Impacts of Climate Change in London



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Note to Reader

This supporting document (Impacts of Climate Change in London) was developed to summarize the current understanding of observed weather-related impacts, historical trends and expected future impacts of climate change on London, Ontario. Mitigation of climate change requires the reduction of greenhouse gas emissions, which is a consistent goal for all jurisdictions pursuing action on climate change, but because the impacts of climate change vary around the world, adaptation looks very different depending on where you look. The analysis presented in this supporting document is required to better understand the relevant, geographically specific challenges of adaptation to climate change in London and ultimately help support the prioritization of proposed adaptation actions.

The details in this document will be of interest to:

- Individuals and community groups
- Businesses and business groups
- Institutions and networks
- Academia
- Government staff at all levels

The summary and analysis contained in this supporting document covers findings, observations and research that occurred or was published prior to November 30, 2021. City staff are regularly monitoring progress and developments on climate change impacts in London and work with staff from other municipalities in Canada to understand and use best practices. Advancements in the observations and understanding of climate change impacts are occurring regularly and City staff rely on connections to Conservation Authorities, academic researchers, membership to associations and groups like the Association of Municipalities of Ontario, the Federation of Canadian Municipalities, ICLEI Sustainable Cities Canada and others to stay up to date on the latest information.

Additional work is required to advance London's adaptation planning and work is expected to continue early in 2021 with consultation and subsequent preparation of a formal adaptation strategy.



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1. Introduction and Background

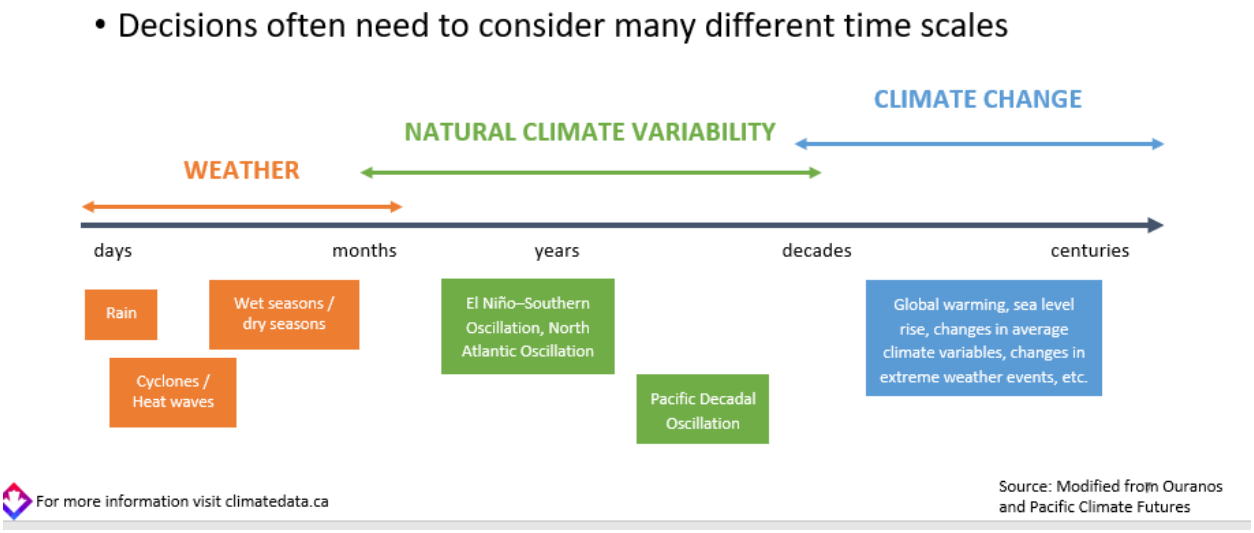
London's weather and climate are directly influenced by its' geographic location being in the most southerly region of Canada and surrounded by the Great Lakes. This establishes London as having a 'humid continental climate' (Köppen *Dfb*) described as having four distinct seasons with large seasonal temperature differences. Precipitation is usually distributed throughout the year. More specifically, London's historic climate has:

- Large seasonal contrast with warm to hot and humid summers and cold winters with frequent thaws.
- Winters are cold with frequent thaws; snowfall totals are heavy averaging 194 cm/year but localized snow squalls mean that average varies from year to year.
- Lake effect snow squalls originating from Lake Huron can drastically influence snow amounts.
- July temperatures average 20.8 ºC with an average of 10 days/year above 30 ºC.
- Humidex temperatures can reach 46 ºC with frequent thunderstorms due to hot humid summer weather as well as the convergence of breezes originating from Lake Huron and Lake Erie.
- The same convergence zone can spawn high winds, funnel clouds and tornados (see Appendix A).
- Impacted by 14 hurricane storm events of which the remnants made their way to southwest Ontario (see Appendix B).
- London's highest temperature = 41.1 in August 6,1918 and lowest temperature was -32.2 on January 20, 1892.
- Both residential heating degree days and cooling degree days have been influenced by longer term temperature conditions (see Appendix C).

With climate change, different time scales need to be considered to ensure successful adaptation. As shown below in Figure 1, weather is the shortest time period with natural climate variability taking several years and climate change encompassing decades. Adaptation in London needs to consider both the short and long-term climate impacts of average conditions changing over long time periods and the changes to extreme events with different intensity and frequency. The expectation from all meteorological analysis is that London's future climate will resemble one that is "warmer, wetter and wilder".

In past decades, many extreme weather events have occurred in all four seasons impacting London. It is difficult to determine conclusively if climate change was the cause of these events. A more reliable test for climate change is identifying changes in trends and seeking answers to the question if the frequency and intensity of these events have increased. The purpose of this background report is to explore past trends, compare climate projections with recent data, and to illustrate what London's projected weather will be in 2050.

Figure 1: Weather, Natural Variability and Climate Change



2. Early Discussions on Climate Impacts

In 2014, the City of London Risk Management Unit completed a report titled, “Climate Change Adaptation – Risk Assessment Report” using a multi-departmental team and by interviewing staff in all major divisions and departments. The team also included staff from the Middlesex London Health Unit and interviewed staff from the Upper Thames River Conservation Authority. Conclusions were derived from historic weather events (see Appendix D for an infographic regarding historic natural disasters), first-hand knowledge by staff of weather observations and available climatic and weather conditions, including future projections at that time.

The report concluded that:

- Risk exposure to weather events up to 2050 will be more frequent and extreme.
- Floods, sleet/hail/ice storms, and heat waves are the top 3 from the 8 weather events identified by the analysis as exposure to risk. (see Figure 2)
- The remaining 5 weather events having a risk exposure in London are intense snow, extreme cold, extreme wind, drought and periods of poor air quality (illustrated in Figure 3).

Figure 2: Risk Exposure by Weather Events

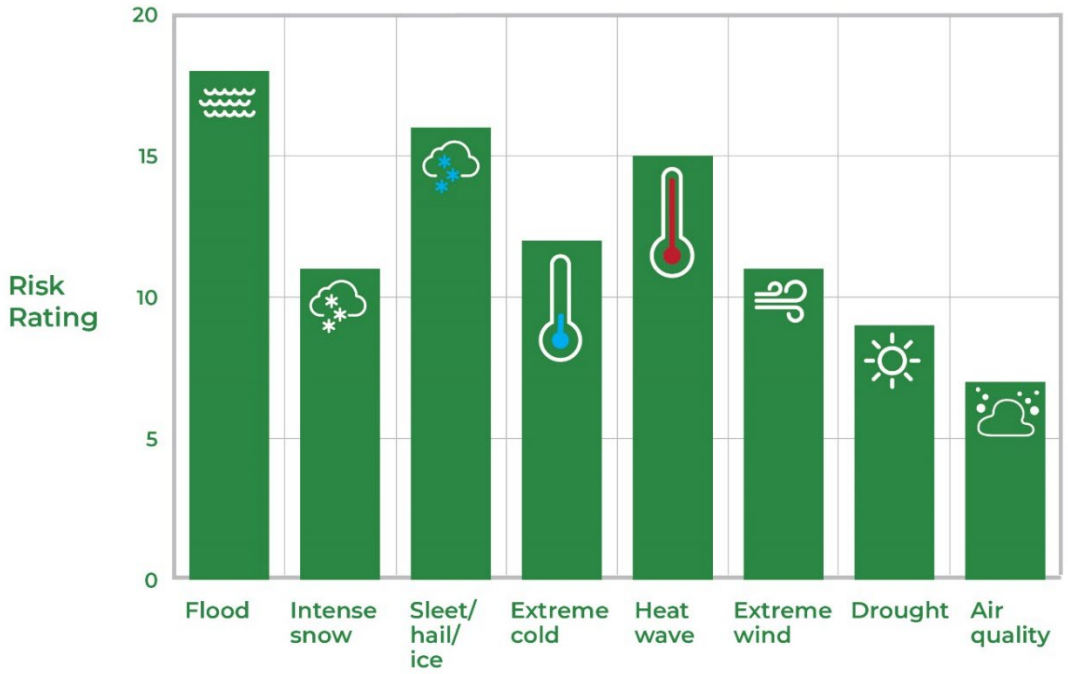


Figure 3: Extreme Weather Impacts in London



The science, research and sources of data have progressed considerably since 2014. At the time of writing the Risk Assessment Report, the projected climatic changes were based on general data from a provincial perspective and assessment that illustrated that Ontario would experience increases in temperature, extreme rainfall events as well as severe winter storms. These earlier estimates are shown below (Table 1) being the projected climate for Ontario from what was known in 2006. Some changes have recently been made, especially regarding Great Lakes water levels, to the projections illustrating the difficulty with projecting precipitation and evaporation amounts into the future.

Table 1: Ontario Weather Estimates Assessed in 2006

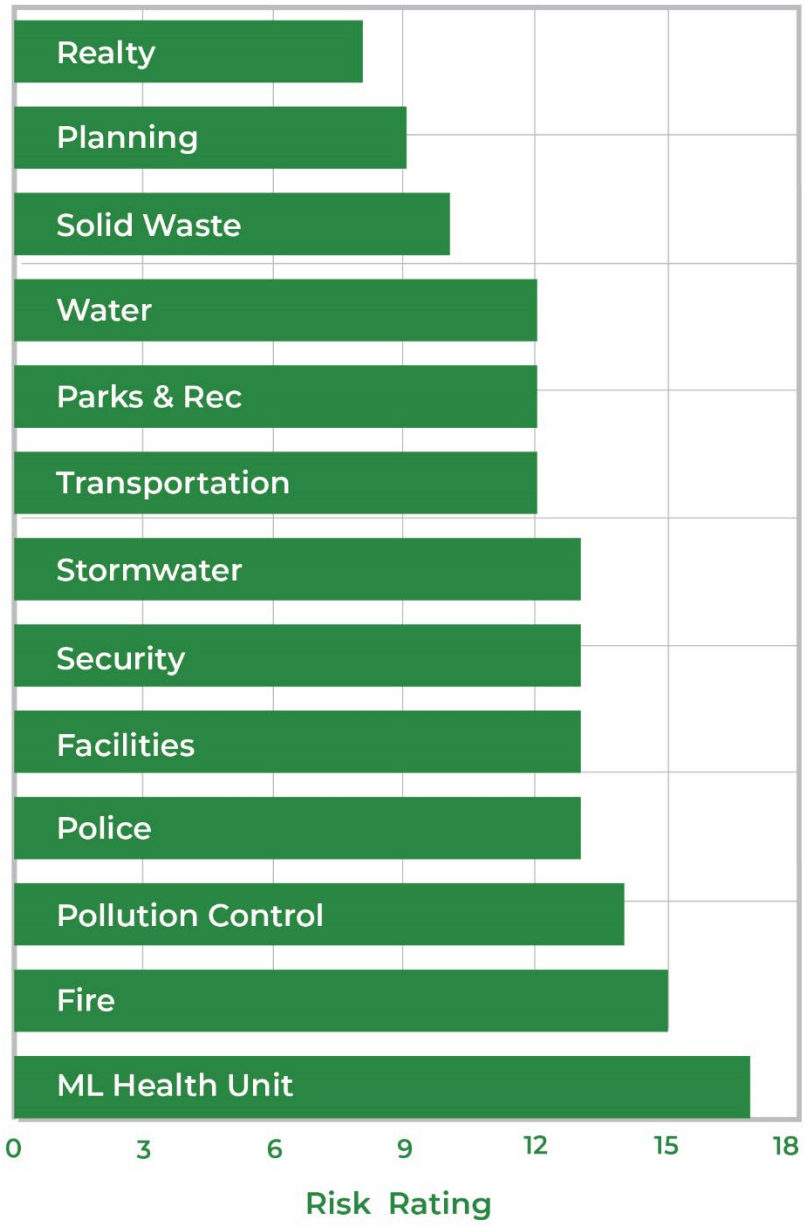
Weather elements	Climate Changes from 1971 to 2006	Projected Changes to 2050
Mean Temperature	0.6 degrees C	2 to 3 degrees C
Total Rainfall	+1% per decade	+1% per decade
Extreme Rain Event	+5 to 7% per decade especially in spring (May)	+5% per decade
Total Runoff and Groundwater	Little change	Decline 10 to 20% (more evaporation
Great Lakes water levels (flow at Niagara which integrates effects of lakes above the Falls	-7% (30 years)	Decline 0.3 to 1 metre in levels
Severe Winter Storms	Increased intensity	15 to 20% increase in intensity

Note: The guide suggests these are significant changes. By comparison, the Earth's mean temperature has only warmed 4 to 5 degrees C since the last ice age.

Source: extract from "Adapting to Climate Change; A Risk-based Guide for Ontario Municipalities", Bruce, James P., Egener, I.D. Mark, and Noble, David. 2006. Accessed from http://www.nrcan.gc.ca/earthsciences/projdb/pdf/176a_e.pdf

An assessment of how these changes to the climate would impact City service areas was completed. The results (see Figure 4) reveal that the risk was spread approximately even across the corporation. The Middlesex London Health Unit (MLHU) was perceived to have the greatest risk and with Realty Services perceived to have the least risk. This information was used to inform asset management decisions at that time.

Figure 4: Risk Exposure Ranked by City of London Service Area



During the process in 2014 of discussing climate risk with the City of London staff, many issues were raised, and concerns expressed regarding actual impacts observed and potential impacts. These impacts were then used as benchmark data and assessments and subsequently summarized into 25 impact statements that suggest the scope and consequence of extreme weather events on specific aspects of life in London. In 2021, these statements were reassessed as part of the 'Advancing Adaptation' project hosted by ICLEI Canada and refined to incorporate more recent climate impacts and events.

The 25 impact statements are listed in the next section in decreasing order of risk scores. Risk scores were estimated in 2014 by multiplying probability and likelihood ratings using a 5 point system to establish a total score. These scores, updated in 2021, are identified in brackets for each statement and are determined with a maximum score of 25. This approach to climate change risk management is widely used across Canada (www.climateontario.ca).

3. Re-assessment of Twenty-five Impact Statements

1. **Urban Forest** - More extreme weather events causing damaging winds and winter sleet storms damaging the urban forest and killing vegetation (Score = 20).

2. **Winter Emergencies** - More extreme weather events causing more heavy snowfall/ice/sleet events creating challenges for transportation and snow clearing resulting in increased medical emergencies (Score = 20).

3. **Straining EMS response** - More extreme weather events resulting in more response calls for EMS for rescue and evacuation due to flooding, severe winds and snow squalls, straining emergency services capacity and ability to respond (staff, and equipment resources) (Score = 20).

4. **Health Service Demands** - More extreme weather events will increase the demand for health services due to increased trauma, testing needs and mental stress (Score = 20).

5. **Basement Flooding** - More extreme rainfall events leading to increased flooding in low-lying areas & basements causing property damage/loss (Score = 20).

6. **Sanitary Sewer Challenges** - Extreme rainfall events increasing inflow and infiltration of rainwater into sanitary sewer systems causing sanitary sewer backup into residential/commercial properties (Score = 20).

7. **Park Infrastructure Damage** - More extreme rainfall events resulting in more frequent and intense localized flooding of environmentally sensitive areas and city park infrastructure, causing the need for repair/replacement of park pathways, structures and vegetation (Score = 20).

8. **Floodplain Reassessment** - More extreme rainfall events resulting in flooding that expands the size of floodplains and requiring property redesignations, acquisitions of the most impacted properties, and re-examination of overland water flow routes (Score = 20).

9. **Summer Energy Demand** - Warmer summer temperatures resulting in an increased energy demand for cooling centres as well as individual residences (Score = 18).

10. **Flooding Related Injury** - More frequent extreme rainfall events resulting in localized flooding causing increased injury to people, property, damage to parks, and infrastructure (Score = 18).

11. **Wind/Ice storm Damage** - More frequent extreme weather events resulting in wind, freezing rain, ice storms that damage trees and hydro lines (Score = 18).

12. **Operational/Maintenance Cost** - More frequent extreme rainfall events resulting in localized flooding causing increased operational and maintenance costs of infrastructure, both private and public (Score = 18).

13. **Emergency Accommodations** - More extreme weather events (e.g., rain, wind, snow, sleet) resulting in more need for emergency accommodations especially involving vulnerable populations (e.g., those experiencing homelessness and damaged affordable housing residents) (Score = 18).

14. **Chronic Health Conditions** - More frequent extreme heat events leading to an increase in chronic health conditions related to poor air quality, causing increased local public health concerns (Score = 15).

15. **Pollution Control Plant Damage** - Increasing precipitation and more extreme rainfall events causing increased urban flooding and reduced sewer capacity creating challenges at pollution control plants due to flood damages and the inability to treat additional quantities (e.g., I&I contributions) (Score = 15).

16. **Snow Squall Business Interruption** - More extreme weather events creating damages from severe wind and snow squalls interrupting City administration and services, impacting staff ability to get to work requiring alternative work arrangements (Score = 15).

17. **Winter Frozen Waterlines** - More extreme weather events creating damages from severe wind and snow squalls causing damage to infrastructure (e.g., frozen water lines) (Score = 15).

18. **Winter Ice Conditions** - Increased winter precipitation and rain on snow events leading to increased risk of ice conditions on roads and sidewalks (e.g., traffic accidents, slips/falls) (Score = 15).

19. **Risk to Vulnerable Population** - More extreme weather events negatively impacting community health and well-being (e.g., health of vulnerable populations, access to recreation, access to social gathering spaces) (Score = 15).

20. **Increased Home Repair** - More frequent extreme weather events resulting in more private property damages leading to increased financial strain for home repairs (Score = 15).

21. **Vector Borne Disease** - Warmer year-round temperatures and increased precipitation leading to increased impacts related to vector-borne diseases (e.g., Lyme Disease, West Nile) (Score = 12).

22. **Agricultural Losses** - Variability in precipitation and temperature leading to increased spring flooding events and longer periods of summer drought, causing increased crop failures and livestock challenges in agricultural production, affecting local food security and economic resilience (Score = 10).

23. **Increased Landfill Material** - More extreme rainfall events leading to increased flooding resulting in increased expenses for home repairs and quantity of debris and household garbage to retrieve curbside material destined for the landfill impacting landfill lifespan (Score = 10).

24. **Invasive Species** - Warmer temperatures increasing the occurrence / likelihood of current and novel invasive species impacting local ecosystems, biodiversity and potentially human health (e.g., ticks and lyme disease) (Score = 10).

25. **Heat Mortality** - More frequent extreme heat events leading to health impacts on vulnerable populations, causing increased morbidity and mortality (Score = 10).

3.1. Additional 'Risk to Monitor' Regarding Heat and Human Health

Increasing temperatures and extreme heat events could lead to local air quality concerns (e.g., increased PM2.5, ground level ozone), causing increased morbidity and mortality related to respiratory illnesses, coronary vascular disease, asthma, and increasing risk of pregnancy complications, especially among vulnerable populations. These concerns should be monitored and included as a future impact statement if confirmed.

4. Recent Analysis of Weather and Climate Scenarios

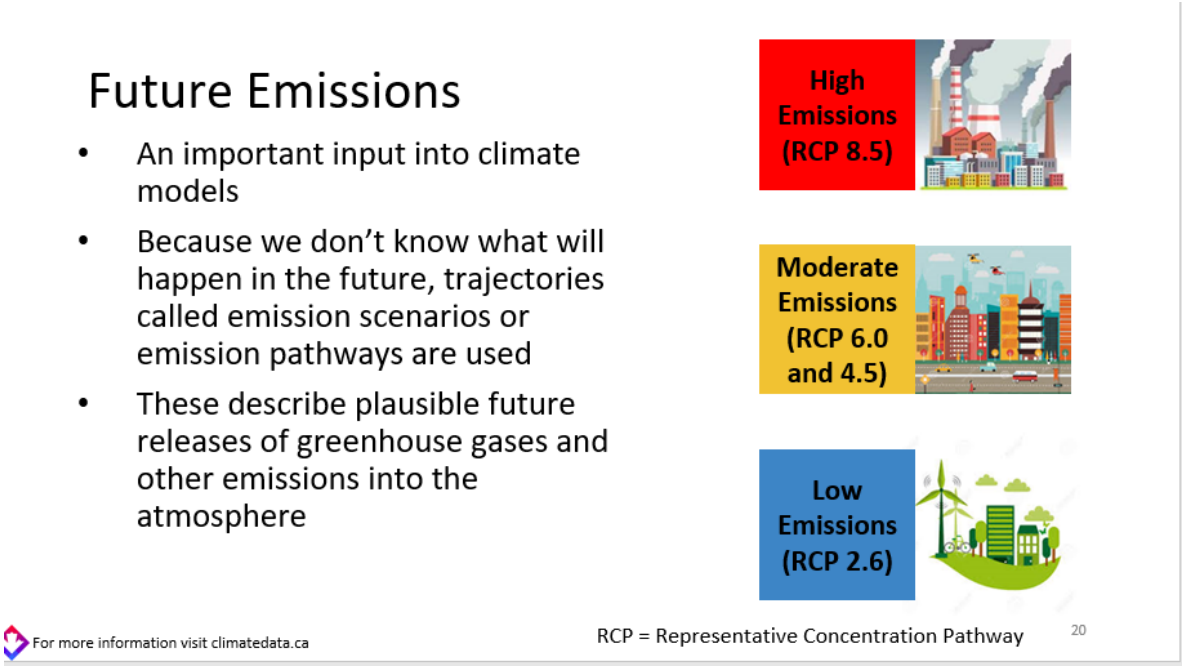
Adapting to the future climate and weather scenarios for any location, including London, is challenging since both are directly related to the quantity of greenhouse gas (GHG) emissions released into the atmosphere. That is the underlying justification for addressing the need for both adaptation and mitigation actions to climate change.

Another challenge is the shifting parameters of our climate to “non-stationary”. The term, ‘non-stationarity” means that what used to be normal is not normal anymore and that our climate system can no longer be considered predictable, or stationary. The extremes in our climate system of the past, are no longer considered the outer limits of what our current and future climate system can exceed. A common example of this is flooding frequency; a 1 in a 100-year flood could now be expected to happen more frequently perhaps becoming a 1 in a 50-year flood, or less.

GHG emission reductions need to occur at all levels; local, national and global to be completely effective and the reason this effort is a global initiative. London needs to play it’s part in this global effort. Adaptation to climate change on the other hand, needs to occur at the local level to ensure communities are prepared for the extreme weather events and incremental climate changes (e.g., warmer weather, more periods of flood and drought).

Emissions - Advances in modelling and web-based data summaries has resulted in improved climate data projections specific to London and region. What remains unclear are the future global GHG emissions that will continue to impact our climate. As shown (Figure 5**)**, three scenarios are being widely used by climate change scientists to approximate the various emission outcomes: High, Moderate and Low GHG emissions.

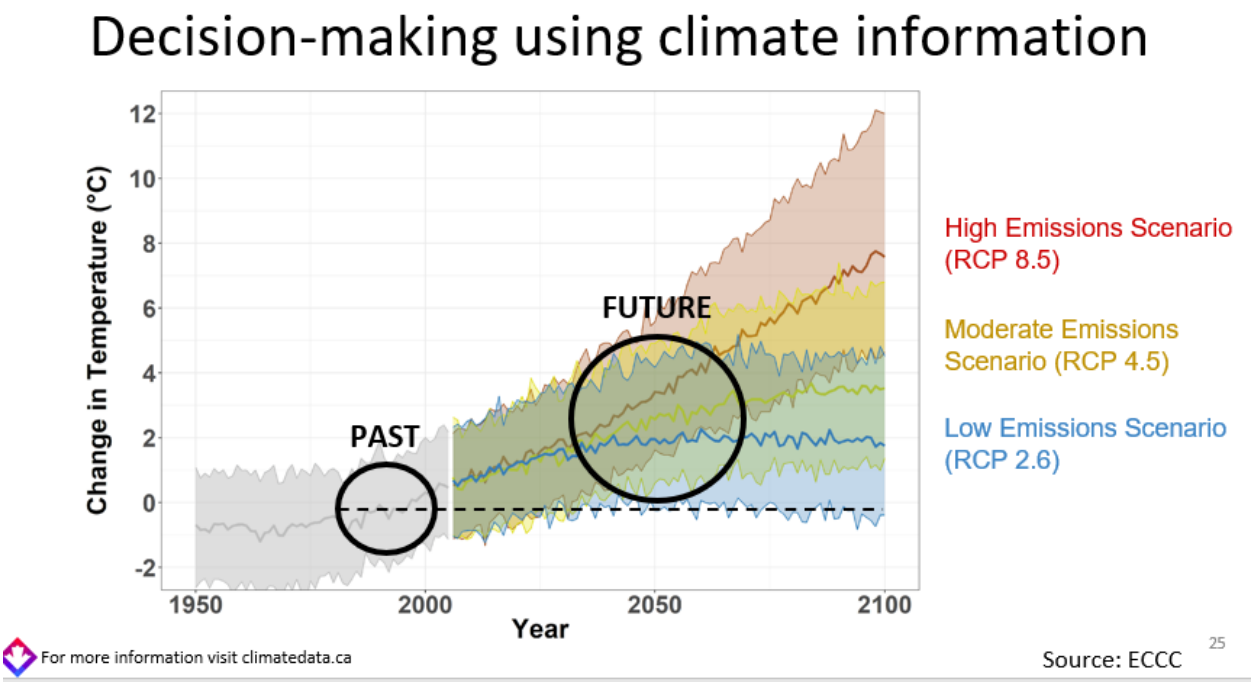
Figure 5: Future Emission Scenarios



These three emissions scenarios, being High Emissions (RCP 8.5, or pessimistic perspective showing minimal reductions in GHG emissions), Moderate Emissions (RCP 6.0 and 4.5, or showing some reductions in GHG emissions) and Low Emissions (RCP 2.6, or optimistic perspective with major reductions in GHG emissions) will mean different projected outcomes impacting the various characteristics of climate. These different emissions outcomes are illustrated using the example of temperature variations (see Figure 6) and provide an explanation as to why specific weather and climate projections are difficult to predict due given their dependence on the various global emission scenarios. This illustrates why climate change mitigation (focusing on reducing GHG emissions globally) and adaptation (focusing on the need to adapt to these climate implications locally) must proceed at the same time.

For the purpose of projecting future London climate, this background report has used the High Emissions (RCP 8.5) scenario to illustrate future weather impacts as further described in background analysis completed for this report.

Figure 6: Decision-making Matrix



Analysis was completed as part of the background work for the CEAP that took advantage of overlapping years of historic weather data compared to previously projected data. This allowed ground-truthing of the projections with 15 years of actual data. This was accomplished by taking existing weather data (e.g., Environment Canada and local sources) compared to projected weather data (Climate Atlas of Canada & Canadian Climate Data) that had an overlapping time period. As was expected, it confirmed that the 15-year time period of actual data followed the High Emissions Scenario (RCP 8.5) for London. This is because the world's GHG emissions are currently following the high emissions scenario.

Past weather events in London support the notion that the changes being discussed and projected into the future are already occurring. Some examples are provided below.

Extreme Weather – London has experienced extreme weather events in the past and data suggest the impacts are getting more frequent and intense. Examples are:

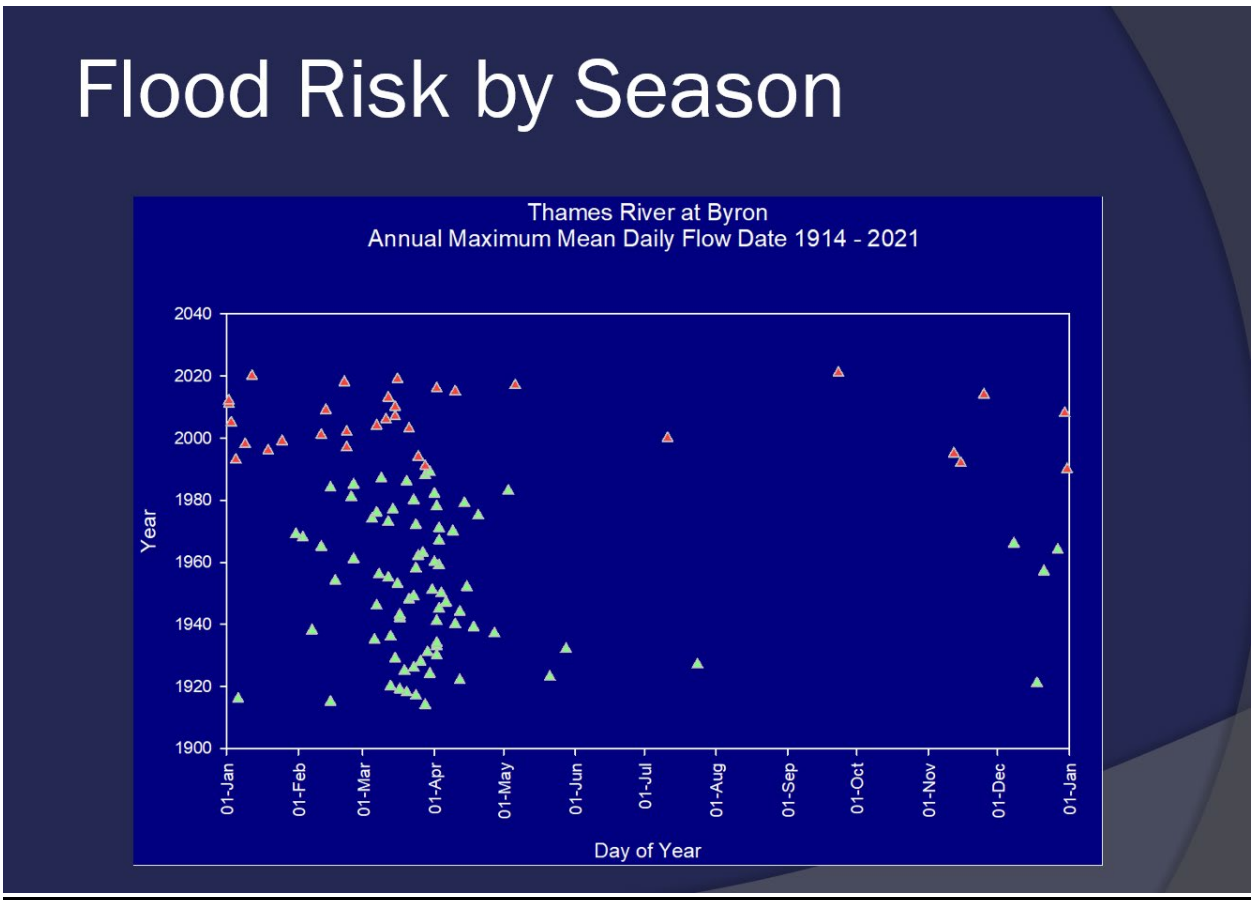
- Lake effect snow – December 5 to 9, 2010 London received 2 metres of snow over 3 days that closed schools, businesses and shut down the transit system (also referred to as "Snowmaggedon").

- Heat waves – in 2016 London experienced 35 days with temperatures at or above 30 ºC and in 2018 four heat wave incidents led to humidex readings up to 46 ºC.

- Winter river flooding – major floods occurring in February 2018 and in January 2020 have revealed a possible future trend since 1990 that spring flooding may no longer be the normal flood season and winter flooding may become the norm for the most extreme river floods. (see Figure 7**).** Floods tracked for 106 years illustrate a possible winter shift in the season of the annual flood.

- London and region has experienced droughts or near drought conditions in 14 of the past 20 years as determined by data from the Low Water Response Program initiated by the Province of Ontario in 2001.

Figure 7: Flood Risk by Season



Source: Upper Thames River Conservation Authority, Dec 1, 2021 Flood Coordinators Meeting.

Hurricanes, tornados and high winds are becoming more frequent as documented by NOAA and Western University's Northern Tornado Project (a project originating in 2017).

- From the first documented hurricanes, London has had 14 track through the London area (within a 100 km radius of London) with the 5 most intense hurricanes/ tropical storms being in the last 35 years.

- The most intense hurricane to eventually cross through the London area was Isabel in 2003 that despite being downgraded still produced a tropical thunderstorm with 60 km/hr winds and rain that dumped 30 mm on Toronto and 50 mm on Sarnia.

- Arguably the most notorious hurricane in Ontario was Hazel in 1954 that caused extensive damage across southern Ontario including London where infrastructure nearest the river was damaged or destroyed (e.g., River Road bridge over Waubuno Creek needed to be rebuilt due to Hazel storm damage).

- Hurricane season in the Atlantic Ocean is typically June to November with an average of 12 hurricanes per year in North America; however, 30 hurricanes occurred in 2020 which surpassed the previous record of 28 in 2005.

- Hurricanes in the past 30 years have increased in number, intensity and speed of intensification creating more “major hurricanes” (Category 3 and above) (ScienceNews.org – July 13,2021).

- Research into hurricanes and the impact of climate change continues to be carefully studied however a key consideration for London is speculation that their ‘staying power’ once they reach land is being increased by warmer waters and air temperatures.

- The Northern Tornado Project (NTP) at Western University has identified 31 tornados or wind gust events in 2021 alone in the London area (within a 100 km radius) with 13 of these confirmed as tornados.

- In the 5 years of their existence, the NTP has investigated over 100 events with 25 being confirmed tornados in the London area.

- Most recently in London, a tornado touched down on August 10, 2021 in northeastern London with a rating of EF0 and wind speeds of 115 km/hr with a destruction path 4 km long and 20 metres wide.

- In London, high wind events were recorded by NTP on July 19, 2020 and August 27, 2020 as downbursts with winds reaching 95 and 115 km/hr respectively with widespread tree damage.

Flooding in London’s waterways has become a year-round occurrence and in addition the opposite extreme, droughts have become much more common. One

London weather event in 2000 is captured in photos (see Figure 8) shows the damage to infrastructure and property.

Figure 8: July 2000 London Flooding Impacts in Photos



Flooding and droughts are characterized in many ways:

- Flooding in London can take 2 forms; river flooding (also called 'riverine flooding') caused by increased precipitation upstream in the Thames River watershed; and urban flooding (also called 'pluvial flooding') caused by storm sewers not being able to handle the overland flows.

- Major Thames River flooding events have occurred historically in London in July 1883, April 1937, March 1977, Sept. 1986, July 2000, April 2008, Dec. 2008, Feb 2018, and Jan 2020.

- Floodplain mapping for London exists publicly and is available on the Zoning CityMap on the London website and these same maps are currently in the process of being updated (City / UTRCA) using modelling that utilizes climate change projections.

- Droughts have been monitored and have increased using data from the Provincial Low Water Response Program and implemented on a watershed basis by Conservation Authorities.

- In the London area, 14 of the past 20 years have had drought-like conditions declared at some point over the year.

- Drought dominated the 2012 / 2013 time period and was unusual given that for 14 consecutive months (through all 4 seasons), a drought existed and made more unusual since 10 of those months were in the more extreme Level 2 condition (Level 3 is considered a full-scale drought).

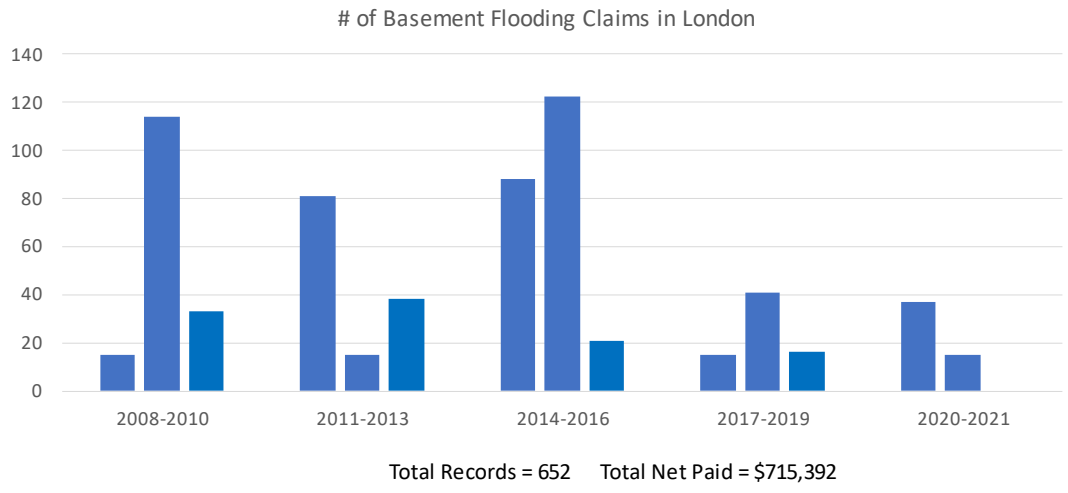
- Basement flooding developed into such a widespread and prevalent issue in London that an incentive program was developed to assist homeowners with prevention techniques.

- The graph below (see Table 9) illustrates the frequency and total number (= 652) of flooding and sewer back-up claims in London from 2008 to 2021 that were caused by both wet weather events as well as infrastructure failure (e.g., power outage for sump pumps, storm drain outlet blockage).

- Total net paid claims on private property for flooding and sewer back-up over the 13 years by the City of London exceed $715,000.

- Estimates suggest that for every flooding and sewer back-up claim reported, there are 10 unreported.

Figure 9: Flooding Claims in London (2008 to 2021)

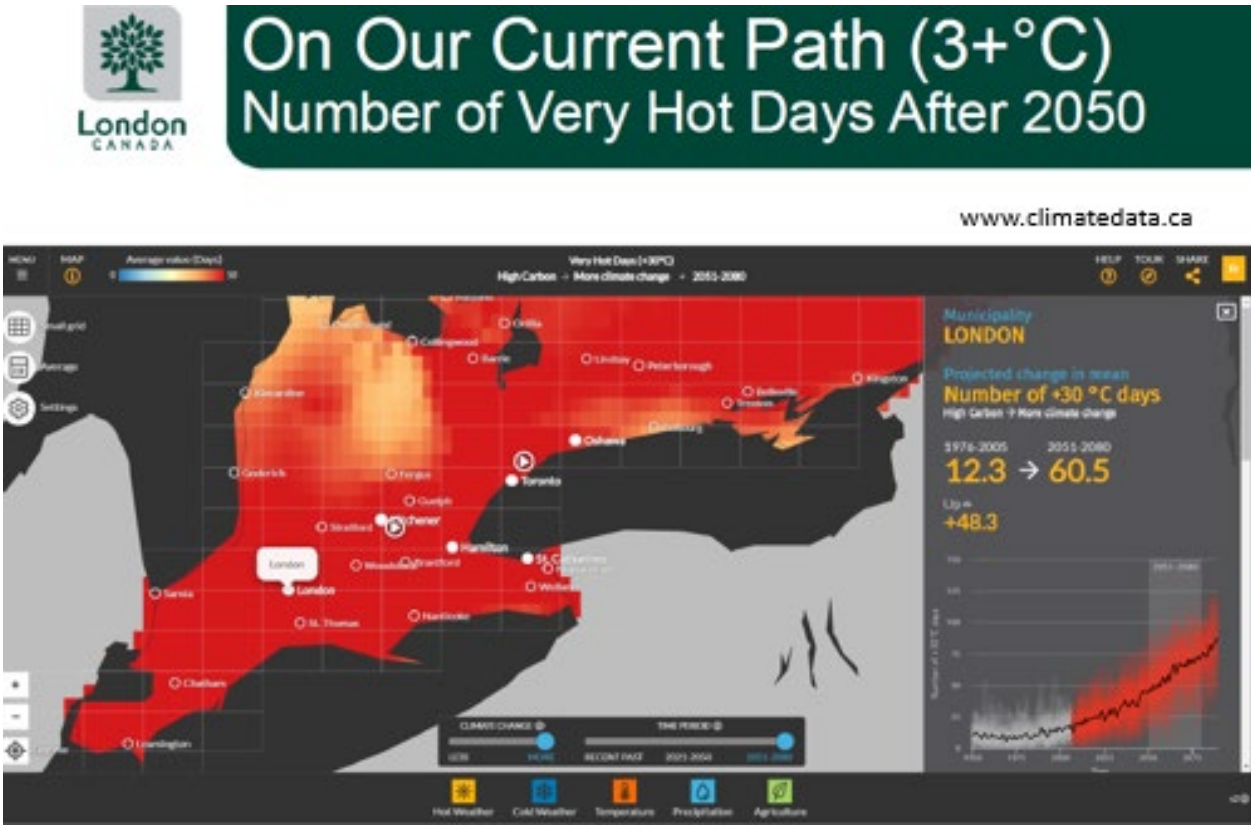


Human Health Impacts have been assessed by the Middlesex London Health Unit (MLHU). In their 2014 report, “Assessment of Vulnerability to the Health Impacts of Climate Change in Middlesex-London" they recommend several measures to advance the response to climate change. These include an action plan for adaptation, increased education and outreach, evaluations of existing adaptations and vulnerabilities, surveillance, and monitoring, as well as approaches to deal with uncertainty of future climates.

Of the many impacts anticipated, many of the human health impacts relate to heat. The warmer temperatures are creating the environment for the northerly spread of ticks that carry Lyme Disease. West Nile Virus and Eastern Equine Encephalitis cases may also rise. Future threats relate to heat waves and the impact on vulnerable populations (e.g., homeless, lower income, seniors, citizens with chronic illnesses). ‘Tower communities’ of people living in high rise apartments and condos may be at risk during power outages where windows cannot open, and air conditioning units cease to work. Urban development can exacerbate ‘urban heat islands’ if the emphasis continues to be on using concrete and pavement as opposed to green infrastructure.

As illustrated below (see Figure 10**)**, the number of hot days per year is expected to increase 5-fold by 2050 given the current global GHG emissions trajectory. A sample of the number of Heat Alerts and the number of Cold Alerts issued by the MLHU are illustrated (see Appendix E). This topic is discussed further in the next section on London’s Future Climate.

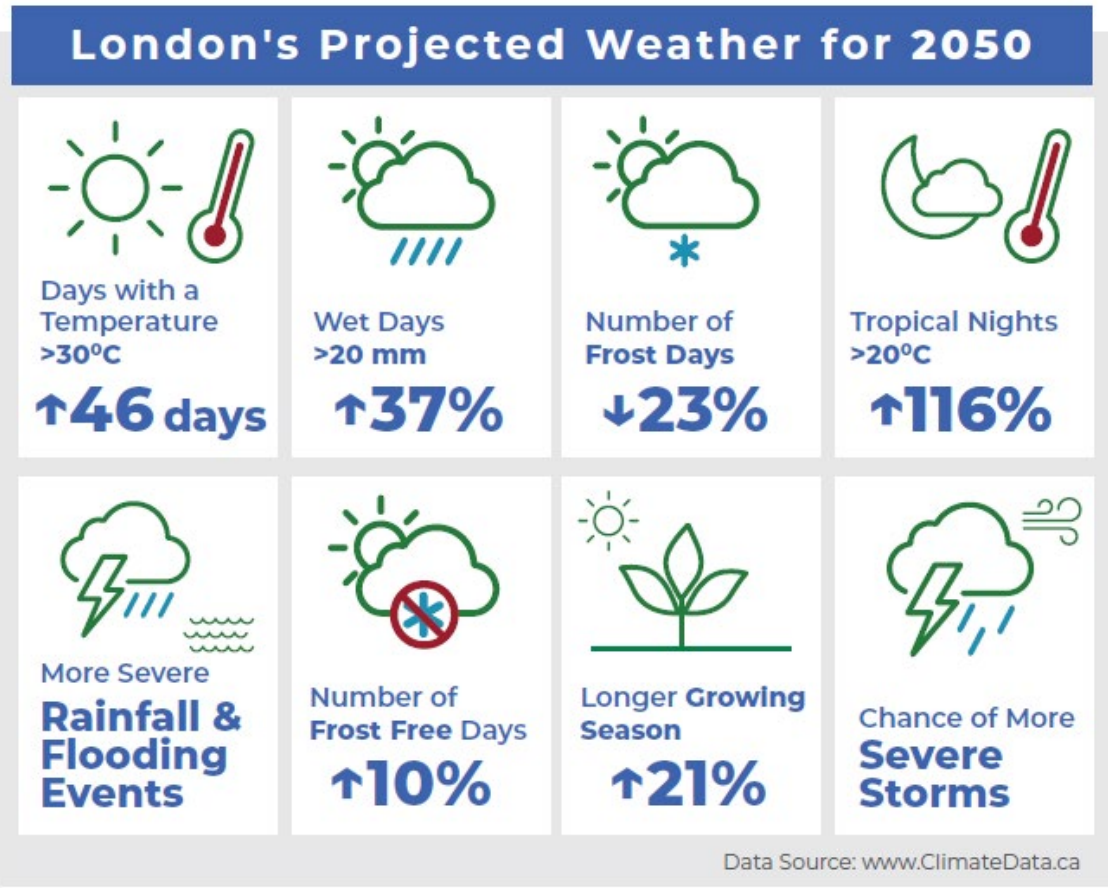
Figure 10: Increase in Very Hot Days for 2050



5. What Does London's Future Climate Look Like?

Elements of London's future climate in 2050 are described and visually represented in an infographic (see Figure 11) showing what 'warmer, wetter and wilder' might look like. It represents the future situation using RCP 8.5 emissions based on inaction to reducing GHG emissions locally, nationally and globally.

Figure 11: London's Projected Weather in 2050



This new environment with more heat, more precipitation and more extreme storms is also reflected in the projection data to 2050 and 2080 (see Table 2) for London. Note that the chart provides a side-by-side comparison of climate variables given the three GHG emissions scenarios; Low = low emissions, or 2.6 RCP; Mean = Moderate emissions or 4.6 RCP; and High = high emissions, or 8.5 RCP. Figure 11 uses the RCP 8.5 scenario to illustrate what London's future will be without aggressive global emissions reductions.

Table 2: London's High Carbon Climate Future

RCP 8.5: High Carbon climate future

GHG emissions continue to increase at current rates

Variable	Period	1976-2005	2021-2050			2051-2080		
		Mean	Low	Mean	High	Low	Mean	High
Precipitation (mm)	annual	938	810	995	1200	827	1022	1224
Precipitation (mm)	spring	232	177	256	348	185	270	366
Precipitation (mm)	summer	227	133	227	331	131	227	344
Precipitation (mm)	fall	254	169	263	371	164	262	376
Precipitation (mm)	winter	226	175	248	330	180	264	351
Mean Temperature (°C)	annual	8	8.8	10.1	11.4	10.7	12.2	13.7
Mean Temperature (°C)	spring	6.7	6.1	8.5	10.8	8.1	10.4	12.7
Mean Temperature (°C)	summer	19.8	20.5	21.9	23.4	22.2	24.1	25.9
Mean Temperature (°C)	fall	9.9	10.3	12.1	13.7	12.1	14	15.8
Mean Temperature (°C)	winter	-4.5	-4.8	-2.1	0.6	-2.6	0.2	2.9
Tropical Nights	annual	5	7	17	31	20	37	58
Very hot days (+30°C)	annual	12	15	33	52	34	61	86
Very cold days (-30°C)	annual	0	0	0	0	0	0	0
Date of Last Spring Frost	annual	May 2	April 1	April 20	May 9	March 19	April 10	April 30
Date of First Fall Frost	annual	Oct. 17	Oct. 12	Nov. 1	Nov. 22	Oct. 21	Nov. 13	Dec. 7
Frost-Free Season (days)	annual	165	162	191	222	181	214	245

6. Climate Projections Summary – London in 2050

Climate projections using the High Emissions Scenario (RCP 8.5) for London's future climate in 2050 indicate:

- precipitation projections for the period ending in 2050 suggest the overall mean increase by 6.08% with the majority of that increase occurring in Spring (10.34%) and Winter (9.73%) and the Fall realizing the smallest increase (3.54%).
- Historically, spring precipitation was the norm however projections indicate that winter precipitation (rain on snow) will be more common and have more harmful impacts (e.g., runoff) into the future.
- Temperature increases are expected in all seasons averaging 2 to 4 ºC
- Hot Days (days over 30 ºC) will increase from 14 to 60 days annually.
- Tropical nights (days with minimum temperature 20ºC +) will increase from 15 to 26 days annually.
- Subsequently, the frost-free period will be longer by an estimated 26 days.
- Tornado activity and wind downbursts as documented by the NTP, is on track to break new annual records in Ontario in 2021 (previous record was 42 tornados in Ontario) with several recent events in the London region (e.g., Parkhill, Ailsa Craig, Bayfield).
- The unpredictability of hurricanes will also be a future weather pattern to monitor as the Atlantic tropical storms become more frequent, more powerful and more sporadic in their travel path (historically the London region has experienced 14 storms originating as hurricanes).
- Thunderstorms with wind gusts and wind downdrafts severe enough to be documented in the Canadian Disaster Database have occurred in London in April 2000, June 2015 and July 2016 described as "Storms and Severe Thunderstorms"; the expectation is more in the future.
- Impacts on human health and vulnerable populations has previously been assessed and documented by the Middlesex London Health Unit in 2014; this

information will be used and updated to reflect the most recent data sources in the Climate Adaptation Strategy underway for London.

- Impacts on agriculture will vary depending on the sensitivity of the crop to climate changes and the agricultural commodity (e.g., maple syrup production may have a shortened or a more irregular season impacting the regular production outcomes shown in Figure 12 for a local London area syrup producer).

Figure 12: Tracking Maple Syrup Production Dates

In summary, a full understanding of these climatic impacts in London are needed to ensure adaptation measures are undertaken to make London more resilient to the current climate changes in addition to those projected to occur in 2050 and beyond. The work being undertaken in partnership with ICLEI Canada to prepare a Climate Adaptation Strategy for London in 2022 will provide additional details of weather projections. This strategy will incorporate a more fulsome discussion of impacts to the health of our citizens, our community and our environment. Adapting to a future climate that is warmer, wetter and wilder is our necessary goal.

7. Resources

The Health Costs of Climate Change
https://climatechoices.ca/wp-content/uploads/2021/06/ClimateChoices_Health-report_Final_June2021.pdf

Climate Atlas
https://climateatlas.ca/

Climate Data Canada
https://climatedata.ca/

Northern Tornado Project
https://westernu.maps.arcgis.com/apps/dashboards/19460b79cf24493680e5792f5247f46d

Canadian Disaster Database
https://www.publicsafety.gc.ca/cnt/rsrcs/cndn-dsstr-dtbs/index-en.aspx

City of London Risk Assessment Report – Climate Change Adaptation, 2014 (unpublished)

8. List of Appendices

Appendix A: Tornados in the London Region

Appendix B: Hurricanes in the London Region

Appendix C: Annual Residential Heating Degree Days and Cooling Degree Days

Appendix D: Infographic of London's Historic Natural Disasters

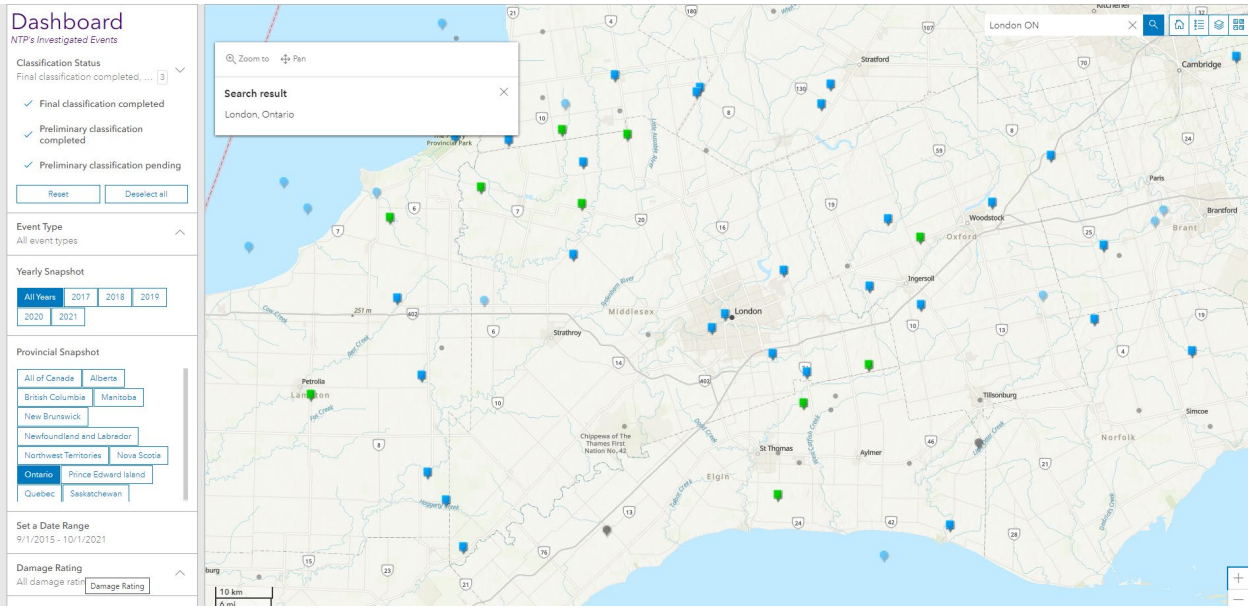
Appendix E: Heat and Cold Weather Alerts by Middlesex London Health Unit

Appendix A: Tornados in the London Region

Based on the open data resource of the Northern Tornado Project (NTP) administrated by Western University, there has been only tornados of type EF0 and EF1 detected for all past years since the NTP creation in 2017 in the approximate radius of 100km from London. Damage rating has 6 classifications of increasing intensity and damage from EF0 (default), EF0, EF1, EF2, EF3, to the most intense event being EF4.

Figure A.1 and Table A.1 illustrate the recorded events including tornados and downbursts of all past years in London and nearby areas and the rating system used. Overall, 4 main events were recorded for London specifically as described in the table.

Figure A.1: Tornado activity in the London Region



The above map shows past tornado events in London (approximate radius of 100km). Blue labels represent EF0 damage and green labels represent EF1 events, the least damaging tornados respectively based on the Tornado Damage Classification. The approach to classifying tornados is described below in Table A.1.

Table A.1: Tornado Activity in the London Area

	London Wind Event	Wind Damage Details
1	7/19/2020 1130hr Event Type: **Downburst** Event Summary Map Link: **(42.958,-81.288)** Rating: **ef0**	Tree damage reported in London following a storm passing through the area. Satellite imagery review did not reveal any visible damage. Event assessed as an EF0 downburst (estimated max. wind speed of 95 km/h).
2	8/27/2020 1500hr Event Type: **Downburst** Event Summary Map Link: **(42.979,-81.2605)** Rating: **ef0**	Tree damage reported at several locations in London following a storm passing through the area. Event assessed as EF0 downburst (estimated max. wind speed of 115 km/h). Satellite imagery review did not reveal any visible damage.
3	7/19/2020 1140hr Event Type: **Tornado (Over Land)** Event Summary Map Link: **(42.9186,-81.1624)**[1] Rating: **ef0**	Damage reported to structures and trees in the Belmont area. Ground and drone survey completed July 20, 2020. Damage assessed as EF0, with an estimated max. wind speed of 125 km/h, track length of 9.27 km and max. path width of 90 m. Tornado motion was from the WNW (approx. 300 degrees). Satellite imagery review did not reveal any visible damage.
4	*8/10/2021 1435hr* Event Type: **Tornado (Over Land)** Event Summary Map Link: **(43.0452,-81.1386)** [2] Rating: **ef0**	A tornado in northeast London was captured on video by several witnesses. An NTP ground survey was completed on August 11, 2021, discovering weak tree damage. Damage assessed as EF0 tornado, with an estimated max. wind speed of 115 km/h, track length of 4.30 km and max. path width of 20 m. Tornado motion was from the SW (approx. 225 degrees). Satellite imagery review did not reveal any visible damage.

[1] https://westernu.maps.arcgis.com/apps/opsdashboard/index.html#/ff188dcc47fa48c097b3a3a9ba77fb48

[2] https://ntpopendata-westernu.opendata.arcgis.com/apps/london-on-aug-10-2021-event-summary-map/explore

Note: Tornados include those that occur over land at any point during their lifetime with a severity rating of EF 0 to EF 4, lowest to highest severity. Downburst includes microbursts with a maximum diameter of 4 km or less

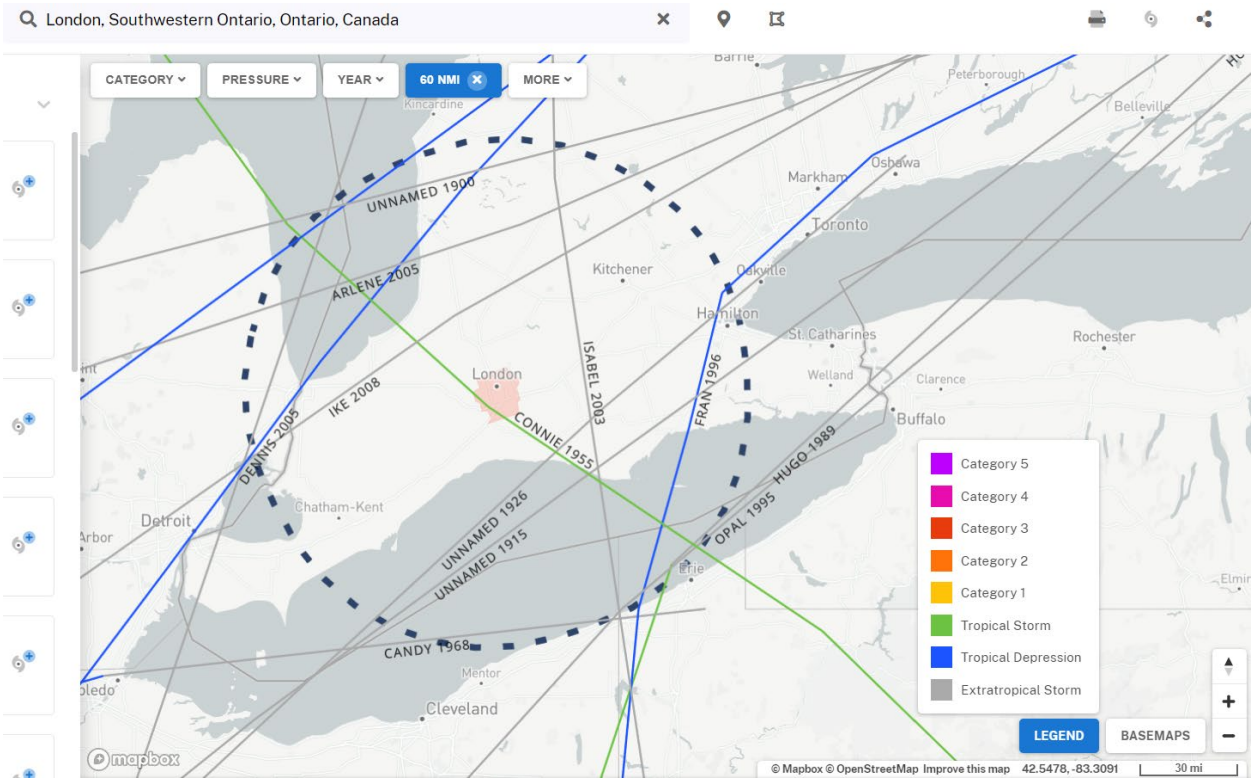
Appendix B: Hurricanes in the London Region

From the beginning of recorded hurricanes in the 1900's, London and region has experienced 14 storm that originated as hurricanes in the Atlantic Ocean and migrated across southwestern Ontario. The location of the tracking lines is illustrated below (Figure B.1). The 5 strongest hurricanes (in order of strength from strongest to weakest) that then slowly degraded to become storms to reach the London area are illustrated in subsequent figures (B.3 to B.6). These storms that traversed southwestern Ontario included tropical storms, tropical depressions, and extratropical storms which are listed in descending order of severity.

Note: the practice of naming hurricanes started in 1954 therefore several unnamed storms are shown below.

Source: NOAA Historical Hurricane Tracks

Figure B.1: Map of southwest Ontario illustrating hurricane storm tracks

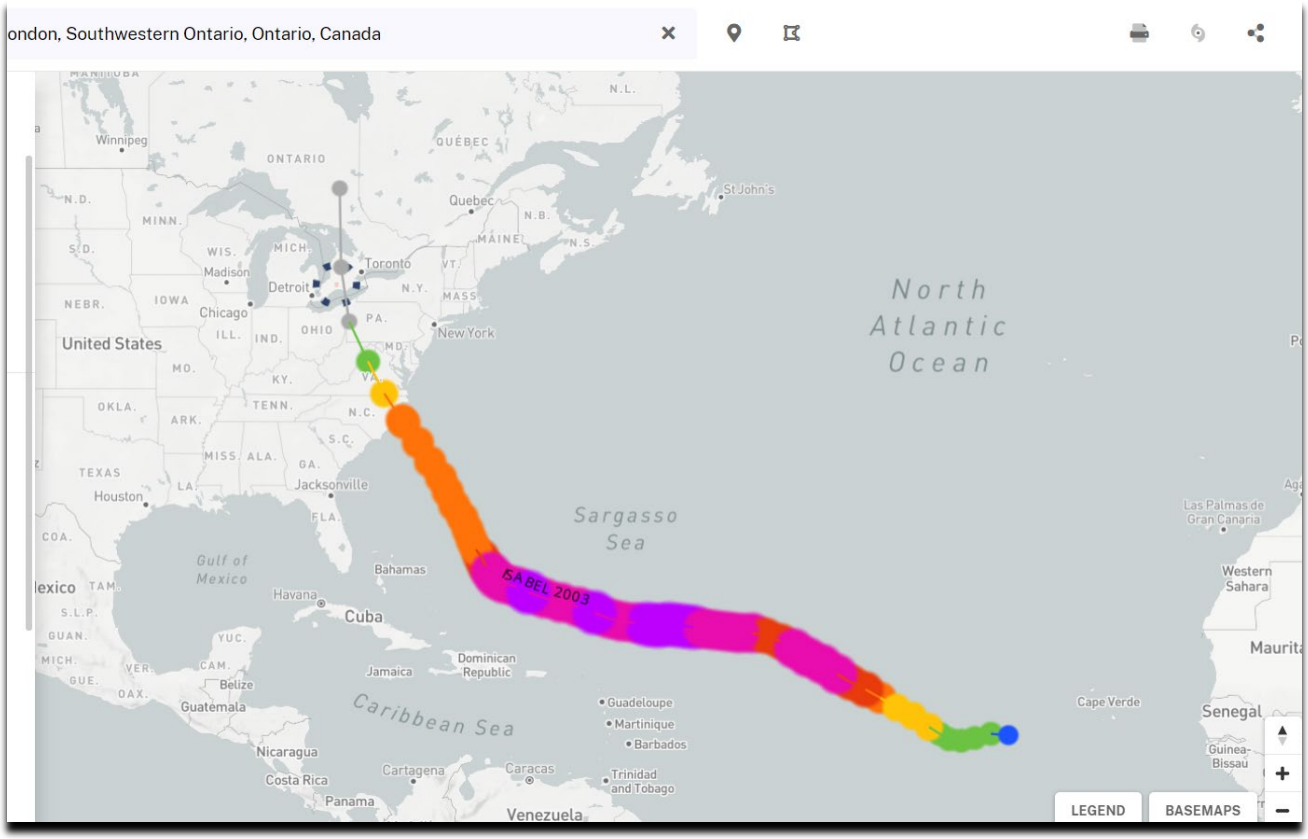


Isabel 2003

Overall Details –Its path (shown in the illustration below) did not follow the usual route through the Gulf of Mexico rather making landfall Sept 18, 2003 near Beaufort, North Carolina as a Category 2 storm with wind speeds of 90 knots (166 km/hr).

London Details – It reached southwest Ontario the next day on Sept 19, 2003 passing through Woodstock as an extratropical storm with wind speeds of 13 knots (24 km/hr) and continued north across Georgian Bay. Note: the colour sequence represents the changing category of the storm and related wind speeds.

Figure B.2: the route of Hurricane Isabel

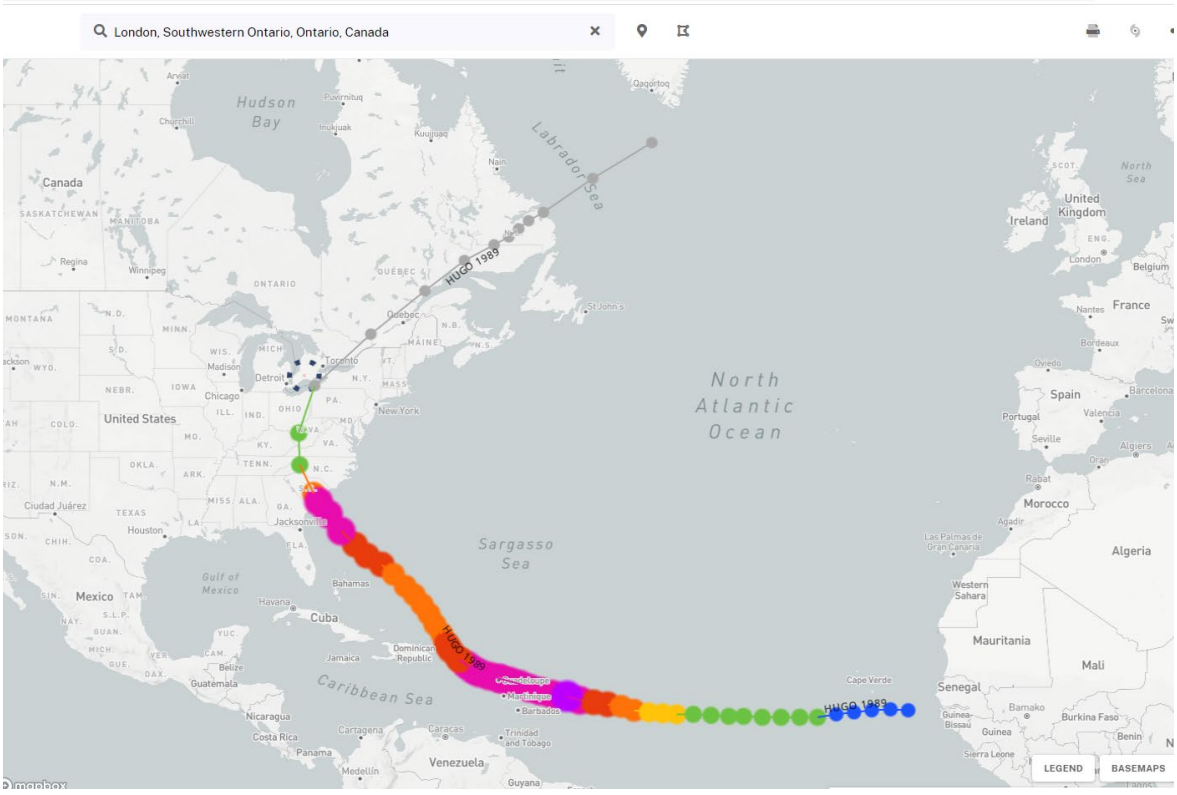


Hugo 1989

Overall Details – Hurricane Hugo originated off the coast of Africa and its life spanned 12 days from September 10 to September 22, 1989. Hugo curved through the Tropical Atlantic and then left a path of death and destruction across the islands of the northeastern Caribbean and over portions of the Carolinas. Charleston, South Carolina reported winds of 117 knots (217 km/hr) and a 1.5 metre tidal surge that flooded much of the town. In the town of McClellanville, South Carolina, a tidal surge of 5.1 metres was reported. The storm then moved north into Canada paralleling the St. Lawrence River and crossing Labrador and continuing northeastward across the far Northern Atlantic Ocean.

London Details - By September 23rd, Hugo had transformed into an extratropical storm. Hugo was tracked for two more days as it moved northeastward across the eastern end of Lake Erie, Lake Ontario and exiting eastern Canada into the far north of the Atlantic Ocean. The Maritime provinces received strong winds as a result of Hurricane Hugo.[3]

Figure B3: the route of Hurricane Hugo



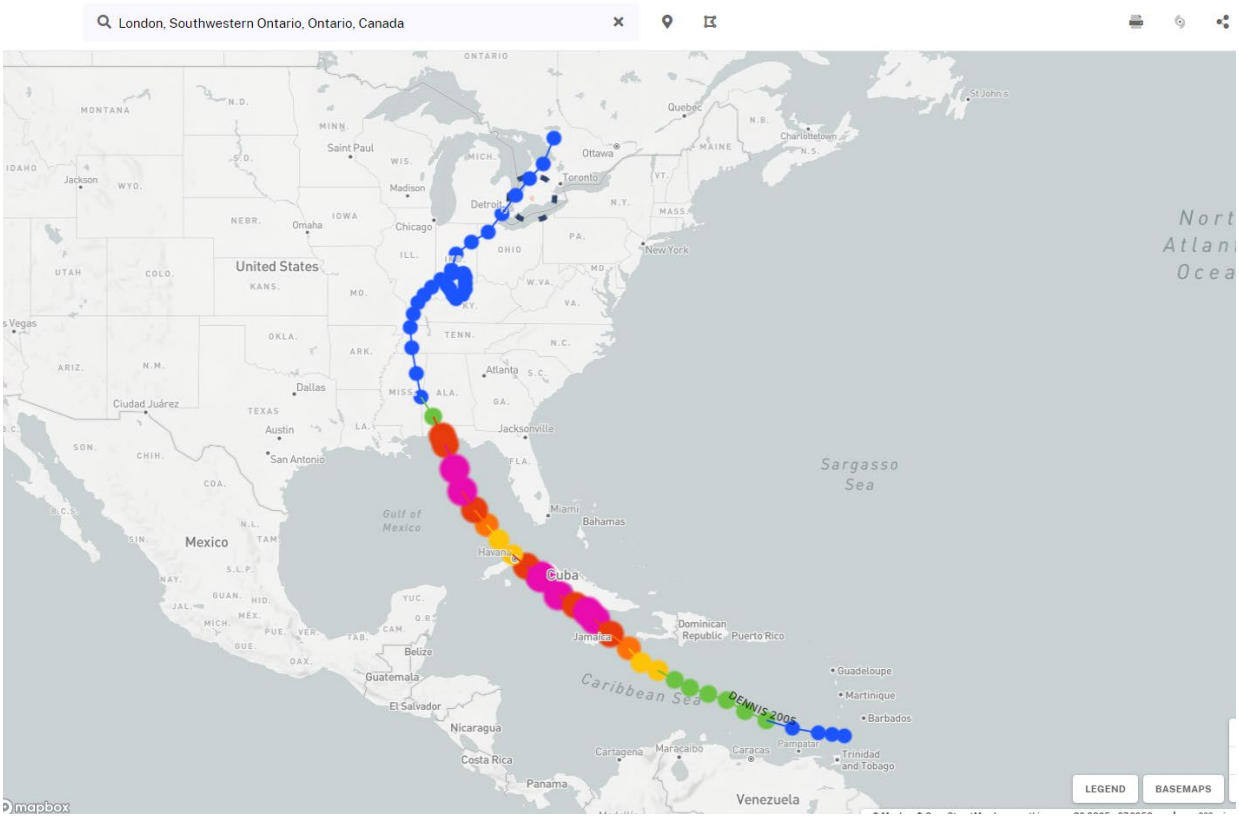
[3] https://www.ec.gc.ca/ouragans-hurricanes/default.asp?lang=en&n=B2E8BC2A-1

Dennis 2005

Overall Details – Hurricane Dennis originated in the Caribbean on July 4 and made landfall at Pensacola Florida on July 10 as a Category 3 hurricane with wind speeds of 105 knots (195 km/hr). It travelled north reaching Sarnia on July 17 with wind speeds of 10 knots (18 km/hr).

London Details – The storm entered Canada at Sarnia as a Tropical Depression travelling northeastern crossing through Goderich, the Bruce Peninsula and Georgian Bay to diminish near North Bay on July 18.

Figure B4: the route of Hurricane Dennis

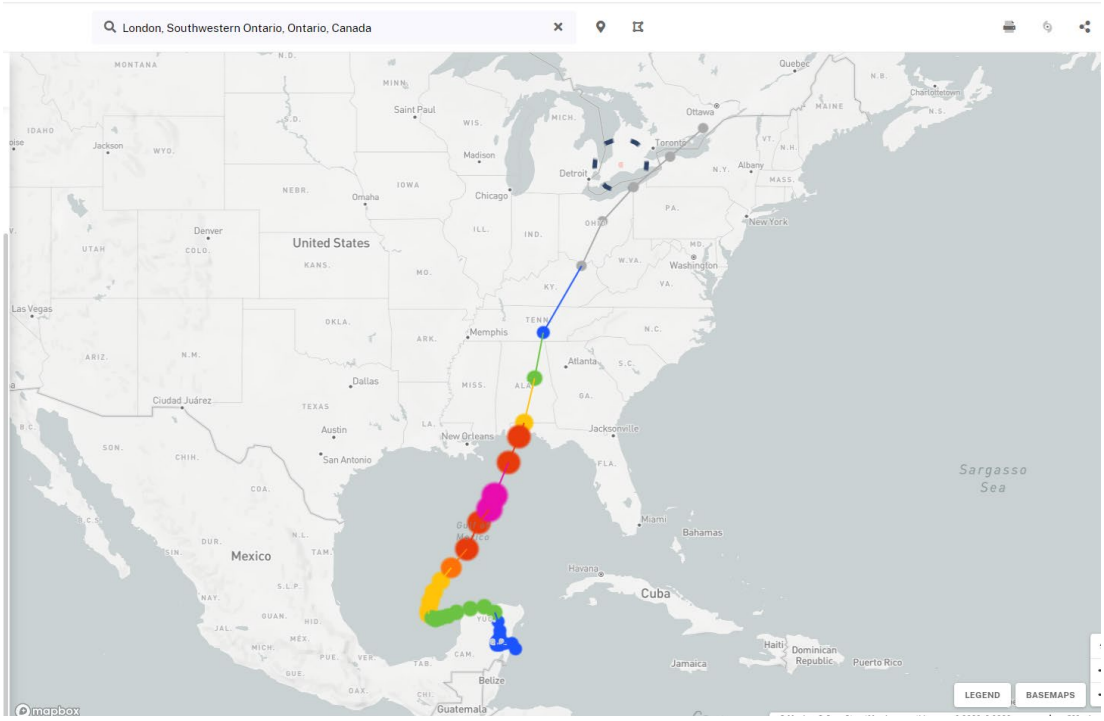


Opal 1995

Overall Details - Opal originated from a tropical wave that emerged from the east coast of the Yucatan Peninsula, Central America on September 27. Starting as a tropical depression, Opal strengthened rapidly after moving north across the Gulf of Mexico reaching land October 4 at Pensacola, Florida as a Category 3 storm with winds reaching 100 knots (185 km/h). Moving inland, it become a tropical depression over Tennessee and declared extratropical it moved northeastward over the Ohio Valley and eastern Great Lakes into southwestern Quebec with winds of 40 knots (74 km/h).

London Details - With heavy rain and strong winds forecast to affect southern Ontario and Quebec, the Canadian Hurricane Centre issued a Hurricane Information Statement on October 5 to advise the Canadian public on Opal, while clearly stressing a much-weakened system. The Canadian Hurricane Centre issued another such bulletin the following morning, but since Opal entered the Canadian Hurricane Centre responsibility area as an extratropical storm, no Prognostic bulletins were needed. [4]

Figure B5: the route of Hurricane Opal



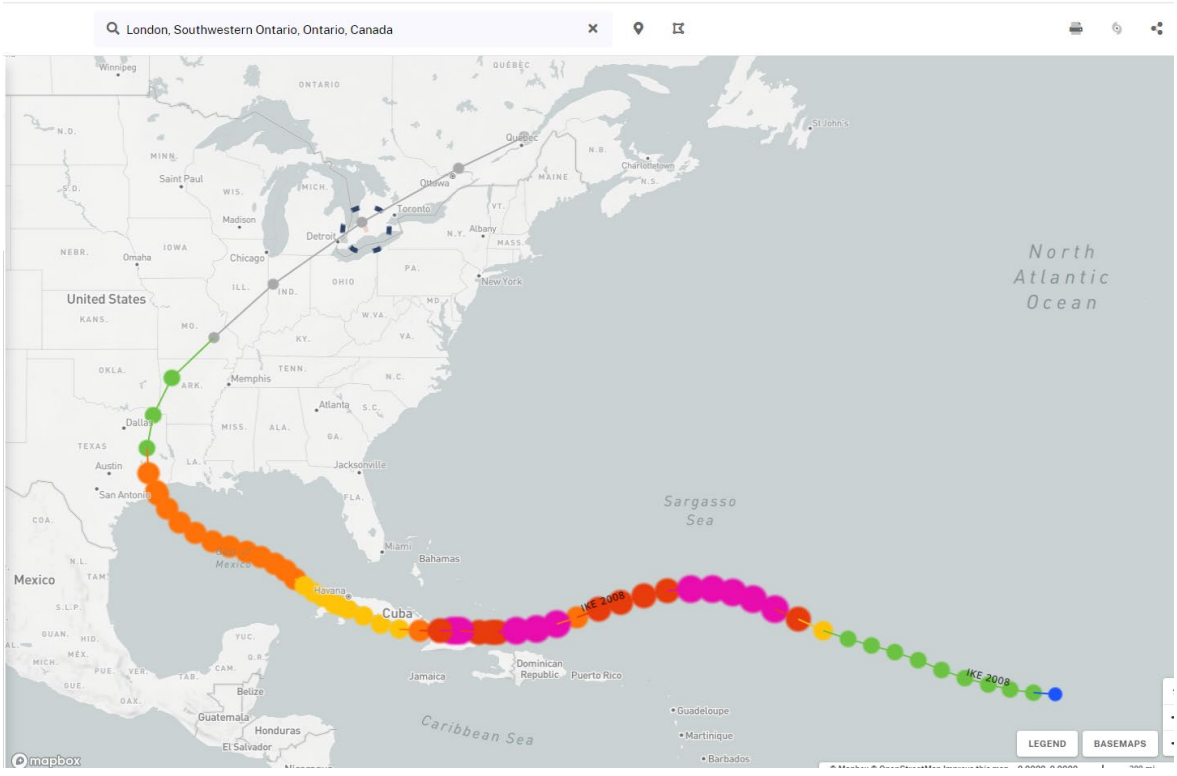
[4] https://www.ec.gc.ca/ouragans-hurricanes/default.asp?lang=en&n=64F88A79-1

Ike 2008

Overall Details – This hurricane started in North Atlantic Ocean off the east coast of Africa on September 1, 2008 and quickly became a Category 4 storm with wind speeds reaching 125 knots (232 km/h). After wreaking destruction in Haiti and Cuba, large Category 2 Hurricane Ike made landfall in the early morning hours of Saturday, September 13 at Galveston Texas. The remnant hurricane exited into the Atlantic 72 hours later, after weakening to a still-potent post-tropical storm following an accelerated track through Ontario, Quebec and Atlantic Canada.

London Details – Ike passed north of London near Exeter on September 15, 13 days after it made landfall. Post-tropical Storm Ike brought record-breaking rainfalls to some localities in eastern Canada as well as storm-force winds gusting to more than 100 km/h. Maximum rainfalls of more than 60 mm were reported in Ontario, Quebec and Labrador as Post-tropical Storm Ike tracked east northeastward. Numerous locations reported rain of 50 mm or greater in less than six hours. The heavy rain passed north of the Maritimes.

Figure B6: the route of Hurricane Ike



Appendix C: Annual Residential Heating Degree Days and Cooling Degree Days

Cooling Degree Days (CDDs)

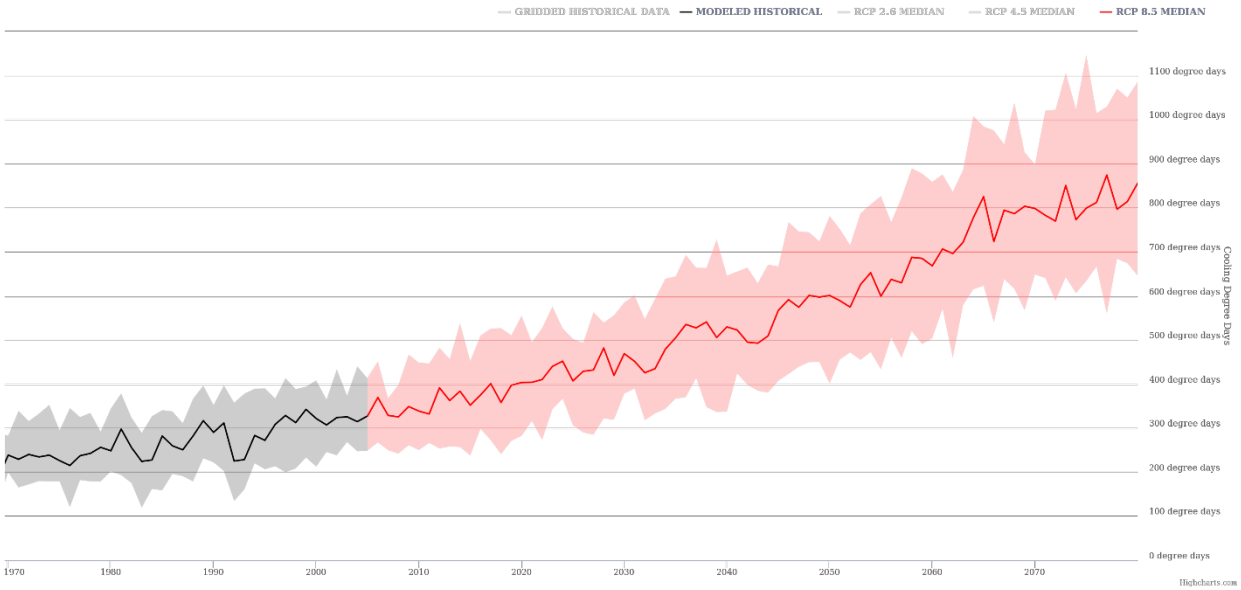
Cooling degree days (CDDs) give an indication of the amount of space cooling, i.e., air conditioning, that may be required to maintain comfortable conditions in a building during warmer months. The number of degree days accumulated above 18°C in the selected time period. [5]

Cooling Degree Days (CDD) are **equal to the number of degrees Celsius** a given day's mean temperature is above 18 °C. For example, if the daily mean temperature is 21 °C, the CDD value for that day is equal to 3 °C. If the daily mean temperature is below 18 °C, the CDD value for that day is set to zero. [6]

[5] https://climatedata.ca/explore/location/?loc=FCAEN&location-select-temperature=tx_max&location-select-precipitation=rx1day&location-select-other=cddcold_18

[6] https://climateatlas.ca/map/canada/cooldd_2060_85#z=8&lat=44.02&lng=-80.46&city=452

Figure C.1: The number of Cooling Degree Days from 1970 to 2080 with RCP 8.5 in London.



Error! Reference source not found.C.1 illustrates the number of Cooling Degree Days from 1970 to 2080. The data was provided by ClimateData and RCP 8.5 was chosen. As it is shown, the number days which space cooling is required has substantially increased from 1970 and will follow the same trend for future years. The average Cooling Degree Days for the time span of 1976-2005 and 2051-2080 are respectively 281 and 747. It suggests 466 (or 166%) increase in Cooling Degree Days in London.

Heating Degree Days (HDDs)

Heating degree days (HDDs) give an indication of the amount of space heating (e.g., from a gas boiler/furnace, baseboard electric heating or fireplace) that may be required to maintain comfortable conditions inside a building during cooler months. The number of degree days accumulated below 17°C in the selected time period. Threshold values may vary, but 17°C or 18°C are commonly used in Canada. Larger HDD values indicate a greater need for space heating. [7]

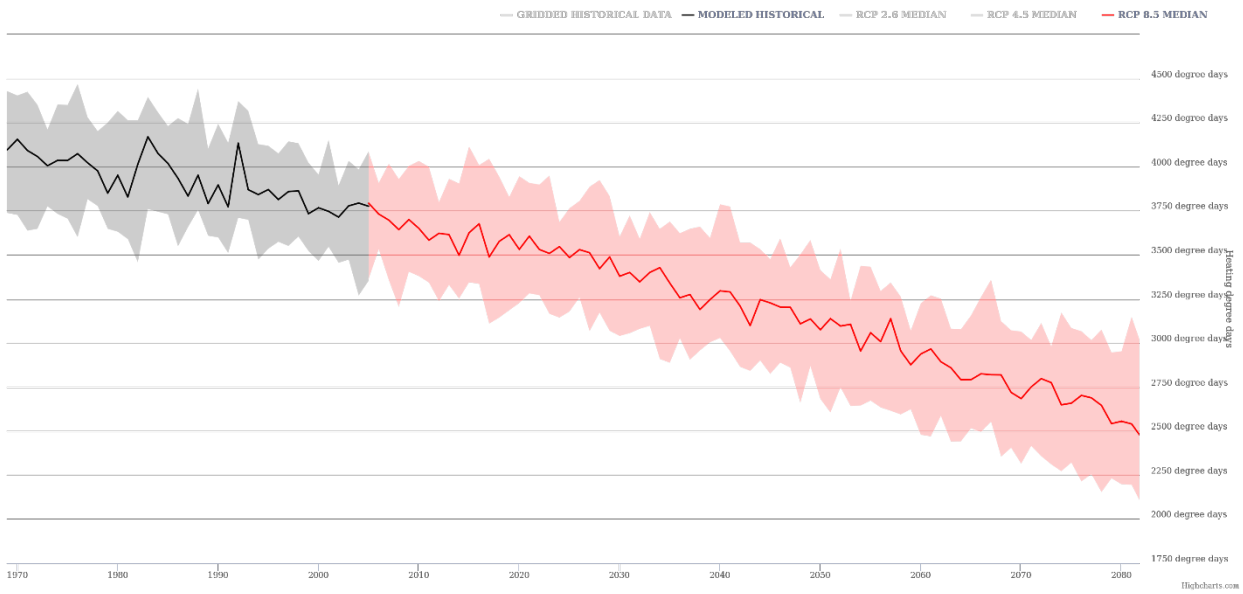
Heating Degree Days (HDD) are equal to the number of degrees Celsius a given day's mean temperature is below 18 °C. For example, if the daily mean temperature is 12 °C, the HDD value for that day is equal to 6 °C. If the daily mean temperature is above 18 °C, the HDD value for that day is set to zero. [8]

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[7] https://climatedata.ca/explore/location/?loc=FCAEN&location-select-temperature=tx_max&location-select-precipitation=rx1day&location-select-other=hddheat_18

[8] https://climateatlas.ca/map/canada/hdd_2060_85#:~:text=Heating%20Degree%20Days%20(HDD)%20are,day%20is%20set%20to%20zero.

Figure C.2: The number of Heating Degree Days from 1970 to 2080 with RCP 8.5 in London

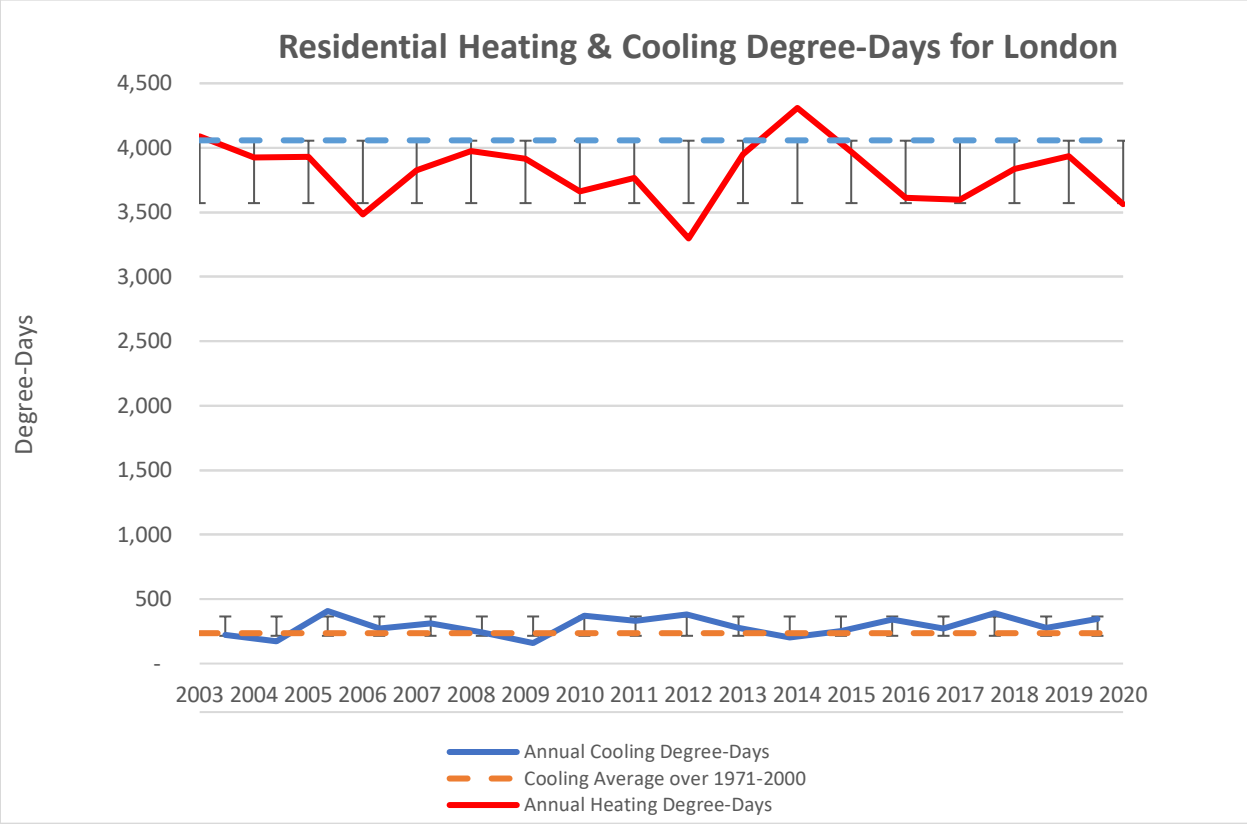


As shown in **Error! Reference source not found.**C.2 the number the number of Degree Days where heating is required has significantly decreased from 1970 in London and will continue with the same trend for future years considering RCP 8.5. For the time period of 1976-2005, 3,914 Heating Degree Days was calculated whereas this number for time span of 2051-2080 is 2,855 that suggests 1,059 Degree Days (or 37%) decrease in HDDs or on average 2.9 °C less heating per day will be needed in future.

Table C.1: The annual residential Heating Degree Days (HDDs) and Cooling Degree-Days (CDDs) in London from 2003 to 2020

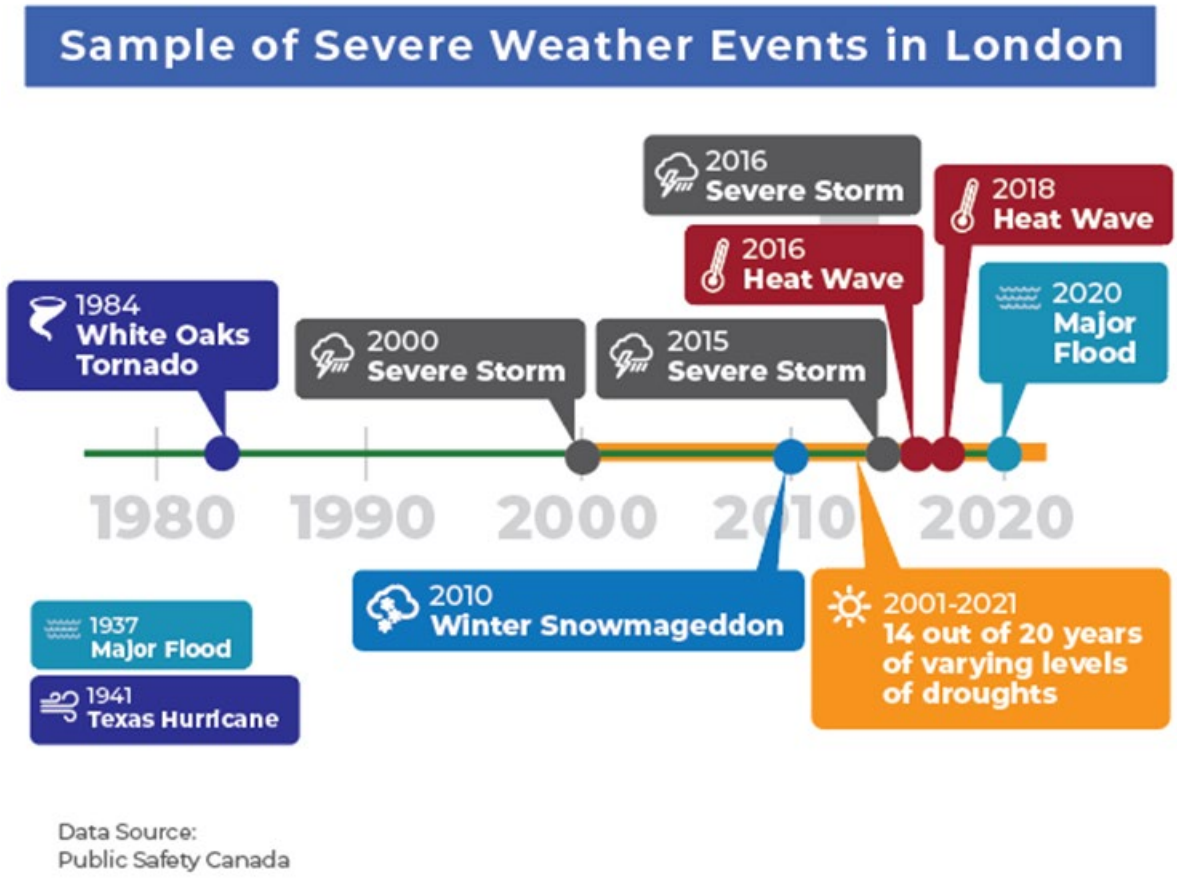
Year	Annual Heating Degree-Days	Annual Cooling Degree-Days
2003	1%	-6%
2004	-3%	-27%
2005	-3%	73%
2006	-14%	16%
2007	-6%	32%
2008	-2%	2%
2009	-4%	-33%
2010	-10%	57%
2011	-7%	40%
2012	-19%	62%
2013	-3%	17%
2014	6%	-15%
2015	-2%	8%
2016	-11%	46%
2017	-11%	15%
2018	-5%	66%
2019	-3%	17%
2020	-12%	47%

Figure C.3: The residential Heating and Cooling Degree-Days in London from 2003 to 2020



Heating degree day (HDD) is a measurement tool used to estimate energy demand needed to heat a home or business. A similar measurement, cooling degree day (CDD), reflects the amount of energy used to cool a home or business. It is based on the average outdoor air temperature over an entire day. The heating needs for a home or a building are generally directly proportional to the number of HDD at that location. A typical winter month would have about 700 HDDs in London. Environment Canada produces Climate Normal data ranges over a historic 30-year period. Over the last 10 years, most winters and summers have been warmer than they were over the 1971-2000 period. Using this data, it can be assumed that, over the last 10 years, building heating needs were about four per cent lower than they would have been back in the 1971-2000 period, and that air conditioning needs were 22 per cent higher. [9]

Appendix D: Sample of Severe Weather Events in London



Data Source:
Public Safety Canada

Appendix E: Heat and Cold Weather Alerts by Middlesex London Health Unit

Extreme Cold [10]

Each winter, London and Middlesex County can experience periods of extreme cold. The Middlesex-London Health Unit issues ‘Cold Alerts’ when any of the following conditions are met:

- Environment Canada forecasts a low temperature of –15°C or lower;
- Environment Canada forecasts a wind chill of -20 or lower, or if
- Environment Canada issues a "Cold Alert" or "Cold Warning."

Table E.1 indicates the total number of cold advisories per year and the number of days which a cold advisory was issued from 2005 to 2014.

Table E.1: Historical overview of cold advisory alerts in Middlesex-London, 2005-2014.

[10] https://www.healthunit.com/extreme-cold

Year	# of Cold Advisories	Total # of Days with Cold Advisory
2014	6	38
2013	1	3
2012	0	0
2011	7	17
2010	1	3
2009	8	20
2008	5	11
2007	6	12
2006	1	3
2005	5	9

ource: MLHU, 2012a

Table E.1 illustrates the variability in the number of days with cold advisory during this time period with an average of 11.6 days / year. Extreme cold weather can be a reflection of several climate change related, meteorological shifts associated with the jet stream and global weather patterns (e.g., polar vortex). These cold conditions can cause health threats to Londoners, especially vulnerable population such as children and older adults. Wind impacts are projected to be more critical to cold weather events with wind chill becoming more severe.

According to Environment Canada, the alerting parameter for issuing an Extreme Cold Warning in South-central and Southwestern Ontario is when the temperature or wind chill is expected to reach minus 30°C for at least two hours.

Extreme Heat [11]

Each summer, London and Middlesex County can experience periods of extreme heat. The Middlesex-London Health Unit issues the following when one or more of the criteria are met:

Heat Alert

- Environment Canada issues a forecast indicating a daily maximum temperature (Tmax) of 31°C or higher, or
- Environment Canada issues a forecast indicating a daily Humidex of 40 or higher.

[11] https://www.healthunit.com/extreme-heat

Heat Warning

- Environment Canada issues when 2 or more consecutive days of daytime maximum temperatures are expected to reach 31°C or warmer and nighttime minimum temperatures are expected to fall to 21°C or warmer, or
- Environment Canada issues when 2 or more consecutive days of humidex values are expected to reach 42°C or higher.

Extended Heat Warning

- Environment Canada issues a forecast indicating a daily Tmax of 31°C or higher with a Tmin of 20°C or higher for duration of three consecutive days or longer, or
- Environment Canada issues a forecast indicating daily Humidex of 40 or higher for a duration of three consecutive days or longer.[12]

The following (Table E.2) illustrates the total number of days which an extreme heat was recorded in London and a warning was issued, from 2005 to 2013:

Table E.2: Overview of recent heat alerts in Middlesex-London, 2005-2013

Year	# of Heat Alerts	# of Days with Heat Alerts
2013	3	10
2012	8	12
2011	3	11
2010	3	8
2009	2	2
2008	0	0
2007	3	7
2006	3	5
2005	4	11

Source: MLHU, 2012a

[12] Note that Tmax is the maximum temperature and Tmin is the minimum temperature in a forecast.

According to the "*Assessment of Health Vulnerabilities to the Health Impacts of Climate Change in Middlesex-London*" report, despite the increase in the number of hot days, (on average 6.6 days / year) there has not been a significant increase in the number of heat alerts called in London during this time frame (on average 3/year). [13]

Alert, Advisory, and Warning

Alert is a transmitted signal used to heighten awareness and/or initiate preparation for action. Alerts are issued by Environment and Climate Change Canada's Meteorological Service (MSC) for weather or environmental hazard events that are either occurring, imminent, or forecast to develop. Alerts are currently issued as special weather statements, advisories, watches and warnings.

Advisory is a type of alert from Environment and Climate Change Canada's Meteorological Service (MSC), where a certain weather or environmental hazard (for example air quality and tsunami) is either occurring, imminent or is expected to occur.

Warning is a type of alert issued by Environment and Climate Change Canada's Meteorological Service (MSC), where a hazardous weather or environmental event that poses a significant threat to public safety and property is certain or imminent.[14]

Watch is a type of alert issued by Environment and Climate Change Canada's Meteorological Service (MSC), where conditions are favourable for the development of weather or an environmental hazard that poses a significant threat to public safety and property, but the occurrence, location, and/or timing of the expected hazardous condition(s) is still too uncertain to issue a warning. It is intended to heighten public awareness of the potential impact of the event and serves as a lead-up to a warning.

[13] file:///C:/Users/hoghabi/Downloads/assessment-of-vulnerability-to-the-health-impacts-of-climate-change-in-middlesex-london.pdf

[14] https://www.canada.ca/en/environment-climate-change/services/weather-general-tools-resources/glossary.html#wsglossaryA