Appendix D:
Precipitation trends in Ontario

Abstract

Floods are now the most-costly type of natural disaster in Canada.

In recent years, the frequency and severity of floods have increased across Canada. These flood events are often associated with spring snowmelt, rain-on-snow, long-duration heavy precipitation events or short-duration intense storms. Climate change makes these events more likely; land use change associated with urbanization worsens the consequences.

In Ontario, and across Canada, these flood events have caused substantial damage, including financial losses, damage to infrastructure, reduced crop productivity, and even loss of human life. Notable and costly extreme flood events have occurred in recent years in the cities of Brampton, Burlington, Etobicoke, Hamilton, Mississauga, Muskoka, North Bay, Ottawa, Peterborough, Parry Sound, Thunder Bay, Toronto, Wawa, and Windsor.

Changes to Ontario’s rainfall patterns under global warming are expected to not only increase the risk of flooding, but also the risk of droughts. The potential cost associated with too much or too little precipitation in Ontario highlights the importance of understanding the characteristics, patterns and trends of precipitation in Ontario.
Climate change makes these events more likely; land use change worsens the consequences.

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We know that more climate disruption is coming to Ontario, but how much is already here?

Precipitation is one the hardest parameters to measure. In the search for this answer, precipitation is one of the most important parameters to measure. Changes in rainfall or precipitation affect a wide range of natural processes and human activities. However, precipitation is also one the hardest parameters to measure. Unlike temperature, rainfall is not spatially uniform. Most rainfall events occur as short, isolated and localized events, and their characteristics (intensity, duration, frequency) vary over space and time – making long-term trend analysis a challenge. Precipitation also occurs in many forms (liquid, solid and a mixture of both, such as freezing rain).

To really understand changes in precipitation, scientists need long-term, continuous data sets with good spatial coverage across the country. Ontario does not yet have these. In fact, Canada’s precipitation monitoring network has been significantly reduced since budget cuts beginning in the 1990s reduced the number of observational stations across the country (see Figure D.1). Spatial coverage of climate stations is also uneven, with relatively few stations in northern Canada (see Figure D.2).

**Figure D.1.** The decline of the manual station network across Canada, with a minimum criteria of 20 years of valid observations. Source: Mekis et al., 2018. Environment and Climate Change Canada (2018).

**Figure D.2.** Locations of the 1,735 surface weather stations across Canada with a Needs Index map in the background as of September 2016. Source: Mekis et al., 2018. Environment and Climate Change Canada (2018).
**D1.1 Annual rainfall is up**

Environment and Climate Change Canada’s (ECCC) available data shows that overall precipitation has increased across Canada over a 60-year time period (1950-2009); however, the changes vary across regions and over time (see Figure D.3). In Ontario, the greatest increases in precipitation (up to 50%, especially during the spring) have occurred in northwestern Ontario (e.g., near Thunder Bay), although southern Ontario has also experienced significant increases. At most stations, snowfall has decreased, especially in western Canada and from Ontario to the Maritimes. Only in southern Ontario, near the Great Lakes snow belt, has winter snowfall significantly increased by 10-30%.

Note: this data is based on a limited number of stations. Work is currently underway at ECCC to improve the quality and reduce the uncertainties in the data.

![Annual rainfall and snowfall trends](image)

**Figure D.3.** Annual total rainfall and snowfall trends for 1950-2009 (compared to the average baseline period of 1961-1990). Upward- and downward-pointing triangles indicate positive and negative trends, respectively. Filled triangles correspond to trends significant at the 5% level. The size of the triangle is proportional to the magnitude of the trend. The legend may not include all sizes shown in the figure.

Source: Mekis and Vincent, 2011.

**D1.2 Extreme events are hard to capture**

Basic physics tells us that climate change will mean more extreme precipitation (high rainfall intensity and or duration). In general, warmer temperatures drive higher evaporation rates of surface water, and increase the amount of moisture that the air can hold. Every degree Celsius that the temperature rises, the air is able to hold (and drop) 7% more moisture, making storms more intense and severe. Overall, global warming will intensify the global hydrological cycle, leading to an increasing intensity of both wet and dry extremes and, by extension, associated hazards such as floods and droughts.

Changes in extreme precipitation events are of particular concern for adaptation and infrastructure planning, especially in light of increased flood damages across Ontario. The spring 2017 flood events in Ontario and Quebec alone resulted in $223 million in insured damage. However, ECCC does not have good data on such events.
Extreme precipitation events have the highest spatial variability of all rainfall events. By definition, these events are rare – making analysis of changes in extreme events challenging. A much denser rainfall monitoring network would be required to accurately capture such extremes and estimate the expected frequency of such events (the return period). Long-term data records (minimum of 10 years) are also required to detect and evaluate trends in extremes. In Ontario, short-duration (2 hour or less), high-intensity rainfall events, are particularly poorly sampled by stations due to the issues mentioned above regarding the current observation network, and small spatial scale and variability of the storms. For example, much flooding is caused by small convective storms that may be no more than 10 kilometres across, while weather monitoring stations may be hundreds of kilometres apart.

With respect to extreme precipitation in Canada, ECCC reports that due to the localized nature of extreme events and poor station density, it cannot yet reliably detect any regional pattern. To further assess this issue, the ECO examined whether some well-documented extreme storms in the Greater Toronto and Hamilton area were accurately measured by ECCC’s network of monitoring stations.

**D1.3 Storms are being missed by monitoring network**

Table D.1 and Figure D.4 below summarize a series of nine extreme rainfall events in the Greater Toronto and Hamilton area. Only the 2013 Toronto storm was accurately measured by the ECCC network. The intensity of the eight other events were missed or under-represented.
As shown in Table D.1, ECCC networks missed the most extreme rainfall during the major Burlington storm of August 2014, which flooded approximately 6,000 properties. ECCC stations, identified by triangles, are not near the maximum area of rainfall (see Figure D.5).

Figure D.5. August 4, 2014 storm event analysis. No ECCC stations would have captured this event.

Thus, we cannot expect the current monitoring network to accurately reflect the extreme precipitation events that are occurring in Ontario.

Many U.S. studies show statistically significant increasing trends in rainfall extremes, particularly in the states directly bordering southern Ontario (see Figure D.6). In particular, the largest increases in the frequency and intensity of daily precipitation events from 1958 to 2016 have been observed in the Midwest (42%) and Northeast U.S. (55%). The ECO knows of no reason why these trends in annual precipitation would create discontinuities at the international border. It seems more plausible that the reported discrepancies at the border are due to Canada’s much weaker observation network.

Figure D.6. NASA ‘Land Data Assimilation System’ accumulated annual precipitation data for (a) 2012 and (b) 2002. Note significant discontinuities across the Canada/U.S. border as highlighted.
Source: Gronewold et al. (2018).

D2 Insights from across the border

American states, just across the border, have a much greater density of weather observation stations than Ontario does, and are therefore likely to have better data on recent climate extremes.
As temperatures continue to rise, global warming is expected to intensify the global hydrological cycle, leading to an increasing intensity of both wet and dry extremes and, by extension, associated hazards such as floods and droughts.

Further insight into the future of precipitation in Ontario have been provided by climate models.

Figure D.7 presents the projected changes in Ontario’s precipitation for two time periods, 2050s (2041–2070) and 2080s (2071–2100) under three climate scenarios. The three scenarios (known as Representative Concentration Pathways or RCP 2.6, 4.5, and 8.5) are adopted from the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. The RCPs represents a range of possible changes (i.e., scenarios) in future GHG emissions. Based on the results of these models, it is likely that the entire province will experience changes in total precipitation under all three scenarios. Overall increases of up to 180 mm of precipitation annually may occur in Ontario by the 2080s. Across the province, more precipitation is projected in the winter, though this could vary greatly by region (the provincial range is from -4 mm to 70 mm relative to historical levels), and much of this will be rain, not snow. Summers are projected to be drier on average (the provincial range is from -50 mm to 40 mm relative to historical levels) by the 2080s. These changes will have multiple impacts, including on water supplies, agriculture, natural resources, stormwater, flooding, and infrastructure.

Figure D.7. Projected changes in total annual precipitation in Ontario from 1971–2000 baseline values for representative concentration pathways (RCP) 2.6, 4.5, and 8.5 over three 30-year time frames (2011–2040, 2041–2070, and 2071–2100). RCP 2.6 reflects significantly reduced global emissions; RCP 4.5 reflects a moderate reduction in global emissions; RCP 8.5 is the business as usual scenario with no emission reductions. Data are derived from the composite AR5 model and statistically downscaled for the province. The three primary watersheds in Ontario are delineated on the map.

Source: Ministry of Natural Resources and Forestry (2015)
Better data and better analysis will help scientists make more accurate predictions of long-term climate trends (i.e., long-term annual and seasonal changes from normal/baseline).

**D4  Flooding in Ontario: not just due to climate change**

Climate change is not the only factor leading to increased costs from flood damage in Ontario. Land use changes also have a significant impact on flooding. In forests, little rainfall runs off as stormwater due to high rates of infiltration (i.e., absorbent soils, trees, and other vegetation) and evapotranspiration. In these natural areas, on average, only 10% of total rainfall becomes runoff. In contrast, 55% of the rain that falls in highly urbanized areas (i.e., paved ground) becomes runoff. Runoff flows reach peak levels quicker, occur at higher levels and last longer, often overwhelming stormwater infrastructure. Flood losses can also increase due to the increased prevalence of finished basements that contain electronics, appliances and other valuables. Substantial underfunding of municipal stormwater management is also contributing to flood losses.

The continuing loss of wetlands in southern Ontario further worsens flood losses. Researchers at the University of Waterloo’s Intact Centre on Climate Adaptation found that in the event of a major storm, the financial costs of flooding in rural and urban areas would be 29% and 38% lower, respectively, if wetlands were kept in their natural state versus being lost due to development. In southern Ontario, at least 72% of the original wetlands have been lost to development (e.g., agriculture, urban sprawl and other land conversion).