5% of wettest days in the reference climate time period (1981-2005). Similarly, an Extreme Wet Day is a day during which the total precipitation amount is more than the daily precipitation amount of the 1% of wettest days in the reference climate time period (1981-2005). The 95th percentile values represent the amount of annual precipitation that falls during events that respectively produce more precipitation than 95% of all events in a year. Similarly, the 99th percentile represents the accumulation from the heaviest 1% of events. For example, if there are 100 precipitation events in a given year, the total accumulation from the five heaviest storms is captured by this indicator. These are measures of how much of the total annual accumulation is falling exclusively during extreme events.

Tables 26-28 show the projected changes in the Maximum One-Day and Five-Day accumulations, Very Wet Day totals, Extreme Wet Day totals, and Simple Day Intensity Index for the study area.

Table 26: Baseline and Projected Extreme Precipitation Indices for Wellington County – RCP2.6, 4.5, and 8.5

Region	Index	Baseline 1986-2005	2050s			2080s		
			RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Wellington County	Maximum One-Day Accumulations (mm)	36.8	41.1	42.9	43	41.5	42.3	45.9
	Maximum Five-Day Accumulations (mm)	60.1	67.1	68.5	69	67	67.1	72.8
	Simple Day Intensity Index (mm/day)	6.6	6.9	6.9	7.4	6.8	6.9	7.2
	Very Wet Day Totals (mm)	198	236	245	254	236	242	287
	Extreme Wet Day Totals (mm)	53	74	81	85	73	80	106

Table 27: Baseline and Projected Extreme Precipitation Indices for Dufferin County – RCP2.6, 4.5, and 8.5

Region	Index	Baseline 1986-2005	2050s			2080s		
			RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Dufferin County	Maximum One-Day Accumulations (mm)	37.3	41.5	43.2	42.9	41.6	42.1	45.1
	Maximum Five-Day Accumulations (mm)	61.4	68.1	69.6	69.5	67.7	67.8	72.8

Region	Index	Baseline 1986-2005	2050s			2080s		
			RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Dufferin County	Simple Day Intensity Index (mm/day)	6.6	6.9	6.9	7	6.8	6.9	7.2
	Very Wet Day Totals (mm)	196	233	242	249	232	238	279
	Extreme Wet Day Totals (mm)	50	70	77	81	69	74	99

Table 28: Baseline and Projected Extreme Precipitation Indices for Waterloo Region – RCP2.6, 4.5, and 8.5

Region	Index	Baseline 1986-2005	2050s			2080s		
			RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Waterloo Region	Maximum One-Day Accumula-tions (mm)	35.5	39.5	41.4	41.6	40.1	40.5	45.2
	Maximum Five-Day Accumula-tions (mm)	58.4	65	66.4	67.4	65.3	65.1	71.9
	Simple Day Intensity Index (mm/day)	6.6	6.9	6.9	7	6.8	6.9	7.2
	Very Wet Day Totals (mm)	193	228	240	252	230	238	285
	Extreme Wet Day Totals (mm)	54	74	81	87	74	81	108

Across all three areas, Very Wet Day totals and Extreme Wet Day totals are expected to increase by the 2080s, for RCP2.6, 4.5, and 8.5. This means that a higher percentage of the precipitation that falls will be occurring during extreme events. The Simple Day Intensity Index projections for all three areas show a slight increase into the 2080s, from a baseline of 6.6 mm/day to a projected 7.2 mm/day for RCP8.5 in Wellington County, Dufferin County, and Waterloo Region respectively. Maximum One-Day and Five-Day events are also expected to increase across all three areas, with the greatest increase in Five-Day events. For example, in Wellington County, maximum Five-Day events are projected to increase from a baseline of 60.1 mm to 72.8 mm by 2080s for RCP8.5.

Changes in the above extreme precipitation indices are visually presented in Figures 13 to 15 for Wellington County.

Figure 13: Baseline and Projected Maximum 1-Day Precipitation Accumulation (mm) for Wellington County

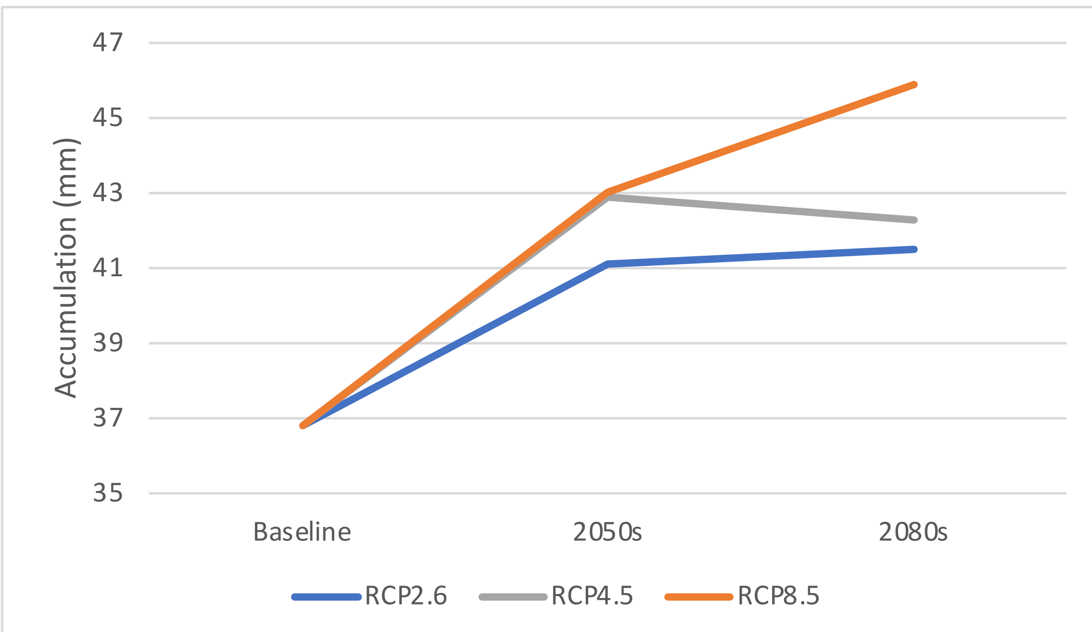


Figure 14: Baseline and Projected Maximum 5-Day Precipitation Accumulation (mm) for Wellington County

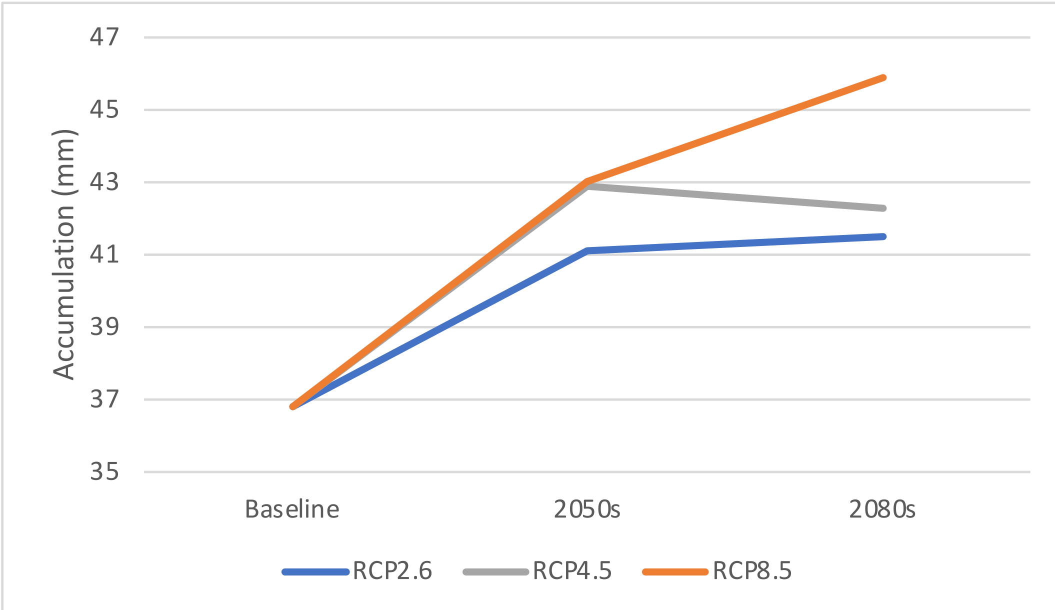
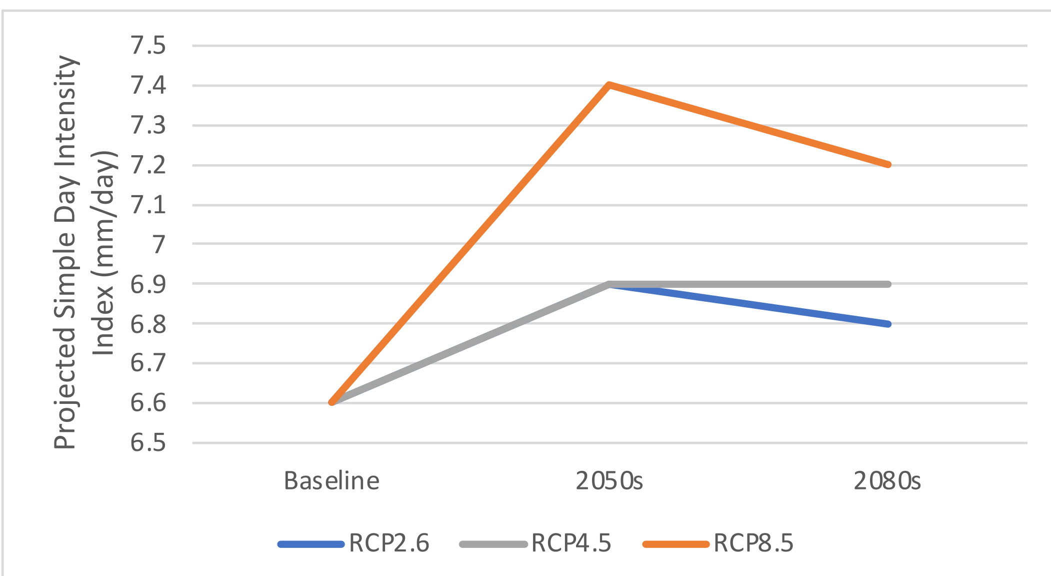


Figure 15: Baseline and Projected Simple Day Intensity Index (mm/day) for Wellington County

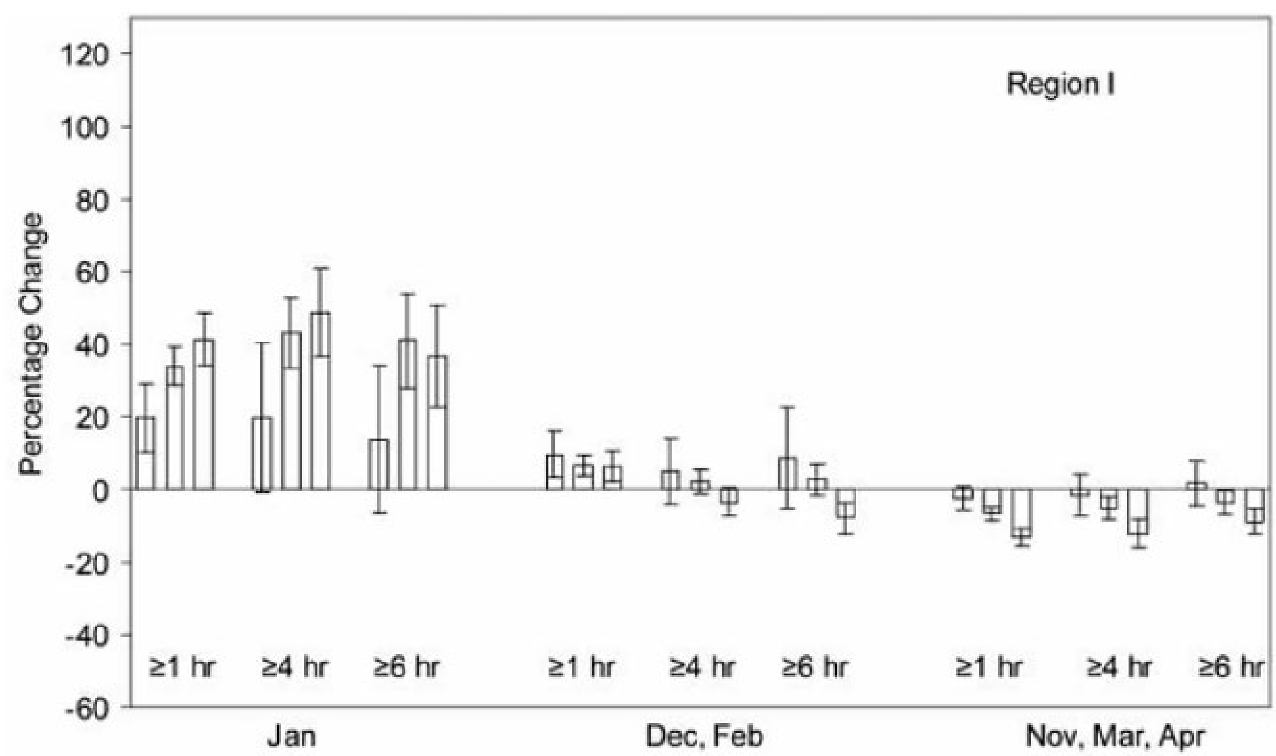


Freezing Rain

A study conducted by the Meteorological Service of Canada and the Science and Technology branch of Environment and Climate Change 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 Fourth Assessment Report.

Region I of the study encompasses a portion of Southwestern Ontario, including the regions of Wellington County, Dufferin County, and Waterloo Region. The study conducted analysis on the projected average percentage change in the number of daily freezing rain events. Figure 16 (Cheng, et al. 2011) presents the averaged percentage change in the number of daily freezing rain events for greater than one hour, four hours, and six hour events per day. For Region I, the percentage increase is most pronounced in the month 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 (greater than six hours per day) are projected to increase up to 30% by 2100.

Figure 16: The average percentage change in the number of daily freezing rain events (%) for Region I relative to 1957-2007 baseline conditions



Air Quality

Ontario has one of the most comprehensive air quality monitoring systems in North America, made up of approximately 39 monitoring sites that undergo regular quality control procedures and maintenance (Ontario Ministry of the Environment, 2016). Over the last few decades, air quality measurements across Canada and Ontario have indicated significant reductions in harmful air pollutants attributed to vehicular and industrial emissions. Between 2007-2016, average sulphur dioxide (SO_2) and carbon monoxide (CO) concentrations decreased 51% and 53%. Furthermore, average nitrogen dioxide (NO_2/NOx) concentrations decreased by 30%, and particulate matter ($PM_{2.5}$) decreased 12%. Ground level ozone (O_3) increased approximately 1% (Ontario Ministry of the Environment, 2016). However, it is important to note that exposure to these pollutants (e.g., $PM_{2.5}$, O_3, and NO_2), even at very low levels, has been associated with negative health impacts including pulmonary, cardiovascular, and respiratory health issues (Ontario Ministry of the Environment, 2016). Table 29 shows the trends in ambient air pollutant concentrations from 2007 to 2016 (Ontario Ministry of the Environment, 2016).

Table 29: Trends in Ambient Air Pollutant Concentrations, Ontario, 2007-2016

Pollutant	Concentrations	Emissions
NO_2/NOx	↓30%	↓38%
SO_2	↓51%	↓40%
CO	↓53%	↓32%
$PM_{2.5}$	↓12%	↓16%
O_3	↑1%	n/a*

Overall, reductions of these harmful pollutants can be attributed to Ontario's air quality initiatives. These include: (1) phasing out coal-fired power plants; (2) cap and trade regulations for nitrogen oxide and sulphur dioxide under Ontario Regulation (O. Reg.) 397/01 and O. Reg. 194/05; (3) new local air quality regulation standards under O. Reg. 419/05; (4) site-specific and technical standard compliances for regulating industrial emissions under O. Reg. 419; (5) established emission controls at Ontario smelters under O. Reg. 419/05; and (6) various vehicle emission testing programs for heavy-duty vehicles and commercial transport trucks (e.g., the Drive Clean program, which was cancelled in 2018 but is expected to be replaced by updates to the Motor Vehicle Inspection Station program). These programs are especially important as the transportation sector contributes roughly 28% to volatile organic compounds (VOCs) emissions.

Toxic air pollutants such as heavy metals, polychlorides, agricultural pesticides, and persistent organic pollutants (POPs) are also a critical issue, particularly for southern Ontario (Yap et al., 2005). Research has shown that southern Ontario, including the study area, regularly experiences the highest levels of ground level ozone, fine particulate matter ($PM_{2.5}$), and toxic air pollutants in all of eastern Canada (Yap et al., 2005). Along with local emissions, severe smog in Ontario has been increasingly linked to transboundary air flows from industrialized areas of the U.S. Midwest to upwind urban areas (Yap et al., 2005). Smog events are also highly dependent on meteorological conditions that vary from year-to-year.

In 2013, the Canadian Ambient Air Quality Standards (CAAQS) was implemented under the Canadian Environmental Protection Act that created stricter targets for pollutants and annual standards for ozone and $PM_{2.5}$. In 2015, territories and provinces became required to report ambient air quality measurements under the CAAQS. Standards for these were updated in 2020. For $PM_{2.5}$, the 24-hour standard is 27 ug/m^3 and the annual standard is 8.8ug/m^3. For ozone, the 8-hour standard is 62 ppb, and for nitrogen dioxide, the 1-hour standard is 60 ppb, and the annual standard is 12.0 ppb (CCME, n.d.). Table 30 (CCME, n.d.) shows the CAAQS standards for fine particulate matter, ozone, sulphur dioxide, and nitrogen dioxide. It is important to note however, that health impacts can still occur even when air pollutant concentrations are within these standards.

Table 30: CAAQS Standards for Fine Particulate Matter, Ozone, Sulphur Dioxide, and Nitrogen Dioxide

Pollutant	Averaging Time	Numerical Value			Statistical Form
		2015	2020	2025	
Fine Particulate Matter ($PM_{2.5}$)	24-hour	28 $\mu g/m^3$	27 $\mu g/m^3$	-	The 3-year average of the annual 98th percentile of the daily 24-hour average concentrations
	Annual	10 $\mu g/m^3$	8 $\mu g/m^3$	-	The 3-year average of the annual average of all 1-hour concentrations
Ozone (O_3)	8-hour	63 ppb	62 ppb	60 ppb	The 3-year average of the annual 4th highest of the daily maximum 8-hour average ozone concentrations
Sulphur Dioxide (SO_2)	1-hour	-	70 ppb	65 ppb	The 3-year average of the annual 99th percentile of the SO_2 daily maximum 1-hour average concentrations
	Annual	-	5.0 ppb	4.0 ppb	The average over a single calendar year of all 1-hour average SO_2 concentrations
Nitrogen Dioxide (NO_2)	1-hour	-	60 ppb	42 ppb	The 3-year average of the annual 98th percentile of the daily maximum 1-hour average concentrations
	Annual	-	17.0 ppb	12.0 ppb	The average over a single calendar year of all 1-hour average concentrations

Along with the CAAQS, Ontario's Ministry of the Environment established the Ambient Air Quality Criteria (AAQC) that defines ideal concentrations of air contaminants based on deduced levels of protection against negative health and environmental effects (Ontario Ministry of the Environment, 2016). The term "ambient" refers to general air quality regardless of location or contamination source (Ontario Ministry of the Environment, 2016). Table 31 displays the AAQC standards for ozone, fine particulate matter, nitrogen oxide, sulphur oxide, and carbon monoxide (Ministry of Environment and Climate Change, 2016).

Table 31: Ambient Air Quality Criteria Standards for Ozone, Fine Particulate Matter, Nitrogen Dioxide, Sulphur Dioxide, and Carbon Monoxide

Contaminant	1-hour AAQC	8-hour AAQC	24-hour AAQC	Annual AAQC
O_3	80 ppb	-	-	-
$PM_{2.5}$	-	-	28 µg/m^3(1)	-
NO_2	200 ppb	-	100 ppb	-
SO_2	250 ppb	-	100 ppb	20 ppb
CO	30 ppm	13 ppm	-	-

(1) Reference level based on Canadian Ambient Air Quality Standard

Ground-level Ozone

Ground-level ozone, one of the key components of smog, is a gas formed when nitrogen oxides (NOx) and volatile organic compounds (VOCs) react in the presence of sunlight. Thus, elevations in ground-level ozone concentrations generally occur on hot, sunny days between May and September. While almost all NOx emissions originate from human activities related to fossil fuel combustion, VOCs can be emitted from both anthropogenic and natural sources. However, both NOx and VOCs are most commonly produced by transportation related infrastructure and products, such as road vehicles and solvents (Yap et al., 2005; Ontario Ministry of the Environment, 2016).

Ground-level ozone is a considerable environmental and health concern that is different from the naturally occurring stratospheric ozone which absorbs much of the sun's ultraviolet radiation. Ozone causes irritations to the eyes, respiratory tract, and raises the chances of respiratory illness by lowering the body's resistance to infection. Accordingly, people afflicted with asthma and bronchitis, along with children, have increased sensitivity to ground-level ozone. Exposure symptoms include chest tightness, coughing, and wheezing.

From 1980 to 2003, ground-level ozone trends declined with regards to one-hour maximum concentrations for Ontario (Yap et al., 2005). However, over the same 24-year period, ozone seasonal averages also increased (in the summer by 21% and in the winter by 29%), relating to increases in global background levels of ozone throughout Ontario and Canada (Yap et al., 2005). This increase is also related to meteorological conditions which strongly affect short-term and year-to-year changes in ozone concentrations.

From 2006 to 2015, ground-level ozone trends in Ontario decreased by 4% in the summer and increased by 9% in the winter. The increase during winter months can be explained by increasing global background concentrations, however, Ontario ozone concentrations during winter remains below the AAQC of 80 ppb (Ontario Ministry of Environment, 2015). The decrease during summer months is attributed to Ontario air quality initiatives reducing NOx emissions as well as lower transboundary pollution movements from the United States during the summer (Ontario Ministry of the Environment, 2016).

Particulate Matter

Particulate Matter (PM), another key component of smog, describes a mix of microscopic particles that are suspended in air, including aerosols, smoke, fumes, dust, fly ash, and pollen. Its composition varies with origin, time in the atmosphere, time of the year, and current environmental conditions. PM is commonly characterized according to its size because there are varying health effects associated with particulate matter of different diameters. $PM_{2.5}$, or fine particulate matter with a diameter less than or equal to 2.5 microns, is especially important in discussions of air quality. $PM_{2.5}$, compared to other particulate matters, is easily respirable due to its small size and is often used as a general indicator for air quality. Exposure to $PM_{2.5}$ is associated with increases in hospital admissions, serious health effects, and premature death, particularly in children, elderly, and people suffering from asthma, and cardiovascular or lung diseases. Moreover, $PM_{2.5}$ influences population health over a short-term period (such as a single day) as well as over a long-term period (such as low, chronic doses over years or more).

Like ground-level ozone, the majority of PM measured within Ontario is directly linked to transboundary pollutant flows and are highest in the most southern part of Ontario. However, high levels of PM in urban areas indicate that Ontario cities also contribute to concentrations via local emission sources. PM measurements are also elevated during hot summer days like that of ground-level ozone. In general, climate change is projected to have complex and interactive impacts on PM concentrations through changing weather patterns and frequencies, increased evaporation of aerosols, and increased stagnation (Nolte et al., 2018). Moreover, longer droughts inducing wildfires and uncertain precipitation patterns will influence local and transboundary PM concentrations (Nolte et al., 2018).

Nitrogen Dioxide

Nitrogen dioxide (NO_2) is a reddish-brown gas with a pungent odour, which transforms in the atmosphere to form gaseous nitric acid and nitrates. It plays a major role in atmospheric reactions that produce ground-level ozone, a major component of smog. Nitrogen dioxide also reacts in the air and contributes to the formation of $PM_{2.5}$ (Seinfeld and Pandis, 2006). Major sources of NO_2 emissions include the transportation sector, industrial processes and electric power generation (Ontario Ministry of the Environment, 2016).

In 2017, there were no exceedances of the provincial one-hour and 24-hour AAQC for NO_2, 200 ppb and 100 ppb, respectively, at any of the Ministry's AQHI air monitoring stations in Ontario (Ontario Ministry of the Environment, 2016). Table 23 outlines the maximum 1-hour and maximum 24-hour measurements for NO_2 at the two AQHI monitoring stations located within the study area in 2017 (Ontario Ministry of the Environment, 2016).

Table 32: 2017 Nitrogen Dioxide (NO_2) Annual Statistics for Guelph and Kitchener Stations

AQHI Station	Maximum 1-hour	Maximum 24-hour
Guelph (WDGPH)	39 ppb	23 ppb
Kitchener (ROWPH)	40 ppb	19 ppb

Breathing air with a high concentration of NO_2 can irritate airways in the human respiratory system. Such exposures over short periods can aggravate respiratory diseases, particularly asthma, leading to respiratory symptoms (such as coughing, wheezing or difficulty breathing), hospital admissions and visits to emergency rooms (Health Canada, 2016). Longer exposures to elevated concentrations of NO_2 may contribute to the development of asthma and potentially increase susceptibility to respiratory infections (Health Canada, 2016). People with asthma, as well as children and the elderly are generally at greater risk for the health effects of NO_2 (Health Canada, 2016). There is currently no established threshold at which NO_2 pollutants do not cause health impacts (Health Canada, 2016).

Projecting Future Air Quality

Climate change will have an impact on future air quality through several means, including changes in the ventilation and dilution of air pollutants, photochemical reaction rates, removal processes, stratosphere–troposphere exchange of ozone, wildfires, and natural biogenic and lightning emissions (Silva et al., 2017). Globally, ozone is likely to increase in polluted regions during the warm season, while projections of particulate matter concentrations are uncertain and vary geographically (Silve et al., 2017).

According to the Ontario Climate Change and Health Modeling Report, air pollution events are expected to rise in the future as a result of increases in average temperature (Gough et al., 2016). In fact, it is estimated that in the eastern United States, an increase of 0.34 parts per billion (ppb) in ozone could occur for every 1°C increase in temperature (Pfister et al., 2014). The report, published in 2016, projected annual increase in days above 80 ppb (in accordance with the 1-hour AAQC for ozone) for all Public Health Unit jurisdictions in Ontario. The average ozone concentration for the baseline period and the projection periods (2050s and 2080s) are presented in Table 33 (Gough et al., 2016). From 1971 to 2000, the days the 80 ppb limit was exceeded for both Waterloo Region and WDG was four days. For the 2050s, both Health Unit areas are projected to exceed the limit five days per year. For the 2080s, Dufferin County, Wellington County, and Waterloo Region are projected to exceed the limit five and six days of the year, respectively (Gough et al., 2016).

Table 33: Changes in the Number of Ozone Exceedances (>80 ppb) Count (days per year) by WDG and Waterloo Region

Public Health Units	Days above 80 ppb (1971-2000)	Days above 80 ppb (2050s)	Days above 80 ppb (2080s)
WDG	4	5	5
Waterloo Region	4	5	6

The Human Health Chapter of the 2014 Canada in a Changing Climate Report outlines air quality impacts for Canada under climate change. Included in this study is Figure 17 (Berry et al., 2014), which outlines simulations of 10 summer seasons (in 2000), and future (2045) air quality in North America. This study suggests that ozone concentrations are expected to increase by up to 9 to 10 parts per billion by volume (PPBV) with climate change, when anthropogenic air pollutant emissions are kept constant (top figure) (Berry et al., 2014). The same simulations forecast lower magnitude increases of $PM_{2.5}$ (< 0.2 µg/m^3) over much of North America (bottom figure) (Berry et al., 2014).

Figure 17: Visualization of Ten-year Averages for Daily Summer Maximum Concentrations of Ozone (on top) and Fine Particulate Matter (on bottom).

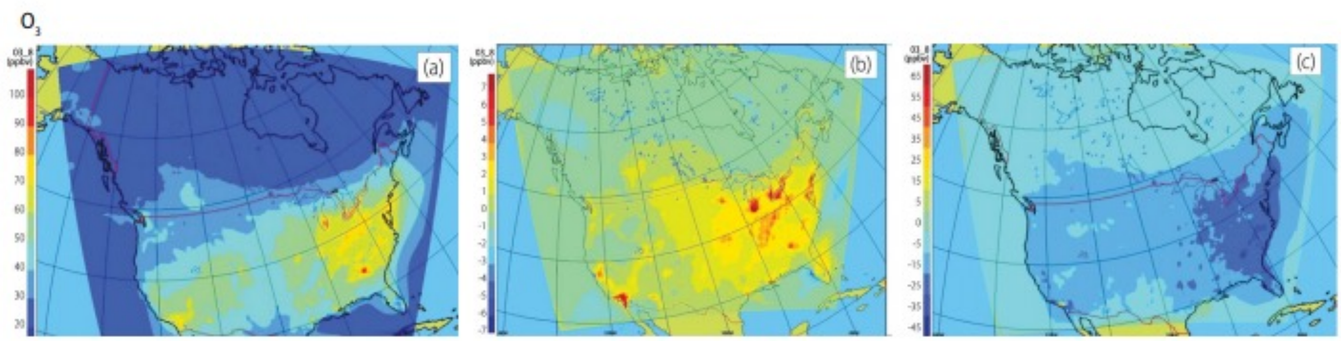


FIGURE 1: a) The ten year average "current" mean summer (June-July-August) daily maximum 8-hour average O_3 concentration; **b)** projected changes in the summer average daily maximum 8-hour O_3 between the "current" case and the "future" case with climate change using constant air pollutant emissions; and the **c)** "current" case and "future" case with possible reductions in future air pollutant emissions *(Source: Kelly et al., 2012)*. Note the different contour intervals used in each panel.

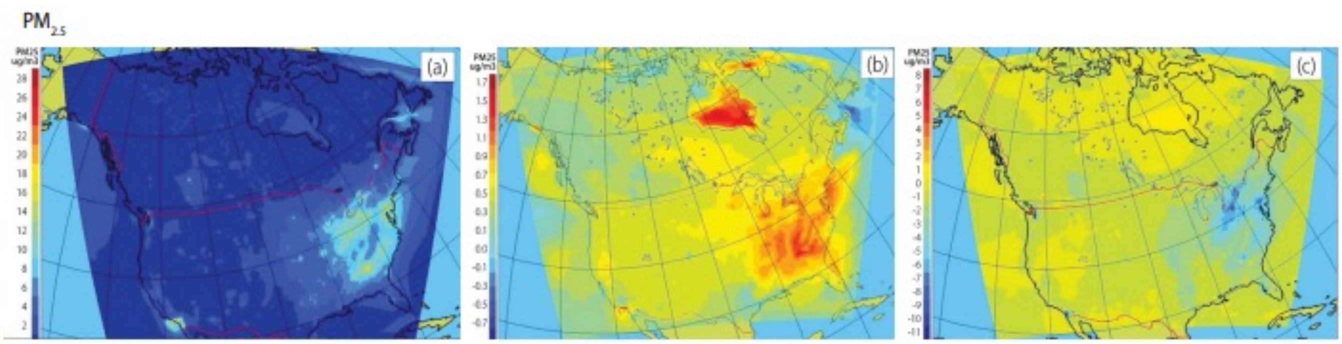


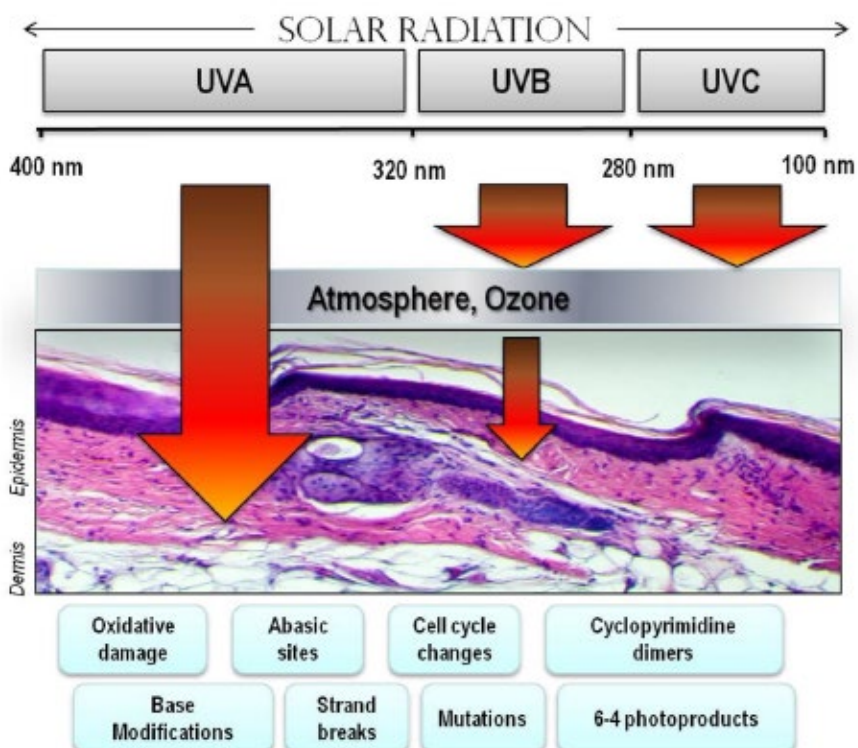
FIGURE 2: a) The ten year average "current" mean summer (June-July-August) 24-hour average $PM_{2.5}$ concentration; **b)** projected changes in the summer 24-hour average $PM_{2.5}$ concentration due to climate change with constant air pollutant emissions; and **c)** projected changes to $PM_{2.5}$ for the future with the combined effects of climate change and possible future decreases in air pollutant emissions *(Source: Kelly et al., 2012)*. Note the different contour intervals used in each panel.

The presence and potential increase in smog-causing ground-level ozone and particulate matter over the coming decades will have a detrimental impact on population health through exacerbation of respiratory conditions and allergies, increased risk of cardiovascular diseases, and even premature death (Silva et al., 2017).

UV Index

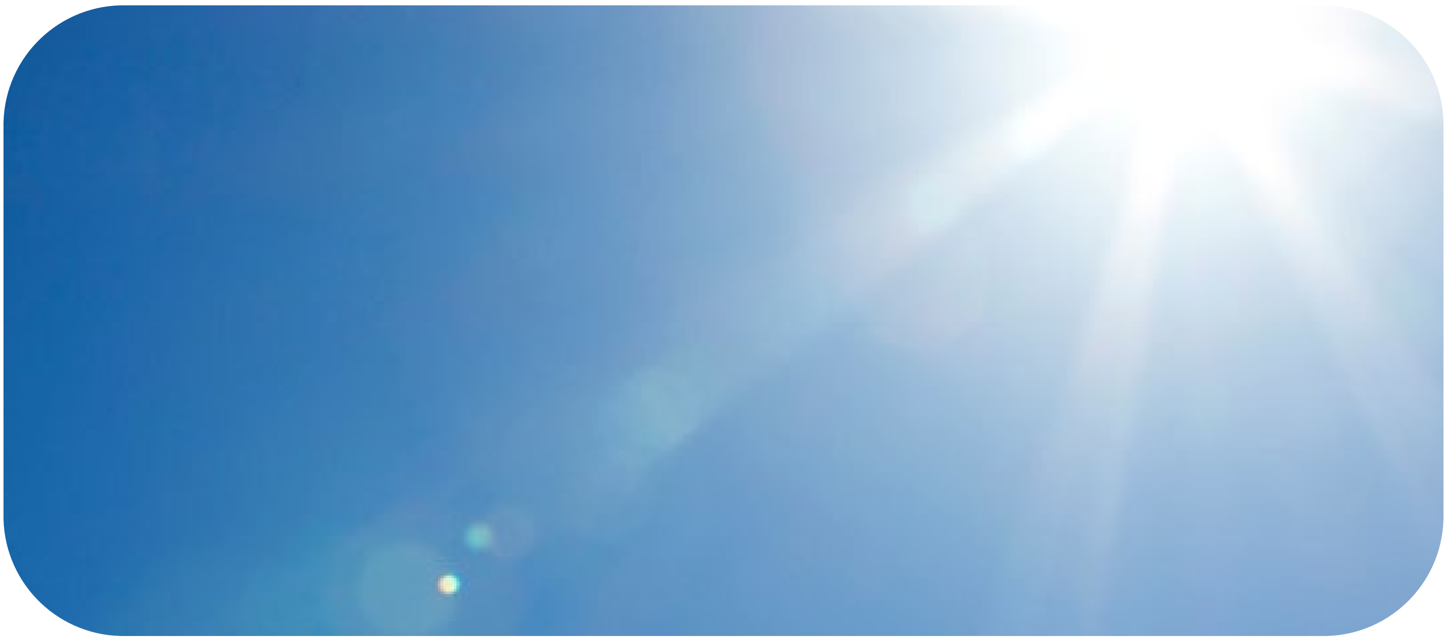
Surface ultraviolet (UV) radiation has a significant impact on population health. Exposure to UV radiation increases the risk of various forms of skin and eye cancer, causes DNA damage, and induces immune suppression, cell atrophy, wrinkling, and cataracts (D'Orazio et al., 2013). In short, ultraviolet (UV) rays are a form of invisible high-energy light produced by the sun that take on three forms: UV-A, UV-B, and UV-C, all of which have different impacts on population health (Figure 18 below) (D'Orazio et al., 2013).

Figure 18: Image Showing the Variability of the Three Types of UV Radiation on Human Skin



Though both UV-A and UV-B cause damage to population health, UV-B is much stronger than UV-A and is the main cause of sunburns and skin damage that can lead to skin cancer and other health issues (Government of Canada, n.d.). The ozone layer absorbs much of the UV-B that enters the atmosphere, providing some protection to the earth, however, there have been increased levels of UV radiation reaching the earth's surface due to the thinning ozone layer (Government of Canada, n.d.). UV-C, on the contrary, does not reach the earth at all as the ozone layer is able to absorb it completely (D'Orazio et al., 2013).

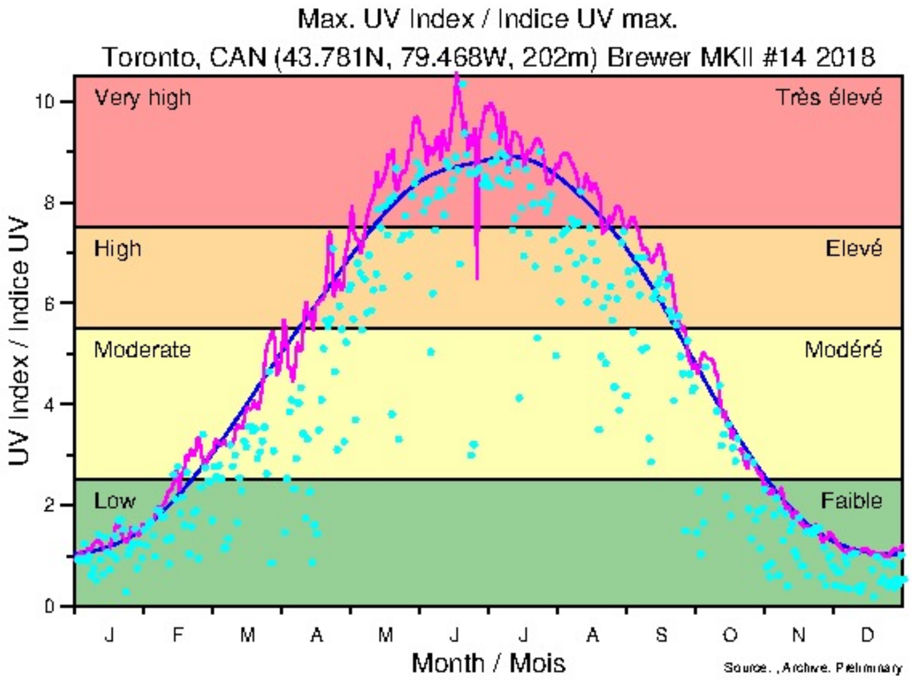
In the 1970s scientists discovered that certain industrial chemicals were destroying the stratospheric ozone layer that protected earth from harmful UV radiation (Government of Canada, n.d.). Global concern led to the signing of the Montreal Protocol in Canada in 1987 which committed nations around the world to phase out the use of ozone-destroying chemicals (Government of Canada, n.d.). The ozone layer now is beginning to show signs of recovery – outside the polar regions, the layer is no longer thinning, and has stabilized at about 3% less than normal (Government of Canada, n.d.). Average summer UV values across Canada remain a few percent higher than they were before 1980, however, a complete recovery of the ozone layer is not expected for decades (Government of Canada, n.d.). Ozone-destroying chemicals can remain in the atmosphere for many years after they have been released, and there are also concerns that the recovery of the ozone layer could be complexified by other factors such as climate change (Government of Canada, n.d.).



The UV Index is an international standard measurement of the strength of ultraviolet (UV) radiation at a specific place and time (Government of Canada, n.d.). The higher the UV Index, the stronger the sun's radiation, and the greater the chance of UV rays reaching earth and impacting population health. It is important to note that UV radiation and temperature (or heat) are not directly linked – UV radiation is invisible and cannot be felt, compared to infrared radiation which can be felt and is hot on the skin (Cancer Council WA, 2019). In short, the sun produces different types of radiation all found on the electromagnetic spectrum, and the type of radiation that causes heat is different than the type of radiation that causes skin cancers and other health issues.

In Canada, the UV Index ranges from 0 to 11+, with a UV index of 8+ considered to be very high or extreme (Government of Canada, n.d.). Extra precaution is urged when the UV Index is at this level as exposed skin can be damaged and burned quickly. Despite there being no correlation between heat and UV radiation, the highest UV index is often found in the summer between the months of May to August due to the closeness of the sun compared to the winter. Figure 19 (Government of Canada, n.d.) displays the average maximum UV Index for Toronto in the year 2018 across each month. While UV index is the highest in the summer, very high levels were also detected in April, September, and October of 2018.

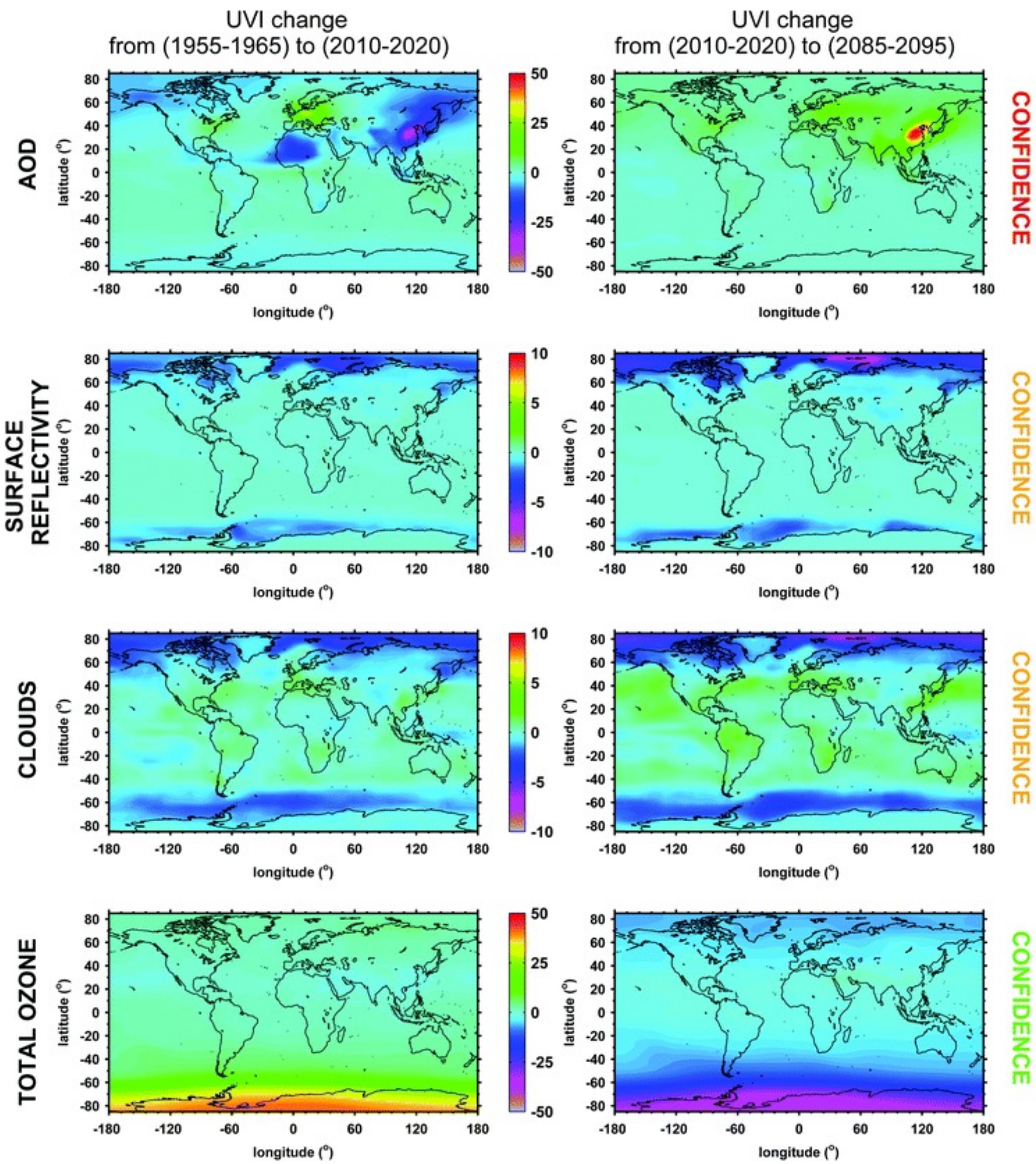
Figure 19: Maximum UV Index in Toronto, Canada, 2018



Projecting Future UV Index

While historical UV index is simple to measure and track, projecting future surface UV radiation is much more difficult, as it is influenced by several factors. These factors include impacts to stratospheric ozone due to the presence of Ozone Depleting Substances (OCDSs); changes in ozone and cloud cover induced by increasing concentrations of GHGs; changes in tropospheric UV-absorbing aerosols; and decreases in surface reflectivity at high latitudes and high altitudes. In a study completed in 2014, researchers analyzed how climate change and ozone depletion could impact future UV radiation across the globe (Baris et al., 2014). Simulations of these UV radiation levels were derived from radiative transfer model calculations that use input parameters estimated by climate models. Figure 20 (Bais, et al., 2014) shows the simulated annually averaged percentage changes in noontime UVI relative to the "present" (i.e., 2010–2020). The left column shows simulated changes since 1955–1965. The right column shows the simulated changes expected from the present to the period 2085–2095. Effects of aerosols, surface reflectivity, cloud cover, and total ozone on UVI are shown in each row, with the assessment of the confidence in UVI projections.

Figure 20: Simulated Annually Averaged Percentage Changes in Noontime UVI Relative to the "Present" (2010–2020)



The positive trends of UV radiation observed after the mid-1990s over northern mid-latitudes are mainly due to decreases in clouds and aerosols. Improvements in overall air quality and reductions of aerosols over the most populated areas of the northern hemisphere may result in a 10-20% increase in UV index (Bais et al., 2014). Aerosols are possibly the most important factor for future UV levels over heavily populated areas, but their projected effects are the most uncertain (Bais et al., 2014).

For Dufferin County, Wellington County, and Waterloo Region, high UV index in the summer and shoulder seasons will continue to be an issue of concern. While there is lower confidence that climate change will result in an increase in UV radiation in Canada, stratospheric ozone depletion from OCDSs will continue to be a concern over the next century. As such, it will be important to continue to monitor and plan for high UV index days now and in the future.

Conclusion

The information provided in this report provides an indication of how current and future climate change is affecting population health, specifically in Dufferin County, Wellington County, and Waterloo Region. Rising temperatures and levels of UV radiation, increases in precipitation, and more frequent and extreme weather events will have major acute and longterm impacts to population health in the study area. This report is intended to provide a foundation of local climate parameters affecting populaiton health currently and in the future. It will be compared against local and national health data to inform the climate change and health vulnerability assessment for Region of Waterloo Public Health and Wellington-Dufferin-Guelph Public Health.

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Appendix A: Ontario Climate Data Portal Annual Regional Averages for All Climate Indices

The following three tables are the summarized, annual regional averages for all climate indices available on the Ontario Climate Data Portal (OCDP). All figures presented are changes from the reference period of 1986-2005. Not all the indices listed below have been presented in the report.

A full definition of the climate indices are from the LAMPS database:

Table 34: Summarized Annual Averages of all OCDP Climate Indices for Wellington County – RCP2.6, 4.5, and 8.5

Indices	Ref	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Tm	7.7	1.9	2.4	3	1.8	3	5.1
Tx	12.1	1.9	2.5	3.1	1.8	3.1	5.3
Tn	3.2	1.9	2.4	3.2	1.8	3.1	5.4
Pr	1012	51	62	64	59	58	94
CDD	242	169	229	322	163	303	606
HDD	3994	-512	-638	-780	-483	-795	-1271
Cold_day	33	-14	-19	-23	-12	-22	-29
Cold_night	34	-15	-20	-24	-13	-22	-29
DTR	9	0	0	0	0	0	0
FD	135	-21	-27	-34	-21	-34	-57
GSL	219	19	24	28	17	30	53
j111	100	-11	-12	-15	-10	-16	-29
j211	318	8	12	14	7	14	24

Indices	Ref	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Hot_day	37	41	55	71	41	72	128
Hot_night	35	40	52	71	40	69	132
HWDI_days	6	5	6	8	5	9	21
HWDI_period	15	30	41	58	31	59	124
HWDI_strength	127	286	393	564	297	582	1297
ID	54	-16	-21	-24	-15	-25	-38
SU	53	24	32	41	23	40	65
tnCSDI	1	0	-1	-1	0	-1	-1
TNn	-22.1	3.3	4.6	5.3	2.9	5.4	8.7
TNx	22.8	1.7	2.2	3.2	1.7	2.8	5.3
TR	11	10	15	25	10	22	50
TXn	-12.5	2.4	3.6	4.3	2.4	4.3	7.2
TXx	33.2	1.9	2.9	3.8	2	3.7	6.3
txWSDI	2	18	25	38	19	38	92
pr95pDays	7	1	1	2	1	1	3
pr95pTOT	198	38	47	56	38	44	89
pr99pDays	1	0	1	1	0	1	1
pr99pTOT	53	21	28	32	20	27	53

Indices	Ref	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
prCDD	14	0	0	1	0	1	1
prCWD	8	0	0	0	0	0	0
PRCPTOT	992	52	63	66	59	59	96
R1mm	151	2	2	1	3	2	0
R5mm	67	2	3	2	3	2	3
R10mm	31	2	2	3	2	2	3
R20mm	8	1	1	2	1	1	3
R25mm	4	1	1	1	1	1	2
RX1day	36.8	4.3	6.1	6.2	4.7	5.5	9.1
RX5day	60.1	7	8.4	8.9	6.9	7	12.7
SDII	6.6	0.3	0.3	0.4	0.2	0.3	0.6

Table 35: Summarized Annual Averages of all OCDP Climate Indices for Dufferin County – RCP2.6, 4.5, and 8.5

Indices	Ref	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Tm	7.4	1.9	2.4	3.1	1.8	3	5.2
Tx	11.8	1.9	2.5	3.1	1.8	3.2	5.3
Tn	2.7	1.9	2.4	3.2	1.8	3.1	5.4
Pr	1002	50	60	62	57	58	90

Indices	Ref	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
CDD	229	166	223	316	159	296	597
HDD	4110	-524	-650	-797	-495	-809	-1300
Cold_day	34	-14	-19	-22	-12	-21	-29
Cold_night	34	-15	-20	-24	-13	-22	-29
DTR	9	0	0	0	0	0	0
FD	140	-21	-26	-33	-20	-34	-57
GSL	215	19	23	28	17	29	51
j111	100	-11	-11	-14	-9	-15	-27
j211	314	8	12	14	7	14	24
Hot_day	37	41	54	70	40	71	127
Hot_night	36	40	51	70	39	68	131
HWDI_days	6	5	6	8	5	9	20
HWDI_period	15	30	41	58	31	58	123
HWDI_strength	133	286	391	562	296	575	1293
ID	57	-16	-21	-24	-15	-25	-39
SU	52	24	32	41	23	40	65
tnCSDI	1	0	-1	-1	0	-1	-1
TNn	-23.6	3.3	4.6	5.4	2.8	5.4	8.9

Indices	Ref	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
TNx	22.6	1.7	2.2	3.2	1.7	2.8	5.3
TR	10	10	14	23	10	20	48
TXn	-13.4	2.5	3.7	4.4	2.5	4.4	7.4
TXx	33.1	2	2.9	3.8	2	3.7	6.3
txWSDI	2	18	25	37	19	37	90
pr95pDays	7	1	1	2	1	1	2
pr95pTOT	196	37	46	53	36	42	83
pr99pDays	1	0	1	1	0	1	1
pr99pTOT	50	20	27	31	19	24	49
prCDD	13	0	0	0	0	0	1
prCWD	8	0	0	0	0	0	0
PRCPTOT	986	50	61	63	57	58	92
R1mm	150	1	2	1	3	2	0
R5mm	67	2	3	3	3	3	4
R10mm	31	2	2	2	2	2	4
R20mm	8	1	1	2	1	1	2
R25mm	3	1	1	1	1	1	2
RX1day	37.3	4.2	5.9	5.6	4.3	4.8	7.8

Indices	Ref	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
RX5day	61.4	6.7	8.2	8.1	6.3	6.4	11.4
SDII	6.6	0.3	0.3	0.4	0.2	0.3	0.6

Table 36: Summarized Annual Averages of all OCDP Climate Indices for the Waterloo Region– RCP2.6, 4.5, and 8.5

Indices	Ref	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Tm	8.2	1.8	2.3	3	1.7	3	5.1
Tx	12.5	1.9	2.4	3.1	1.8	3.1	5.2
Tn	3.8	1.8	2.4	3.1	1.8	3	5.3
Pr	1005	51	62	65	58	57	95
CDD	261	170	232	327	164	307	610
HDD	3860	-493	-616	-754	-465	-768	-1229
Cold_day	33	-14	-19	-23	-12	-22	-29
Cold_night	34	-16	-20	-24	-13	-22	-29
DTR	8	0	0	0	0	0	0
FD	128	-21	-27	-34	-21	-35	-57
GSL	224	19	24	29	18	31	54
j111	98	-12	-12	-15	-11	-17	-31
j211	322	8	11	13	7	14	23

Indices	Ref	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Hot_day	38	42	55	72	41	72	129
Hot_night	36	41	52	72	41	70	134
HWDI_days	6	5	6	8	5	9	22
HWDI_period	14	31	43	60	32	61	126
HWDI_strength	120	298	405	576	308	596	1309
ID	51	-15	-20	-23	-15	-24	-36
SU	53	24	32	40	23	39	64
tnCSDI	1	0	-1	-1	0	-1	-1
TNn	-20.7	3.2	4.5	5.2	2.9	5.3	8.4
TNx	22.9	1.6	2.2	3.1	1.6	2.8	5.3
TR	12	12	17	27	12	24	53
TXn	-11.9	2.4	3.5	4.2	2.4	4.2	7
TXx	32.9	1.9	2.8	3.7	1.9	3.6	6.3
txWSDI	2	18	26	39	19	39	93
pr95pDays	7	1	1	2	1	1	3
pr95pTOT	193	35	47	59	37	45	92
pr99pDays	1	0	1	1	0	1	1
pr99pTOT	54	20	27	33	20	27	54

Indices	Ref	2050s			2080s		
		RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
prCDD	14	0	0	1	0	1	1
prCWD	8	0	0	0	0	0	0
PRCPTOT	989	51	63	66	58	58	97
R1mm	150	2	2	1	3	2	0
R5mm	67	2	3	2	3	2	3
R10mm	31	2	2	3	2	2	3
R20mm	7	1	1	2	1	1	3
R25mm	4	1	1	1	1	1	2
RX1day	35.5	4	5.9	6.1	4.6	5	9.7
RX5day	58.4	6.6	8	9	6.9	6.7	13.5
SDII	6.6	0.3	0.3	0.4	0.2	0.3	0.6

Tables

Figures

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