TEAM GREEN ANALYTICS

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OCCIAR
Ontario Centre for Climate Impacts and Adaptation Resources

The Economic Impacts
OF THE WEATHER EFFECTS OF CLIMATE CHANGE ON COMMUNITIES

FINAL REPORT

Date:
May 8, 2015

Submitted to:
Insurance Bureau of Canada | Bureau D'Assurance Du Canada

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Acknowledgments

The study was made possible with the support of the Insurance Bureau of Canada and Natural Resources Canada and the Adaptation Platform Economics Working Group. The project team would like to acknowledge the contribution of community liaisons and advisory groups from the City of Mississauga and the Halifax Regional Municipality in addition to the excellent feedback provided by the external advisors.

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Executive Summary

Green Analytics and the Ontario Centre for Climate Change Impacts and Adaptation Resources were commissioned by the Insurance Bureau of Canada, with support from Natural Resources Canada, to conduct **a study on the economic impacts of climate-related extreme events on communities in Canada**. The focus of the study was threefold:

1. **To complete a community engagement process** with local and regional advisors from relevant municipal offices and departments in the communities under consideration. The engagement process progressed through the following series of tasks: **inform** (provide information on the project goals, approach and timeline) → **engage** (support the communities as they confirm their ability to participate in data collection) → **collect** (collect data for the analysis) → **share** (share information on the analysis) → **review** (review project results).
2. **To conduct a case study analysis** of the impacts of climate-related extreme events on two case study communities: the Halifax Regional Municipality (HRM) and the City of Mississauga (Mississauga).[1] For each of the case study communities, two climate-related extreme events were selected for investigation: storm surge flooding and extreme wind in HRM and storm water flooding and freezing rain in Mississauga.
3. **To develop a community impact analysis tool** for each of the climate-related extreme events analyzed in the case study communities. The community impact analysis tool automates the equations used in the case study impact analysis and in so doing provides a replicable analytical framework that analysts can use to estimate the impact of climate-related extreme events in other communities.

This *Executive Summary* presents the key findings and lessons learned pertaining to the focus areas of this study. It begins with a brief overview of the rationale for the study.

Study Rationale

The accumulation of greenhouse gases in the Earth's atmosphere is unprecedented. These gases are changing the Earth's climate as temperatures around the globe gradually rise. The consequences of climate change are widespread and include an increase in the frequency and magnitude of climate-related extreme events; events that will intensify and become more frequent in the future as the release

[1] The two case study communities were selected from a list of five communities identified in work previously commissioned by IBC based on their geographic locations (i.e. one centrally located community and one coastal community) and their respective exposure to climate-related extreme events.

and accumulation of greenhouse gases persists. Extreme weather events have and will continue to cause significant loss in the form of impacts to human settlements and ecosystems. To counter such impacts, communities are increasingly considering and investing in adaptation measures. Such investments may be justified on the basis of the avoided impacts from extreme weather events, but without community-specific estimates of the expected cost of impacts, making the case for adaptation measures is difficult. Thus, to help identify areas where adaptation investments may be justified, there is a need to quantify, at a community-specific level, the expected impacts to communities from such events. Within this context, the current project focuses on quantifying the impacts of climate-related extreme events at the community scale. It does this through an analysis of climate-related extreme events in two case study communities and through the development of a community impact assessment tool designed for use by analysts seeking to estimate the impact of climate-related extreme events for a particular community. A summary of the results of the case study analysis follows.

Case Study Analysis – Scope

The case study analysis entailed calculating the *direct impacts* of climate-related extreme events on fixed assets (e.g. buildings and their contents) and from business interruptions (e.g. lost economic output) due to power outages from the extreme events. The *secondary impacts* (i.e. indirect and induced impacts) of the direct impact to assets and lost economic output were also estimated. See the *Concept Note – Direct and Secondary Impacts Defined*, below for definitions. For each of the two case study communities and their associated climate-related extreme events, the analysis of the direct and secondary impacts was completed for three timeframes and three climate scenarios – a baseline climate change scenario (reflecting today's climate), a moderate climate change scenario and a high climate change scenario. The year 2015 was chosen as the baseline year and results were tabulated for two future time periods, 2020 and 2040, for each of the climate change scenarios.

Case Study Analysis

The results of the analysis demonstrate the expected cost of direct and secondary impacts from asset damage and business interruptions due to climate-related extreme events in the case study communities assuming no climate adaptation actions are taken.

CONCEPT NOTE - Direct and Secondary Impacts Defined

Direct impacts in this study constitute the economic impact that occurs at the source of where the climate-related extreme event influences the economy; this source could be either an economic sector or an asset class (e.g. residential buildings). The economic impact can result from damages to fixed assets (e.g. buildings and their contents damaged due to a flood) – measured as the value of the assets - and losses due to business interruptions (e.g. a restaurant has no electricity because of a power outage and so cannot operate) – measured as lost revenue - (see definitions for Impacts to Assets and Business Interruption below).

Secondary impacts result from the ripple effect of the direct impacts on the broader economy as subsequent spending (both indirect and induced) takes place. In this context, the spending resulting from the direct impact does not lead to a net gain to society. While some industries, such as those related to construction and remediation, might *benefit* from an increased demand for clean-up, repair and construction services following an extreme event, this benefit is more accurately characterized as a *transfer* of activity towards those industries responding to the event and away from those that suffer damages as a result of the event. The investment incurred to restore infrastructure to the state it was in prior to the extreme event thus represents an "opportunity cost" – the opportunity cost is the forgone benefit from transferring expenditure away from the activities that would have occurred in the absence of damage from the extreme event. Two categories of secondary impacts, which reflect indirect and induced spending, are captured in this study and the community impact analysis tool:

1. **Indirect impacts** encompass impacts resulting from inter-industry upstream purchases by the directly impacted sector. For example, increased demand for construction and repair services following a climate-related extreme event would lead to spending by the construction industry on all the inputs needed to support their industry (e.g. building supplies and tools). The indirect impact is the spending on inputs from all supporting industries of the sector that is directly impacted. There is an opportunity cost associated with this spending; the indirect spending resulting from the direct spending that takes place in response to damages from a climate-related extreme event represents an opportunity cost in that it is spending that would have taken place elsewhere (in response to direct spending elsewhere) in the absence of damages from a climate-related extreme event (i.e. instead of taking place in response to the climate-related extreme event it would have taken place in response to expenditure elsewhere in the economy).
2. **Induced impacts** encompass impacts resulting from changes in the production of goods and services in response to increased consumer income and hence expenditures driven by the direct and indirect impacts. For example, in response to a climate-related extreme event, employees in the directly impacted industry and indirect supporting industries would spend the income they earn on housing, utilities, groceries, and other consumer goods and services. The induced impact results from this household spending as it ripples through the region's economy. There is an opportunity cost associated with this spending; the induced spending resulting from the direct and indirect spending that takes place in response to damages from a climate-related extreme event represents an opportunity cost in that it is spending that would have taken place elsewhere (in response to direct and indirect spending elsewhere) in the absence of damages from a climate-related extreme event (i.e. instead of being induced by expenditure in response to the climate-related extreme event it would have been induced by expenditure elsewhere in the economy).

Two categories of direct and secondary impacts are captured in this study and in the community impact analysis tool:

Impacts resulting from damage to assets encompass damages to assets such as buildings, building contents and electrical power lines. For example, the damage to the contents of a residential building due to a flooding event is an impact from damaged assets. In the context of this study, impacts to assets are equivalent to the restoration costs required to restore the given asset to a renewed state directly after the damage is caused by the given climate-related event. The spending resulting from the impact does not lead to a net gain to society. Rather, it is a redistribution of spending across the economy, from sectors experiencing losses due to damage from climate-related events to sectors realizing gains as they respond to the damages and return the economy to its former state. This spending is therefore associated with an opportunity cost (because in the absence of climate-related damaged, the spending would have taken place elsewhere in the economy) and is hence captured here as an impact.

Impacts resulting from business interruptions or lost economic activity encompass impacts to the flow of monetary transactions from business interruptions due to power outages. For example, the temporary closure of a retail store or a restaurant during a power outage constitutes an impact from business interruptions. Note that in this context, the lost economic activity generally leads to a net loss to society because each affected business is forced to cease economic activities during regular working hours for as long as it takes for power to be restored (Appendices A and B provide greater details on how impacts from business interruptions are calculated in this study).

In this report, direct impacts are first expressed in terms of *gross output*. Gross output is a measure of economic activity that includes intermediate inputs (i.e. materials used in production processes) and value added (i.e. land, labour and capital). Gross output is used as the starting point in the analysis because the inclusion of intermediate inputs allows for a better reflection of the inter-industry linkages in the secondary impact analysis (which employs *within* province multipliers published by Statistics Canada). The direct and secondary impacts are then expressed in terms of *gross domestic product* (GDP) as this reflects the value of production in any given year independent of the intermediate inputs that could have been produced in prior years (GDP is also known as 'net output'). In the secondary impacts sections of the case study sections of this report, the graphs include both the direct and secondary impacts expressed in terms of GDP. Note that results expressed in terms of gross output will always be greater than GDP as GDP is a sub-component of gross output. The gross output results are therefore not directly comparable to the results expressed as GDP.

The **sum of the direct and secondary impact estimates** should not be interpreted as a total impact estimate. Total implies a full and all-encompassing assessment of impacts, which is not the focus of the current study. The focus of this study is on the direct and secondary impacts of select climate-related extreme events on community assets and business interruptions given the data available to inform such an analysis.

Expected cost estimates are generated for two time periods (i.e. 2020 and 2040) and across climate change scenarios (i.e. from a baseline climate change scenario to moderate and high climate change scenarios). Within the context provide above and in the preceding text boxes, the series of bullets below clearly articulate what this study **does** and **does not do**.

Expected Annual Damage

This study quantifies the direct and secondary impacts of climate-related extreme events as the **expected annual damage (EAD)** of the event. This measurement, commonly used when considering impacts across climate change scenarios, describes the damages per year expected from a climate-related extreme event, accounting for both the *magnitude* of the range of possible events and the *probability* of the range of possible events occurring.

This study DOES:

- Measure impacts from climate change in relation to a baseline scenario that accounts for the expected growth of the economy in the case study communities over time.
- Estimate the impact of select climate-related extreme events in two case study communities in terms of:
    - The expected annual damage (see the definition in the text box to the right) to fixed assets (e.g. buildings and their contents) and from business interruptions (due to power outage) in 2020 and 2040 from two climate-related extreme events in each community for moderate and high climate change scenarios in relation to a baseline climate change scenario.
    - The expected annual damage of specific climate-related extreme events (e.g. a 1 in 100 year flood event) under moderate and high climate change scenarios in relation to a baseline climate change scenario.
    - The cumulative expected annual damage to assets and from business interruptions over time resulting from high and moderate climate change scenarios in relation to a baseline climate change scenario.

  - The direct and secondary (i.e. indirect and induced) expected annual damage to assets and from business interruptions over time and for moderate and high climate change scenarios as measured by changes in gross domestic product, gross output and employment.
  - Three alternative approaches to measuring secondary impacts demonstrating variations in estimates across the different approaches.
- Help to create a business case for investing in community-level adaptation measures by estimating the impacts of select climate-related extreme events in the absence of additional adaptation measures.
- Add to the currently limited body of research concerning the economic impacts of climate change at a local level.
- Incorporate a peer-reviewed approach to estimating impacts into a replicable spreadsheet tool that can be used by analysts seeking to quantify the impacts of select climate-related extreme events in other communities.

This study DOES NOT:

- Provide a comprehensive account of all of the costs associated with all climate-related extreme events in the two case study communities because:
  - In some cases, data gaps limited the ability to adequately quantify some costs (e.g. business interruption costs associated with travel delays).
  - In other cases, costs were deemed outside the scope of the analysis (e.g. restoring coastal wetlands damaged by storm surge flooding).
  - The analysis of impacts was limited to two of several possible climate-related extreme events in each community.
- Assess impacts associated with climate change adaptation actions.
- Predict where and when a climate-related extreme event will happen.

Within this important context, key findings for the case study analysis are presented, beginning with the Halifax Regional Municipality.

Key Findings for the Halifax Regional Municipality

The case study analysis for the HRM focused on the climate-related extreme events of storm surge flooding and extreme wind. The analysis revealed the following key findings:

1. **Greater direct impacts under the climate change scenarios:** For the moderate and high climate change scenarios, increases in direct impacts (measured as changes in gross output between scenarios) were found over time and in relation to the baseline scenario for both storm surge flooding and extreme wind events. By measuring changes relative to a baseline scenario, factors such as normal community growth are accounted for – allowing the analysis to isolate the climate-related

impacts. Comparing the baseline scenario with the moderate and high scenarios revealed the following:

- **Building stock, sector output and re-construction costs drive baseline increases:** From 2020 to 2040, the direct impacts to gross output for the baseline scenario increased (132% for flooding and 43% for wind) due to increases in sector output, new building stock and the cost of re-construction over the same time period.
- **Impacts of moderate climate change relative to baseline:** From 2020 to 2040, the direct gross output impacts for the moderate climate change scenario increased relatively more than the increase under the baseline scenario; the increase in impacts under the moderate climate change scenario relative to the baseline scenario was found to be 59% greater for flooding and 5% greater for wind. These increases are attributed to climate change.
- **Impacts of high climate change relative to baseline:** From 2020 to 2040, the direct gross output impacts for the high climate change scenario increased relatively more than the increase under the baseline scenario; the increase in impacts under the high climate change scenario relative to the baseline scenario was found to be 85% greater for flooding and 46% greater for wind. These increases are attributed to climate change.

2. **Relative increase in flood impacts between 2020 and 2040 substantially larger than the increase in wind impacts between 2020 and 2040:** Under the high climate change scenario, between 2020 and 2040 the estimated direct and secondary gross domestic product impacts from climate-related storm surge increased by a factor of seven (from $400 thousand to $3.1 million). In comparison, impacts from extreme wind were estimated to increase threefold (from $2.8 million to $8.4 million) over the same time period.
3. **Secondary impacts comparable across modelling approaches:** The magnitude of the secondary impacts (i.e. the indirect and induced impacts) resulting from storm surge flooding and extreme wind were found to be comparable across the three approaches to modelling secondary impacts employed in this analysis.
4. **Climate change driving increases in cumulative impacts over time:** The cumulative sum of direct and secondary impact estimates attributed to climate change for storm surge flooding could reach over $35 million of gross domestic product ($2013) by 2040. Even more dramatic, the cumulative sum of direct and secondary impact estimates attributed to climate change from extreme wind could reach over $140 million of gross domestic product ($2013) by 2040.
5. **Extreme events more costly with high climate change:** Impacts from specific climate-related events can be compared across climate change scenarios to demonstrate the difference in impacts resulting from varying climate assumptions. For example, measured in terms of gross domestic product, a 1 in 25 year storm surge event occurring in 2040 under a high climate change scenario is estimated to be $22 million ($2013) more costly than a 1 in 25 year event occurring in the same year under today's climate conditions. This increased cost is the result of storm surges occurring more

frequently with greater flood depths. In the case of extreme wind, a 1 in 25 year event occurring in 2040 under a high climate change scenario is estimated to be $16 million ($2013) more costly than a 1 in 25 year event occurring in 2040 under today's climate conditions. This increased cost is the result of extreme wind events occurring more frequently with greater wind speeds.

Key Findings for the City of Mississauga

The case study analysis for Mississauga focused on the climate-related extreme events of storm water flooding and freezing rain. The analysis revealed the following key findings:

1. **Greater direct impacts under the climate change scenarios:** For the moderate and high climate change scenarios, increases in direct impacts (measured as changes in gross output between scenarios) were found over time and in relation to the baseline scenario for both freezing rain and storm water flooding. By measuring changes relative to a baseline scenario, factors such as normal community growth are accounted for – allowing the analysis to isolate the climate-related impacts. Comparing the baseline scenario with the moderate and high scenarios revealed the following:
    - **Value of buildings, cost of re-construction and sector output driving baseline increases:** From 2020 to 2040, the direct impacts to gross output for the baseline scenario increased (38% for storm water flooding and 14% for freezing rain) due to increases in the value of buildings, the cost of re-construction and sector output over the same time period.
    - **Impacts of moderate climate change relative to baseline:** From 2020 to 2040, the direct gross output impacts for the moderate climate change scenario increased more than the increase under the baseline scenario; the increase in impacts under the moderate climate change scenario relative to the baseline scenario was found to be 30% greater for freezing rain and 10% greater for storm water flooding. These increases are attributed to climate change.
    - **Impacts of high climate change relative to baseline:** From 2020 to 2040, the direct gross output impacts for the high climate change scenario increased relatively more than the increase under the baseline scenario; the increase in impacts under the high climate change scenario relative to the baseline scenario was found to be 30% greater for freezing rain and 4% greater for storm water flooding. These increases are attributed to climate change.
2. **Business interruption dominates freezing rain impacts:** The majority of the direct gross output impact resulting from freezing rain is due to business interruptions. More than 80% of the estimated impact is due to business interruptions while 17% is attributed to tree-related impacts. Costs associated with power restoration were found to be relatively minimal (0.4%), which is to be expected given that approximately 65% of the power lines in Mississauga are underground.
3. **Residential homes hit the hardest during storm water flood events:** Almost all of the buildings located in the flood zone (96% or 645 of 674 buildings) were found to be residential detached

buildings. Because of this, the residential sector accounts for about 87% of the direct impact estimates in 2020 and 2040.

4. **Secondary impacts are comparable across modelling approaches:** The magnitude of the secondary impacts (i.e. the indirect and induced impacts) resulting from freezing rain and storm water flooding were found to be comparable across the three approaches to modelling secondary impacts employed in the analysis.
5. **Climate change driving increases in cumulative impacts over time:** The cumulative sum of direct and secondary impact estimates attributed to climate change for freezing rain could reach over $30 million of gross domestic product ($2013) by 2040. Similarly, for storm water flooding, the cumulative sum of direct and secondary impact estimates attributed to climate change could reach $70 million of gross domestic product ($2013) by 2040.
6. **Extreme events more costly with climate change:** Impacts from specific climate-related events can be compared across climate change scenarios to demonstrate the difference in impacts resulting from varying climate change assumptions. For example, measured in terms of gross domestic product, a 1 in 25 year freezing rain event occurring in 2040 under a high climate change scenario is estimated to be $15.7 million (2013$) more costly than a 1 in 25 year event occurring in the same year under today's climate conditions. This increased cost is the result of freezing rain events occurring more frequently during the winter months. In the case of storm water flooding, a 1 in 25 year event occurring in 2040 under a high climate change scenario is estimated to be $12 million (2013$) more costly than a 1 in 25 year event occurring in 2040 under today's climate conditions. This increased cost is the result of more frequent heavy rainfall events causing greater flood depths.

Lessons Learned

In conclusion, it is informative to note a number of key lessons derived through the completion of the case study analysis as well as the community engagement process and the development of the community impact analysis tool. They are specified below, by theme.

- **Data requirements:** The data required to conduct an impact analysis of climate-related extreme events is dispersed across numerous municipal departments and organizations, which means that the completion of an analysis such as this necessarily requires a minimum degree of engagement from many departments (such as parks, forestry, water, power, planning, economic development and geographic information systems) and organizations (conservation authorities and power utilities).
- **Estimating direct impacts:** It became evident early in the project that the completion of this type of analysis is relatively cutting edge in Canada, especially at the community level. This is both a benefit of the project, in terms of responding to a need within communities to conduct this type of analysis, and a challenge, as it made for relatively more difficult data collection. Within this context, it was acknowledged during the community engagement process that the analysis would fill a gap in the

case study communities and the community impact analysis tool would fill a gap for communities across the country.

- **Modelling secondary impacts:** Modelling approaches need to be accessible to municipalities to be useful; overly complicated and/or costly approaches will not be employed by communities. The use of basic input-output multipliers, that are readily available from Statistics Canada, was identified as the most appropriate method for measuring secondary impacts at the scale and application of relevance to this type of study.
- **Applying the community impact analysis tool in Canada:** The use of the community impact analysis tool in other communities will help build community awareness and capacity related to climate change impacts and options for adaptation. The data available to communities will range vastly in quality and detail, which will ultimately influence the accuracy of the results. The community impact analysis tool is designed to provide significant guidance to users seeking to employ the tool in other case study communities, including guidance on how and where to collect data from. Working through the data collection process and applying the community impact analysis tool could have a profound impact on a community's capacity to understand and assess adaptive actions.

1. Introduction

Green Analytics and the Ontario Centre for Climate Change Impacts and Adaptation Resources were commissioned by the Insurance Bureau of Canada (IBC), with support from Natural Resources Canada, to conduct a study on the economic impacts of climate-related extreme events on communities in Canada. The focus of the study was threefold:

1. To complete a **community engagement process** to garner support for a climate change impact analysis and aid in data collection for the study.
2. To undertake a **case study analysis** of the direct and secondary impacts of climate-related extreme events on community assets and economic activity.
3. To develop a **Community Impact Analysis Tool (CIAT)** that analysts can use to estimate the impacts of climate-related extreme events in Canadian communities.

The outputs of each of these focus areas are presented in this report as well as in accompanying materials (i.e. the Community Impact Analysis Tool and its *How-to* Guide). This *Introduction* provides a brief overview of the study focus and approach. See the *Glossary of Terms and Concepts* at the end of the report for definitions of key terms referenced in this and other sections of the report.

1.1 Overview of Study Focus and Approach

In the sub-sections below, brief overviews of the three focus areas for the study – the community engagement process, the case study analysis and the CIAT – are presented. This is followed by an outline of this report.

1.1.1 Community Engagement

The first focus of the study was on the completion of a community engagement[2] process in each of the case study communities. Engagement focused on local and regional advisors from relevant municipal offices and departments. The engagement process followed a continuum depicted by the following steps: inform → engage → collect → share → review, each of which is described briefly below.

Inform: Provide information on the project goals, approach and timeline.

[2] For the purpose of this report, "community" (i.e. community engagement) should be understood to mean engagement with key staff at city, region, conservation authority, province or other agency. It does not represent broad public consultation (e.g. public forums, information sessions). Likewise, "communities" includes the local governance bodies that operate within the geographical boundaries of Halifax and Mississauga.

Engage: Support the communities as they share project information internally and confirm their ability to support data collection.

Collect: Collect data for the study analysis.

Share: Continue with regular updates to communities to share information on the analysis.

Review: Provide a review loop of results with communities.

The steps identified above were accomplished through regular communication with community representatives and two meetings that were held in each community.

1.1.2 Case Study Analysis

Through the case study impact analysis, the impacts of climate-related extreme events were estimated for two case study communities: The Halifax Regional Municipality (HRM) and the City of Mississauga (Mississauga). The two case study communities were selected from a list of five communities identified in work previously commissioned by IBC based on their geographic locations (i.e. one centrally located community and one coastal community) and their respective exposure to climate-related extreme events. It was desirable to have a degree of variation between the communities but also choose communities that would be associated with events that would be applicable to other Canadian communities. For each of the case study communities, two climate-related extreme events were selected for investigation. In particular, the following climate-related extreme events were chosen for analysis:

- Storm surge flooding in the HRM
- Extreme wind in the HRM
- Storm water flooding in Mississauga
- Freezing rain in Mississauga

The extreme events identified above were chosen for a number of reasons. One, there was a need to scope the list of events to a manageable number to ensure that the analysis could be completed within the time and budget constraints of the project. Two, it was desirable to choose a range of unique events across the case study communities. Doing so allowed the application of the methods for assessing the impact of those events on assets and economic activity for a higher number of unique event types rather than a smaller number of redundant events. Third, it was desirable to include events that are either (or both) relatively prevalent in Canada, or of particular interest to the case study communities under consideration. Fourth, the climate-related extreme events for these communities were discussed and confirmed as priority events with community representatives from each of the HRM and Mississauga.

For each of the two case study communities and their associated climate-related extreme events, the analysis was completed for three timeframes and three climate scenarios. The year 2015 was chosen as the baseline year and results were tabulated for two future time periods, 2020 and 2040, for each of the climate change scenarios. The first climate change scenario, the baseline scenario, is based on recent historical weather data dating back no earlier than 1954 and no later than 2013. The second and third climate scenarios consider the future climate projected across 2020 and 2040 under moderate and high climate change pathways.

1.1.3 Community Impact Analysis Tool

The third and final focus of the study was on the development of the CIAT. This spreadsheet-based tool was developed for each of the climate-related extreme events analyzed in the case study communities. The CIAT automates the equations used in the case study impact analysis and in so doing provides a replicable analytical framework that other analysts can use to estimate the impact of climate-related extreme events in communities.

1.2 Interpreting the Findings

The results of the analysis demonstrate **the expected cost of impacts from asset damage and business interruptions due to climate-related extreme events in the case study communities assuming no climate adaptation actions are taken.** To aid in the interpretation of the results presented in this report, the series of bullets below clearly articulate what this study **DOES** and **DOES NOT** do.

> This study quantifies the direct and secondary impacts of climate-related extreme events as the **expected annual damage (EAD)** of the event. This measurement, commonly used when considering impacts across climate change scenarios, describes the damages per year expected from a climate-related extreme event, accounting for both the *magnitude* of the event and the *probability* of the event occurring. "Expected annual" does not mean these damages will occur every year.

This study DOES:

- Measure impacts from climate change in relation to a baseline scenario that accounts for the expected growth in the economy in the case study communities over time.
- Estimate the potential impact of select climate-related extreme events in two case study communities in terms of:
    - The expected annual damage (see the definition in the text box to the right) to fixed assets (e.g. buildings and their contents) and from business interruptions (due to power outages) in 2020 and 2040 from two climate-related extreme events in each community for moderate and high climate change scenarios in relation to a baseline climate change scenario.
    - The expected annual damage of specific climate-related extreme events (e.g. a 1 in 100 year flood event) under moderate and high climate change scenarios in relation to a baseline climate change scenario.
    - The cumulative expected annual damage to assets and from business interruptions over time resulting from high and moderate climate change scenarios in relation to a baseline climate change scenario.

    - The direct and secondary (i.e. indirect and induced) expected annual damage to assets and from business interruptions over time and for moderate and high climate change scenarios as measured by changes in gross domestic product, gross output and employment.
    - Three alternative approaches to measuring secondary impacts demonstrating variations in estimates across the different approaches.
- Help create a business case for investing in community-level adaptation measures by quantifying the potential impacts of select climate-related extreme events in the absence of additional adaptation measures.
- Add to the currently limited body of research concerning the economic impacts of climate change at a local level.
- Incorporate a peer-reviewed approach to quantifying impacts into a replicable spreadsheet tool that can be used by analysts seeking to quantify the impacts of select climate-related extreme events in other communities.

This study DOES NOT:

- Provide a comprehensive account of all of the costs associated with climate-related extreme events in the two case study communities because:
    - In some cases, data gaps limited the ability to adequately quantify some costs (e.g. business interruption costs associated with travel delays).
    - In other cases, costs were deemed outside the scope of the analysis (e.g. restoring coastal wetlands damaged by storm surge flooding).
    - The analysis of impacts was limited to two of several possible climate-related extreme events in each community.
- Assess impacts associated with climate change adaptation actions.
- Predict where and when a climate-related extreme event will happen.

1.3 Report Outline

This report is organized as follows:

- The *Background* presents global and national perspectives on increasing greenhouse gas emissions, the changing climate and increasing damages and hence costs from climate-related extreme events. In doing so, it presents the rationale for conducting the community-level analyses completed in the current study.
- The *Approach* provides a general description of the steps taken to complete the impact analysis in each of the case study communities.
- The *Halifax Regional Municipality Case Study* describes case study-specific approaches, the community engagement process, and the findings for each of the climate-related extreme events.

- The *Mississauga Case Study* describes case study-specific approaches, the community engagement process, and the findings for each of the climate-related extreme events.
- The *Community Impact Analysis Tool* provides an overview of the use and functionality of the spreadsheet tool for the climate-related extreme events.
- The *Summary and Conclusions* provide an overview of the key findings, identifies analytical challenges and limitations, and articulates key lessons learned.
- A *Glossary of Terms and Concepts* is provided at the end of the document prior to a series of *Appendices* which detail key assumptions and data sources used in the impact analysis.

2. Background: Study Context and Rationale

The accumulation of greenhouse gases (GHG) in the Earth's atmosphere is unprecedented. These gases are changing the Earth's climate as temperatures around the globe gradually rise. The consequences of climate change are widespread and include an increase in the frequency and magnitude of climate-related extreme events; events that will intensify and become more frequent in the future as the release and accumulation of GHG persists. Extreme weather events have and will continue to cause significant loss in the form of impacts to human settlements and ecosystems. To counter such impacts, communities are increasingly considering and investing in adaptation measures. Such investments may be justified on the basis of the avoided impacts from extreme weather events, but without community-specific estimates of the expected cost of impacts, making the case for adaptation measures is difficult. This background chapter describes the latest data on the release and accumulation of GHG emissions and the rise in temperature that is being experienced on Earth. It puts these changes into the context of the losses resulting from climate-related extreme events and in so doing demonstrates the need to quantify, at a community-specific level, the expected impacts to communities from vulnerability[3] to such events.

2.1 The Global Perspective: Rising Greenhouse Gas Emissions, Temperatures and Losses

According to the Intergovernmental Panel on Climate Change (IPCC) anthropogenic GHG emissions have increased since the pre-industrial era and are now higher than ever. Figure 1 shows the trend in global anthropogenic CO_2 emissions from forestry and other land use as well as from the burning of fossil fuel, cement production and flaring.[4] Cumulative emissions (shown as bars) of CO_2 from these sources and their uncertainties (shown as whiskers)[5] are included on the right hand side of the figure.

[3] The vulnerability of a community is a function of exposure to a climate-related extreme event and the adaptive capacity of the community. See the Glossary of Terms and Concepts at the end of this report for this and other relevant definitions.
[4] IPCC, 2014: Summary for Policymakers. In: Climate Change 2014 Synthesis Report. Intergovernmental Panel on Climate Change Fifth Assessment Report. Cambridge University Press, Cambridge, UK, and New York, NY, USA.
[5] The degree of uncertainty associated with this data is represented by the "whiskers" or thin lines extended up and down from the value represented by the bar. The greater the uncertainty the longer the whiskers. In this case it is evident that the degree of uncertainty associated with emissions from forestry and other land uses is greater than that associated with fossil fuels, cement and flaring.

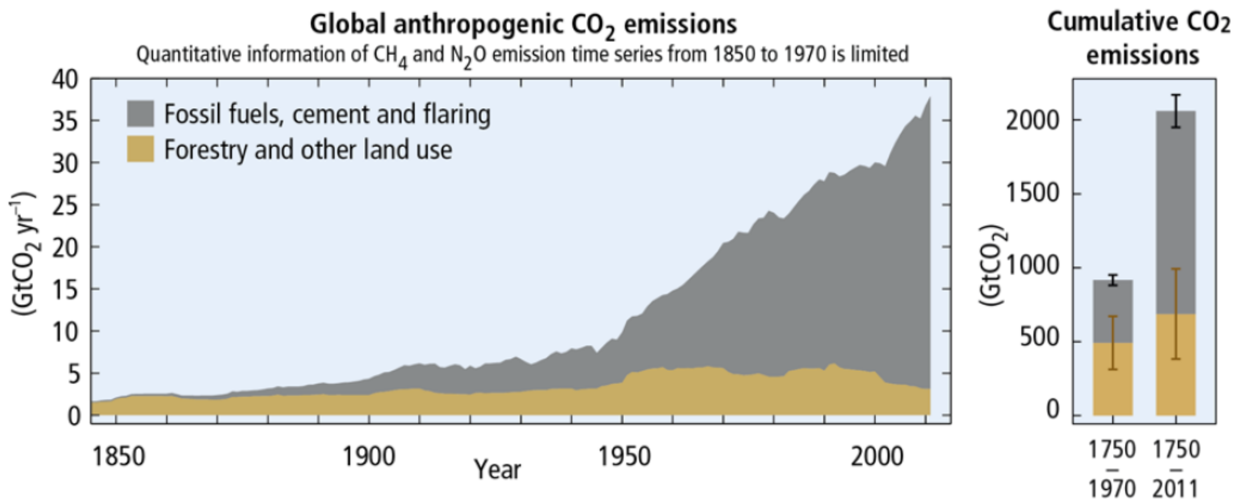

Figure 1. Global anthropogenic CO_2 emissions by source since 1950.

This increase has led to atmospheric concentrations of GHG emissions (carbon dioxide, methane and nitrous oxide) at levels that have not been experienced in at least the last 800,000 years.[6] Figure 2 shows the trend in atmospheric concentrations of the carbon dioxide (CO_2, green), methane (CH_4, orange), and nitrous oxide (N_2O, red) as determined from ice core data (dots) and from direct atmospheric measurements (lines).[7]

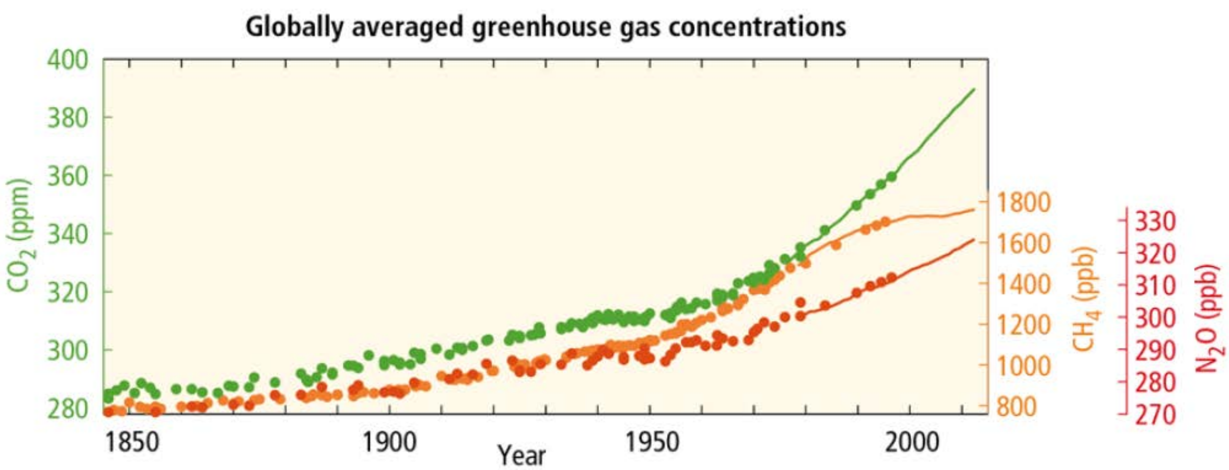

Figure 2. Globally averaged greenhouse gas concentrations.

[6] IPCC, 2014: Summary for Policymakers. In: Climate Change 2014 Synthesis Report. Intergovernmental Panel on Climate Change Fifth Assessment Report. Cambridge University Press, Cambridge, UK, and New York, NY, USA.
[7] IPCC, 2014: Summary for Policymakers. In: Climate Change 2014 Synthesis Report. Intergovernmental Panel on Climate Change Fifth Assessment Report. Cambridge University Press, Cambridge, UK, and New York, NY, USA.

The scientific community agrees that these unprecedented levels of emissions are extremely likely to be the dominant cause of the observed warming of the earth's atmosphere since the mid-20th century.[8] Evidence of the Earth's changing climate is abundant. Figure 3 demonstrates the trend in annually and globally averaged combined land and ocean surface temperature anomalies relative to the average over the period 1986 to 2005 (the colours indicate different data sets that have been observed). [9] The upward trend in the combined temperature is evident.

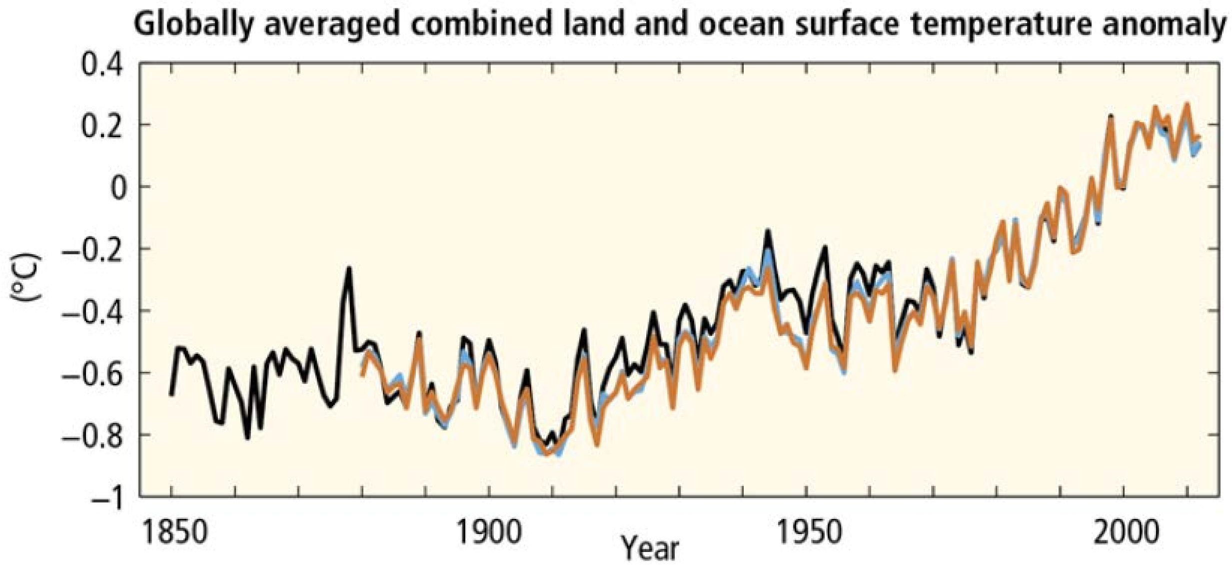

Figure 3. **Globally averaged combined land and ocean surface temperature anomaly, observed data trends.**

Specific examples of the observed warming trend include:

- Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850.[10]
- With the exception of 1998, the 10 warmest years in the 134-year record have all occurred since 2000, with 2010 and 2005 ranking as the warmest years on record.[11]
- The average global temperature in 2013 was 14.6 Celsius (C), which is 0.6 C warmer than the mid-20th century baseline.[12]
- According to new analysis, the average global temperature has risen about 0.8 C since 1880.[13]

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[8] IPCC, 2014: Summary for Policymakers. In: Climate Change 2014 Synthesis Report. Intergovernmental Panel on Climate Change Fifth Assessment Report. Cambridge University Press, Cambridge, UK, and New York, NY, USA.
[9] IPCC, 2014: Summary for Policymakers. In: Climate Change 2014 Synthesis Report. Intergovernmental Panel on Climate Change Fifth Assessment Report. Cambridge University Press, Cambridge, UK, and New York, NY, USA.
[10] IPCC, 2014: Summary for Policymakers. In: Climate Change 2014 Synthesis Report. Intergovernmental Panel on Climate Change Fifth Assessment Report. Cambridge University Press, Cambridge, UK, and New York, NY, USA.
[11] Cole, Steve and Leslie McCarthy. 2014. *Long-term global warming trend sustained in 2013*. NASA Features Article 1029: http://climate.nasa.gov/news/1029/
[12] Cole, Steve and Leslie McCarthy. 2014. *Long-term global warming trend sustained in 2013*. NASA Features Article 1029: http://climate.nasa.gov/news/1029/

Impacts resulting from climate change, including alteration of ecosystems, disruption of food production and water supply, damage to infrastructure and settlements, morbidity and mortality, and consequences for mental health and human well-being, have been detected throughout the globe.[14] Such impacts are forecasted to continue and even to amplify. According to the IPCC, surface temperature is projected to rise over the 21st century under all assessed emission scenarios. As a result, scientists predict that heat waves will occur more often and last longer, extreme precipitation events will become more intense and frequent in many regions, oceans will continue to warm and acidify, and global mean sea level will rise.[15] Indeed, the changing climate is expected to lead to shifts in the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events.[16] In other words, the continued accumulation of greenhouse gases will cause further climate change and thus increase the likelihood of severe and pervasive impacts to people and ecosystems.[17]

Evidence from a global insurance research group demonstrates the significant risks to people from climate-related extreme events. Swiss Re Sigma Insurance Research (2014) has been tracking economic losses from natural disasters over time and has been releasing a global summary of impacts since 2005. Using data from the Sigma Insurance Research website data application,[18] Figure 4 demonstrates an estimated exponential increase in the economic losses from climate-related extreme events[19] around the world over the period of 1970 to 2014.

[13] Cole, Steve and Leslie McCarthy. 2014. *Long-term global warming trend sustained in 2013*. NASA Features Article 1029: http://climate.nasa.gov/news/1029/
[14] IPCC, 2014: Summary for Policymakers. In: Climate Change 2014 Synthesis Report. Intergovernmental Panel on Climate Change Fifth Assessment Report. Cambridge University Press, Cambridge, UK, and New York, NY, USA.
[15] IPCC, 2014: Summary for Policymakers. In: Climate Change 2014 Synthesis Report. Intergovernmental Panel on Climate Change Fifth Assessment Report. Cambridge University Press, Cambridge, UK, and New York, NY, USA.
[16] IPCC, 2012: Summary for Policymakers. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA.
[17] IPCC, 2014: Summary for Policymakers. In: Climate Change 2014 Synthesis Report. Intergovernmental Panel on Climate Change Fifth Assessment Report. Cambridge University Press, Cambridge, UK, and New York, NY, USA.
[18] http://www.swissre.com/reinsurance/insurers/sigma_explorer_the_data_you_need_at_your_fingertips.html
[19] Referred to as weather-related catastrophies by Swiss Re Sigma Insurance Research.

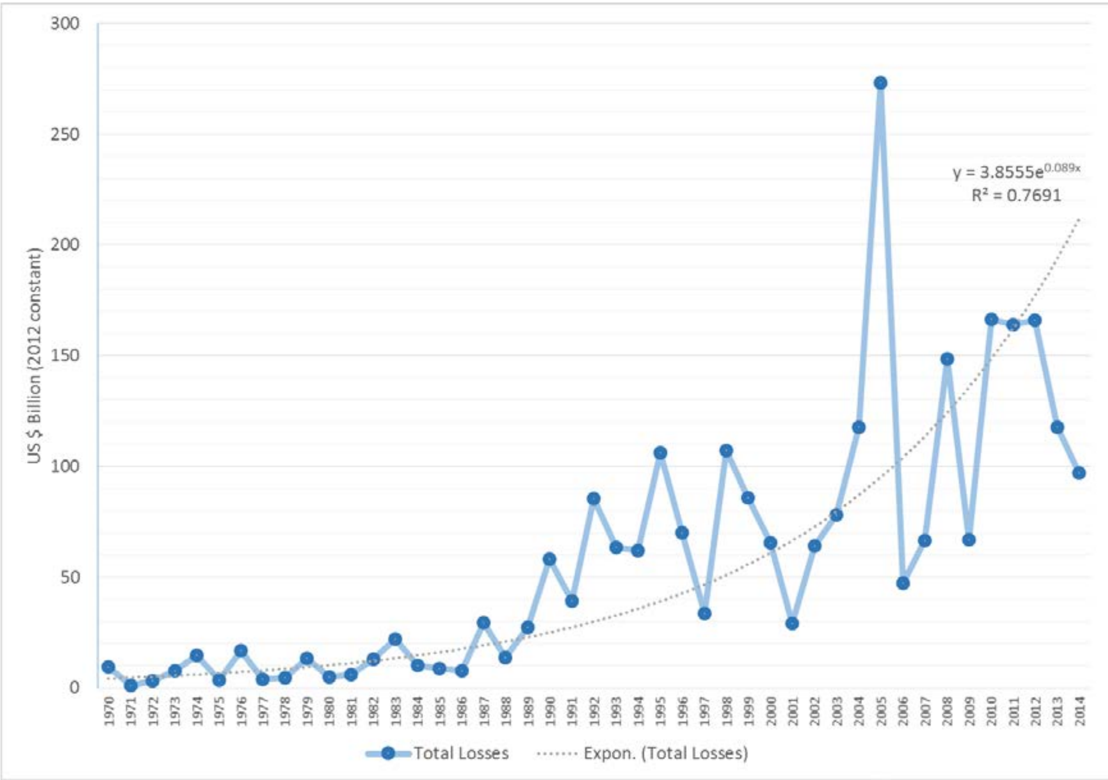

Figure 4: **Trend in Global Economic Losses from Climate-related Extreme Events.**

Even ignoring the estimated exponential trend in total economic losses, the 10 year moving average global economic losses has increased by approximately 13 times from 1970 to 2014. In the 1970s, the global economic losses from climate-related extreme events were in the order of magnitude of $10 Billion (2012 US constant dollars). In the past 5 years, the estimated total economic losses exceeded $100 Billion (2012 US constant dollars) on average. According to Swiss Re Sigma Insurance Research (2014), peak losses to date from climate-related extreme events occurred in 2005 with an estimated total of $217.14 Billion (2012 US constant dollars). As will be described below, Canada has not been insulated from the impacts and losses resulting from the Earth's changing climate.

2.2 The Canadian Perspective: Rising Temperatures, Extreme Events and Losses

As is the case globally, Canada's climate is changing. Observed changes in air temperature, precipitation, snow and ice cover have been realized. Over the past six decades, Canada has become warmer. Average surface temperatures increased by 1.5 ºC between 1950 and 2010.[20] Given Canada's northern

[20] Warren, F.J. and Lemmen, D.S. (2014): Synthesis; in Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation, (ed.) F.J. Warren and D.S. Lemmen; Government of Canada, Ottawa, ON, p. 1-18.

geography, this rate of warming is about twice as much as the global average over the same time period.[21] Table 1 provides an overview of observed trends related to climate change in Canada. [22]

Table 1: Observed climate trends across Canada

Climate System Element	Observed Trends
Hot temperature extremes	The frequency of warm days during summer has increased nationally since 1950.
Cold temperature extremes	The frequency of cold nights during the winter has decreased nationally since 1950.
Annual precipitation	Canada has generally become wetter in recent decades, as indicated by the increased trend in annual average precipitation.
Snowfall	Annual snowfall has declined over most of southern Canada and increased in the north over the last 6 decades.
Ground temperature	Permafrost temperatures at numerous borehole sites across Canada have increased over the past two to three decades.
Sea level – Canada	Relative sea level rise of over 3 mm/yr has been observed on coastlines of Atlantic Canada and the Beaufort Sea. Relative sea level fall of 10 mm/yr has been observed around Hudson Bay where the land is rising due to post-glacial rebound.
Seasonal Arctic sea ice	End-of-summer minimum ice extent has declined at a rate of 13% per decade over 1979-2012, while maximum winter sea ice extent has declined at a rate of 2.6% per decade.

Further changes in Canada's climate are inevitable. Relative to past Canada-wide averages, warmer temperatures and greater rainfall are expected along with increases in extreme heat and persistent heavy rainfall events, while snow precipitation and ice cover will decline over time. Coastal sea levels will continue to rise, while warmer waters and ocean acidification are expected to become more evident in most Canadian waters.[23] An overview of select projected climate changes across Canada are provided in Table 2.[24]

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[21] Hartmann, D.L., Klein Tank, A.G., and Rusticucci, M. (2013): Chapter 2: Observations: Atmosphere and Surface – Final Draft Underlying Scientific-Technical Assessment; in Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, (ed.) T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA..
[22] Adapted from Warren, F.J. and Lemmen, D.S. (2014): Synthesis; in Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation, (ed.) F.J. Warren and D.S. Lemmen; Government of Canada, Ottawa, ON.
[23] Warren, F.J. and Lemmen, D.S. (2014): Synthesis; in Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation, (ed.) F.J. Warren and D.S. Lemmen; Government of Canada, Ottawa, ON.
[24] Adapted from Warren, F.J. and Lemmen, D.S. (2014): Synthesis; in Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation, (ed.) F.J. Warren and D.S. Lemmen; Government of Canada, Ottawa, ON.

Table 2: **Projected climate trends across Canada**

Climate System Element	Observed Trends
Long duration hot events	The length, frequency and/or intensity of warm spells, including heat waves, are projected to increase over most land areas in Canada.
Rare hot extremes	Rare hot extremes are projected to become more frequent. For example, a 1 in 20 year extreme hot day is projected to become about a 1 in 5 year event over most of Canada by mid-century.
Heavy precipitation	More frequent heavy precipitation events are projected, with an associated increased risk of flooding.
Rare precipitation events	Rare extreme precipitation events are projected to become about twice as frequent by mid-century over most of Canada.
Snow cover duration	Widespread decreases in the duration of snow cover are projected across the Northern Hemisphere with the largest changes in maritime mountain regions, such as the west coast of North America.
Snow depth	Maximum snow accumulation over northern high latitudes is projected to increase in response to projected increases in cold season precipitation.
Global sea level rise to 2100	Estimates of the magnitude of future changes in global sea level by the year 2100 range from a few tens of centimetres to more than a metre. Over millennia, global sea-level rise may eventually amount to several metres.
Seasonal Arctic sea ice	A nearly ice-free summer is considered a strong possibility for the Arctic Ocean by the middle of the century although summer sea ice may persist longer in the Canadian Arctic Archipelago region.
Lake ice	With the continued advance of ice cover break-up dates and delays in ice-cover freeze up, ice cover duration is expected to decrease by up to a month by mid-century.

In Canada, studies are finding that droughts, especially in the southern prairies, heavy precipitation events with associated increased risk of flooding, wild forest fires, storms, and hot days and warm nights will increase in frequency and/or intensity in a warmer climate.[25]

Among the many challenges that have been revealed, in part because of Canada's changing climate and the associated impacts, is the state and age of the country's urban infrastructure. Canada is an urban nation. Over 80 per cent of Canada's population live in large cities (e.g. Montreal, Toronto and Calgary) and rapidly growing communities (e.g. Regina, Surrey and Markham).[26] The individuals, families and businesses that reside in Canada's urban locations rely on municipal infrastructure – roads, community buildings, recreational facilities, transit systems and water, wastewater and storm water infrastructure – for their survival and livelihood. This infrastructure, along with other assets such as the residential, commercial and industrial buildings, in which individuals and families reside, work and purchase goods and services, needs to be maintained and increased to support growing populations and expanding economies as well as to reduce the vulnerability of people and communities to the impacts of climate-related extreme events. Aging, inadequate and/or ill-maintained assets and infrastructure increase a community's risk to damage from such events.

[25] Warren, F.J. and Lemmen, D.S. (2014): Synthesis; in Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation, (ed.) F.J. Warren and D.S. Lemmen; Government of Canada, Ottawa, ON.
[26] http://www.davidsuzuki.org/blogs/science-matters/2014/03/canadas-success-depends-on-municipal-infrastructure-investments/

A recent study described the current state of Canada's municipal infrastructure, highlighting areas where investments are needed: Canada's first report card on municipal infrastructure was released in 2012.[27] The report card ranked the condition, as of 2009-2010, of infrastructure and infrastructure management in Canada through a survey of 123 Canadian municipalities. The infrastructure of relevance to this report includes that related to wastewater, drinking water, storm water and roads. Overall, the report card rated 30% of municipal infrastructure in Canada as "fair" and "very poor." The report card points to the cost of delaying infrastructure repairs, rehabilitation or renewal. The replacement cost of the assets ranked as fair and very poor was estimated to total $171.8 billion, nationally. While this paints a troubling picture for communities from a fiscal perspective, it also represents an opportunity to adapt infrastructure for a changing climate. As communities begin to invest in infrastructure repairs and renewal, future costs saving can be achieved by updating the infrastructure with climate change in mind. To do so communities will require the right analytical tools and capacity to make informed adaption decisions.

The need for repairs, rehabilitation and renewal, not just of municipal infrastructure but of other important assets (i.e. residential, commercial and industrial buildings), will be magnified in the face of Canada's changing climate. Water systems in some areas of Canada are currently unable to handle the increasing levels of precipitation. As a result, water damage has now surpassed fire as the number one cause of home insurance claims in some regions of the country.[28] Trends such as this will continue as the frequency and intensity of climate-related extreme events increase as will the damage and losses resulting from their impacts.

Indeed, losses from severe weather have been rising across the country. Extreme events, including storms (wind, ice and snow), flooding and heat waves have had significant economic and health and safety impacts on Canadians. In 2011, the Canadian insurance industry paid out a record $1.7 billion for property damage associated with major weather events, such as flooding, wind and wildfires.[29] This record was broken in 2013, when the insured losses from flooding damage in Southern Alberta (June) and Toronto (July) were tallied. Those flood events contributed to a total loss value of $3.2 billion.[30] Although factors other than climate also contributed to the rising insurance payout trend (e.g. increased exposure of property, increasing wealth and aging infrastructure), these losses demonstrate that Canadians are vulnerable to climate-related extreme events. To reduce the vulnerability of communities to such losses requires an understanding of the potential magnitude of the impacts and the associated expected costs at a community-specific level.

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[27] Felio, Guy, 2012, *Canadian Infrastructure Report Card*, http://www.canadainfrastructure.ca/downloads/Canadian_Infrastructure_Report_Card_EN.pdf
[28] Insurance Bureau of Canada, 2013, Request for Proposals, *The Economic Impacts of the Weather Effects of Climate Change on Vulnerable Communities*.
[29] Warren, F.J. and Lemmen, D.S. (2014): Synthesis; in Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation, (ed.) F.J. Warren and D.S. Lemmen; Government of Canada, Ottawa, ON.
[30] Personal communication, Insurance Bureau of Canada, April 10, 2015.

There is a growing body of literature on the economic impacts from climate change. The Economics of Climate Adaptation Working Group[31] published a study in 2009 estimating the costs versus benefits of adaptation measures using several case studies from around the world.[32] In Canada, the National Round Table on the Environment and the Economy (NRTEE) conducted a national analysis using various climate and growth scenarios to estimate the economic costs of climate change.[33] The NRTEE report projected that national costs due to climate change could increase from roughly $5 billion per year in 2020 to between $21 billion and $43 billion per year by the 2050's. These efforts, however, do not address the need to assess the specific projected impacts of climate change at the local level.

2.3 The Importance of Community-Specific Analysis

The losses described above are a product of a number of factors including not only the occurrence of climate-related extreme events, but also the vulnerability of human settlements and ecosystems to those events. In the case of the latter, vulnerability is in turn influenced by a range of factors including economic, social, geographic, demographic, cultural, institutional, governance, and environmental conditions.[34] These factors vary across time and space, which means that vulnerability and hence the risk of impacts from climate-related extreme events vary across time and space. All of this speaks to the need to assess the potential losses from extreme events on a community by community basis.

While assessments of the impacts of climate change have largely been focused at global[35] or national scales,[36] there is a growing body of work looking at community or city scale impacts.[37] A recent survey of the literature noted that a small number of cities have begun conducting bottom-up quantitative assessments of climate change risks under alternative scenarios.[38] In addition to the imperative to conduct city or community-specific analysis of potential impacts from climate-related extreme events due

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[31] The Economics of Climate Adaptation Working Group is a partnership between the Global Environment Facility, McKinsey & Company, Swiss Re, the Rockefeller Foundation, ClimateWorks Foundation, the European Commission, and Standard Chartered Bank
[32] Economics of Climate Adaptation Working Group (2009), Shaping Climate-Resilient Development: A Framework for Decision Making. Accessed Sept. 12, 2011. Available: http://media.swissre.com/documents/rethinking_shaping_climate_resilent_development_en.pdf.
[33] NRTEE, (2011), Paying the Price: The Economic Impacts of Climate Change for Canada.
[34] IPCC, 2012: Summary for Policymakers. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA.
[35] Stern, N., 2007, The Economics of Climate Change: The Stern Review. Cambridge University Press.
[36] National Round Table on the Environment and the Economy, 2011, Paying the Price: The Economic Impacts of Climate Change for Canada.
[37] Hunt, A., & Watkiss, P., 2011, Climate change impacts and adaptation in cities: a review of the literature. Climatic Change, 104(1), 13-49.
[38] Hunt, A., & Watkiss, P., 2011, Climate change impacts and adaptation in cities: a review of the literature. Climatic Change, 104(1), 13-49.

to variations in a number of factors across time and space, there are a number of benefits to conducting such analysis at the local or city-specific scale:[39]

- Integrating local knowledge with scientific and technical knowledge can arm decision makers with the best available local knowledge.
- The availability of location-specific climate information can reduce risk and improve climate change adaptation.
- Local populations document experiences with extreme weather events in many different ways and this knowledge can uncover existing capacity as well as vulnerabilities within specific communities.

Within this context, the current project focuses on quantifying the impacts of climate-related extreme events at the community scale. More specifically, this project quantifies the direct economic impacts of climate-related extreme events on built assets (stock) and business interruption (flow), as well as the secondary impacts (i.e. indirect and induced impacts) resulting from the ripple effect of the direct costs on the wider economy. It does this through an analysis of climate-related extreme events in two case study communities and through the development of a community impact assessment tool designed for use by analysts seeking to estimate the impact of climate-related extreme events for a particular community. The next chapter describes the approaches employed to undertake the case study impact analysis and develop the community impact assessment tool.

[39] IPCC, 2012: Summary for Policymakers. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA.

3. Approach

The *Background* section of this report describes the links between increasing greenhouse gas (GHG) emissions, rising global temperatures, increases in the frequency and magnitude of climate-related extreme events and the associated trend in damage to infrastructure and assets (depicted by exponential increases in the value of insurance claims associated with natural disasters). In doing so, it demonstrates the need for communities to better understand their potential vulnerability to impacts from climate-related extreme events, which is the focus of the current study. The approach employed in this study was designed to provide a replicable framework that analysts can use to quantify the impacts of climate-related extreme events at the community level. The replicable framework is comprised of a community engagement process and the community impact assessment tool (CIAT). The engagement process and the CIAT were developed by estimating the impact of climate-related extreme events in two case study communities.

This section of the report summarizes the approach employed to complete the community engagement process in the two case study communities. It also describes the steps employed to estimate the expected impact from climate-related extreme events in the two case study communities. In completing these steps, the research team developed the CIAT that can now be applied, along with an appropriate community engagement process, to other case study communities in Canada.

Note that case study-specific methods, data, and assumptions are presented in the two case study sections of this report as well as in technical appendices (Appendices A to C), which are referenced where appropriate throughout this and the case study-specific sections. See the *Glossary of Terms and Concepts* at the end of the report for definitions on key terms referenced in this section of the report.

3.1 Community Engagement

An important part of the approach employed in this study was the completion of a community engagement process with the two case study communities. The community engagement process served three purposes: 1) it was used to help scope the possible climate-related extreme events to a sub-set of events (two for each community) for further analysis; 2) it provided an avenue for data collection; and 3) it provided access to community members that could review the findings of the study. For each case study community, individuals with local knowledge pertaining to the study were identified and solicited for participation in a community advisory group.

The focal points of the community engagement process were two community advisory group meetings. Meeting #1 built an understanding on the project approach and goals, and saw participants identify and select the climate-related extreme events they wished to have addressed in the economic analysis. The participants engaged with the project team to discuss the multiple and diverse impacts, direct and indirect, that result from each hazard type. Meeting #2 saw participants revisit the assumptions and data used, identify gaps, and discuss preliminary results.

3.2 Case Study Impact Analysis

The community engagement process described above served several important purposes including providing access to data that was essential for estimating the impact of climate-related extreme events in the two case study communities. The case study impact analysis involved the quantification of:

1. The direct impact of climate-related extreme events
2. The secondary impacts of climate-related extreme events

CONCEPT NOTE - Direct and Secondary Impacts Defined

Direct impacts in this study constitute the economic impact that occurs at the source of where the climate-related extreme event influences the economy; this source could be either an economic sector or an asset class (e.g. residential buildings). The economic impact can result from damages to fixed assets (e.g. buildings and their contents damaged due to a flood) – measured as the value of the assets - and losses due to business interruptions (e.g. a restaurant has no electricity because of a power outage and so cannot operate) – measured as lost revenue - (see definitions for Impacts to Assets and Business Interruption below).

Secondary impacts result from the ripple effect of the direct impacts on the broader economy as subsequent spending (both indirect and induced) takes place. In this context, the spending resulting from the direct impact does not lead to a net gain to society. While some industries, such as those related to construction and remediation, might *benefit* from an increased demand for clean-up, repair and construction services following an extreme event, this benefit is more accurately characterized as a *transfer* of activity towards those industries responding to the event and away from those that suffer damages as a result of the event. The investment incurred to restore infrastructure to the state it was in prior to the extreme event thus represents an "opportunity cost" – the opportunity cost is the forgone benefit from transferring expenditure away from the activities that would have occurred in the absence of damage from the extreme event. Two categories of secondary impacts, which reflect indirect and induced spending, are captured in this study and the community impact analysis tool:

3. **Indirect impacts** encompass impacts resulting from inter-industry upstream purchases by the directly impacted sector. For example, increased demand for construction and repair services following a climate-related extreme event would lead to spending by the construction industry on all the inputs needed to support their industry (e.g. building supplies and tools). The indirect impact is the spending on inputs from all supporting industries of the sector that is directly impacted. There is an opportunity cost associated with this spending; the indirect spending resulting from the direct spending that takes place in response to damages from a climate-related extreme event represents an opportunity cost in that it is spending that would have taken place elsewhere (in response to direct spending elsewhere) in the absence of damages from a climate-related extreme event (i.e. instead of taking place in response to the climate-related extreme event it would have taken place in response to expenditure elsewhere in the economy).
4. **Induced impacts** encompass impacts resulting from changes in the production of goods and services in response to increased consumer income and hence expenditures driven by the direct and indirect impacts. For example, in response to a climate-related extreme event, employees in the directly impacted industry and indirect supporting industries would spend the income they earn on housing, utilities, groceries, and other consumer goods and services. The induced impact results from this household spending as it ripples through the region's economy. There is an

opportunity cost associated with this spending; the induced spending resulting from the direct and indirect spending that takes place in response to damages from a climate-related extreme event represents an opportunity cost in that it is spending that would have taken place elsewhere (in response to direct and indirect spending elsewhere) in the absence of damages from a climate-related extreme event (i.e. instead of being induced by expenditure in response to the climate-related extreme event it would have been induced by expenditure elsewhere in the economy).

Two categories of direct and secondary impacts are captured in this study and in the community impact analysis tool:

Impacts resulting from damage to assets encompass damages to assets such as buildings, building contents and electrical power lines. For example, the damage to the contents of a residential building due to a flooding event is an impact from damaged assets. In the context of this study, impacts to assets are equivalent to the restoration costs required to restore the given asset to a renewed state directly after the damage is caused by the given climate-related event. The spending resulting from the impact does not lead to a net gain to society. Rather, it is a redistribution of spending across the economy, from sectors experiencing losses due to damage from climate-related events to sectors realizing gains as they respond to the damages and return the economy to its former state. This spending is therefore associated with an opportunity cost (because in the absence of climate-related damaged, the spending would have taken place elsewhere in the economy) and is hence captured here as an impact.

Impacts resulting from business interruptions or lost economic activity encompass impacts to the flow of monetary transactions from business interruptions due to power outages. For example, the temporary closure of a retail store or a restaurant during a power outage constitutes an impact from business interruptions. Note that in this context, the lost economic activity generally leads to a net loss to society because each affected business is forced to cease economic activities during regular working hours for as long as it takes for power to be restored (Appendices A and B provide greater details on how impacts from business interruptions are calculated in this study).

In this report, direct impacts are first expressed in terms of *gross output*. Gross output is a measure of economic activity that includes intermediate inputs (i.e. materials used in production processes) and value added (i.e. land, labour and capital). Gross output is used as the starting point in the analysis because the inclusion of intermediate inputs allows for a better reflection of the inter-industry linkages in the secondary impact analysis (which employs *within* province multipliers published by Statistics Canada). The direct and secondary impacts are then expressed in terms of *gross domestic product* (GDP) as this reflects the value of production in any given year independent of the intermediate inputs that could have been produced in prior years (GDP is also known as 'net output'). In the secondary impacts sections of the case study sections of this report, the graphs include both the direct and secondary impacts expressed in terms of GDP. Note that results expressed in terms of gross output will always be greater than GDP as GDP is a sub-component of gross output. The gross output results are therefore not directly comparable to the results expressed as GDP.

The **sum of the direct and secondary impact estimates** should not be interpreted as a total impact estimate. Total implies a full and all-encompassing assessment of impacts, which is not the focus of the current study. The focus of this study is on the direct and secondary impacts of select climate-related extreme events on community assets and business interruptions given the data available to inform such an analysis.

By working through the quantification of direct and secondary impacts to assets and from business interruptions from climate-related extreme events in the two case study communities, a series of elaborate spreadsheet tools (one for each climate-related extreme event under consideration) were developed. The resulting spreadsheets form the basis of the CIAT that can be applied to other case study communities. The approaches employed to develop the spreadsheets and thus calculate the direct and secondary impacts for each of the timeframes and climate scenarios, which were subject to an expert peer review process, are described in turn in the sub-sections below. This is followed by a description of the CIAT.

3.2.1 Measuring the Direct Impact of Climate-related Extreme Events

As is noted in the text box above, direct and secondary impacts from climate-related extreme events are captured in the case study analysis from damage to physical assets and impacts resulting from business interruptions (i.e. lost economic activity) due to power outages. In this study, these impacts are measured under different climate change scenarios to capture the direct and secondary impacts that are attributed to climate change. This section of the report describes the approach employed to measuring the direct impacts of climate-related extreme events. Section 3.2.2 describes the approach employed for secondary impacts.

The generally agreed upon approach to measuring the direct impacts from probabilistic natural hazards at a specific location is to estimate the expected annual damages (EAD), which is particularly prevalent within the flood risk analysis literature.[40] This process fits well when analyzing climate related extreme events under alternative climate change scenarios for two primary reasons: 1) it accounts for the probabilities of different event intensities occurring at a specific site; and 2) climate change is ultimately driving changes in those probabilities (i.e. climate change results in more frequent extreme events). **Expected annual damages are a measure of the value of the impacts in any given year that can be expected from a specific extreme event taking into account the magnitude of the event and the probability of the event occurring.**[41]

Climate-related extreme events are by nature uncertain. It is not known when or where they will occur. To account for this uncertainty in the context of measuring the direct impacts of an event, the probability of a particular extreme event occurring is taken into consideration by calculating the EAD for the particular event. The EAD for any given event is equal to the probability of the event occurring multiplied by the damage costs that result from the event.[42] To determine damage costs, the expected physical impact from the event (e.g. the number of units affected) is multiplied by the unit value (e.g. the dollars per unit) of the affected assets. Where applicable, damage costs also include impacts associated with business interruption. The text box below contains a simplified mathematical equation for EAD.

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[40] Jonkman, S. N., Bočkarjova, M., Kok, M., & Bernardini, P. (2008). Integrated hydrodynamic and economic modelling of flood damage in the Netherlands.Ecological economics, 66(1), 77-90.
[41] Forster, S.; Kuhlmann, B.; Lindenscmidt, K.E.; Bronstert, A. 2008. Assessing flood risk for a rural detention area. *Natural Hazards and Earth System Sciences* 8: 311-322.
[42] Merz, F.; Thieken, A.H.; Gocht, M. 2007. Flood risk mapping at the local scale: concepts and challenges. In: Flood Risk Management in Europe: Advances in Natural and Technological Hazards Research. Springer, 231-251.

Calculating Expected Annual Damages (EAD)

Expected Annual Damages (EAD) are described by the following mathematical equation:

$$EAD = \sum D_i \times P_i$$

where EAD = expected annual damage across all possible event probabilities

D_i = damage costs for event *i*

P_i = probability for event *i*

In the case of this analysis, damages (D_i) account for damages to assets and business interruption.

Figure 5 depicts hypothetical current (baseline) and future damage probability relationships. For any given level of damage, the “future damages” curve is associated with higher probability estimates, relative to the “current damages” curve, and vice versa.

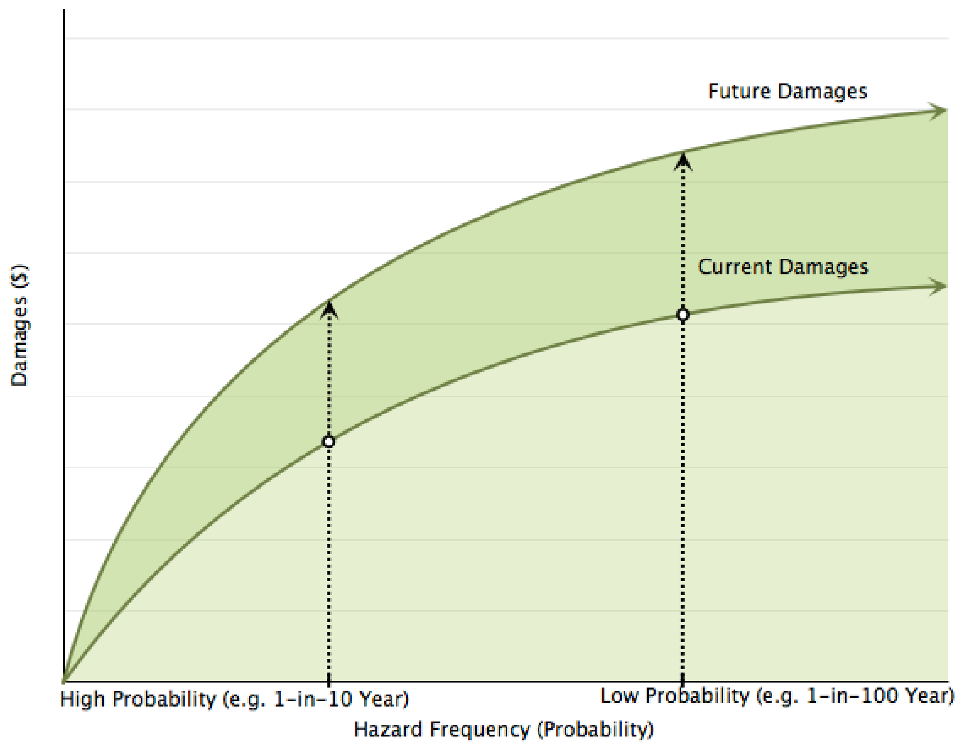

Figure 5: **Damage probability relationship for hypothetical current and future climate scenarios**

CONCEPT NOTE – The Importance and Implications of Probability in Calculating Direct Impacts

Climate-related extreme events are inherently uncertain. It is not known when an event of a particular magnitude will occur. For instance, a 1-in-10 year event could occur 2 years in a row, then not again for 20 years. By examining the frequency with which events occur, one can estimate the likelihood or probability that an event of a given magnitude will occur in any given year. Capturing the probability of extreme events occurring across a range of event magnitudes is important because it provides a means to adjust damage cost estimates to account for the uncertainty associated with the occurrence of extreme events. Probability also plays a role in analyzing potential impacts of events under future climate change scenarios. In this capacity, probability values for any given event are adjusted upwards or downwards to reflect either an increase in the likelihood of the event occurring under an alternative climate change scenario or a decrease in the likelihood of the event occurring under an alternative climate change scenario.

The figure above demonstrates the increase in damages and probabilities under a future climate scenario relative to a current climate scenario. A number of factors can cause a current damage probability curve to shift in the manner depicted in the figure. For example, a changing climate can increase or decrease the probability of an event occurring or the magnitude of the event. Shifts in socio-economic conditions (i.e. that would result in changes in the physical distribution of assets on the landscape or population growth) can also result in changes in damages and probabilities. Thus, it is necessary to capture both changes in damage costs and probabilities, and expected changes in future socio-economic conditions in EAD calculations. This was done in the current project for each of the timeframes of relevance to the analysis. More specifically, for each of the two case study communities, the general approach to the impact analysis was to:

1. Establish the current socio-economic conditions.
2. Establish the current climate-related extreme events.
3. Project current socio-economic conditions to estimate baseline socio-economic conditions for 2020 and 2040.
4. Project current climate-related extreme events to estimate baseline climate change conditions and expected annual damages for 2020 and 2040.
5. Project climate-related extreme events and expected annual damages for a moderate climate change scenario and a high climate change scenario for 2020 and 2040.
6. Calculate the expected annual damages attributed to climate change for each scenario by subtracting the expected annual damages in 2020 and 2040 under the baseline climate change conditions from the expected annual damages in 2020 and 2040 for each of the moderate and high climate change scenarios.

Figure 6 below depicts the scope of the impact analysis in terms of the future year and climate change scenarios considered. In the figure, the current conditions are defined by the intersection of today's climate (which is based on recent pre-2014 climate conditions) with today's socio-economic conditions. It is the current conditions from which socio-economic conditions for 2020 and 2040 are projected taking into consideration expected population growth and future land use planning (labelled “EAD - Baseline 2020” and “EAD – Baseline 2040” in the figure). The baseline conditions describe the EAD resulting from today’s climate given the projections in socio-economic conditions for 2020 and 2040. The baseline forms the basis of comparison for calculating damages that are attributed to climate change under the moderate and high climate change scenarios. More specifically, **the EAD that is attributed to climate change in a given future year is calculated as the difference between the EAD for the baseline climate scenario (today’s climate) and the EAD of the future climate scenarios (moderate and high climate).**

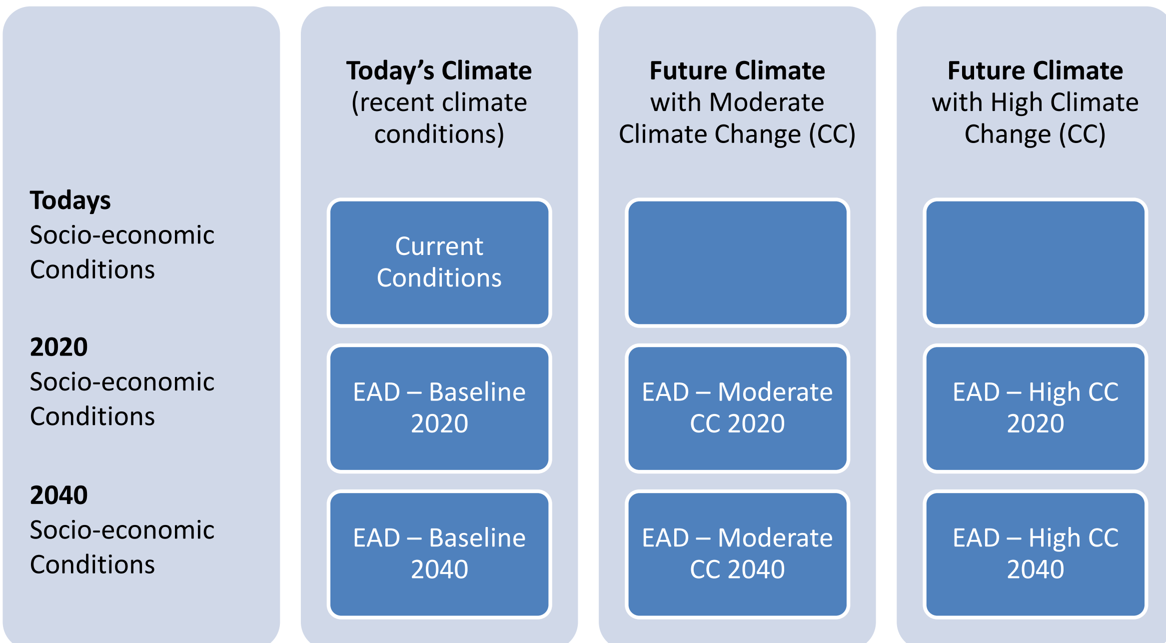

Figure 6: Scope of the direct impact analysis

The sub-sections below provide details on the approaches employed to estimate the EAD under the baseline, moderate and high climate change scenarios as well as the process for projecting climate-related extreme events and socio-economic conditions for 2020 and 2040, beginning with the latter.

3.2.1.1 Projecting Socio-economic Conditions

As is noted above, when estimating the EAD from climate change it is important to account for anticipated changes in socio-economic conditions that could influence exposure to extreme events. Indeed, a significant component of estimating future damage costs is the spatial distribution and value of assets that could be damaged by extreme events and the economic output in the community under consideration.

In this analysis, the future (2020 and 2040) distribution of assets is estimated based on a combination of population forecasts and official land use plan mapping. Population forecasting for each of the case study communities was used to calculate the additional number of people each community would need to accommodate and hence the corresponding assets required (i.e. the number of residential, commercial and industrial buildings). Land use planning documents were used to spatially allocate assumed new buildings and businesses in each of the communities.

3.2.1.2 Projecting Moderate and High Climate Conditions

The data employed to establish the moderate and high climate change scenarios was obtained from a number of publicly available sources. In particular, it was obtained from historical and local sources and includes data from general circulation models (GCM) - Special Report Emission Scenarios (SRES)[43] and Representative Concentration Pathway (RCP)[44] scenarios - depending on data availability.[45] The method used to project the scenarios is replicable and represents a robust range of possible climate outcomes (beyond the moderate and high climate change scenarios employed in this analysis) that can be used in future economic analyses.

The figure below demonstrates the timeframes over which the climate data centred in the direct impact analysis. For the baseline climate conditions, historical climate data, covering a period from 20 to 50 years ago, was obtained. This data was used to define the climate change conditions for the baseline year of 2015. For the two future years, data was obtained from climate projection models and scenarios (noted above) where the data spanned a time window of 10 to 20 years on either side of the future year, 2020 or 2040.

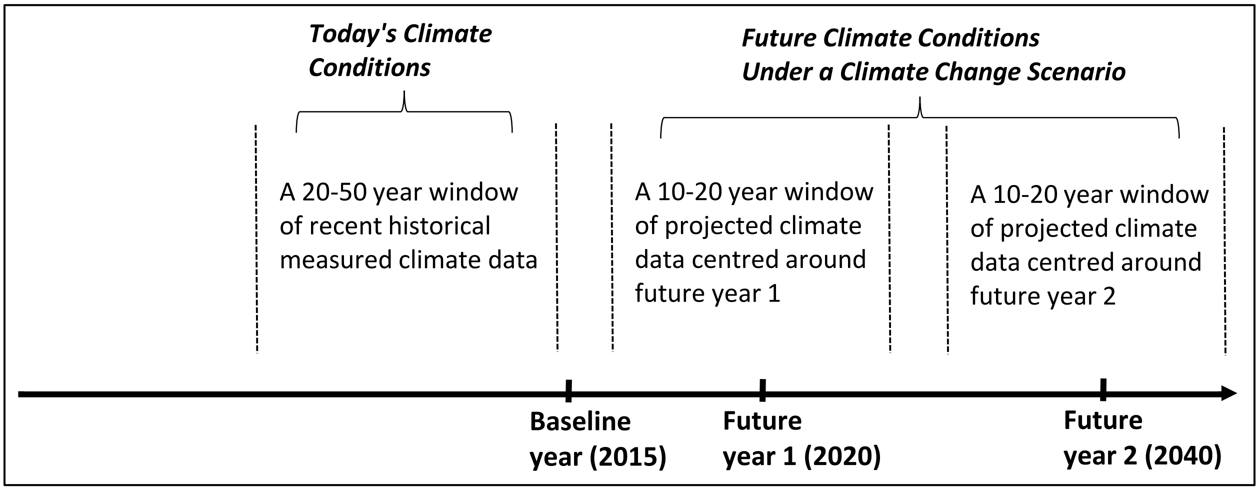

Figure 7: **A conceptual overview linking climate data with the baseline and future climate conditions**

[43] IPCC, 2000. Special Report, Emissions Scenarios. ISBN: 92-9169-113-5 [Accessed 10.10.2014] https://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf.
[44] IPCC, 2014. Scenario Process for AR5, Representative Concentration Pathways (RCPs). [Accessed 02.02.2015] http://sedac.ipcc-data.org/ddc/ar5_scenario_process/RCPs.html.
[45] See Appendix A and B for greater details into what RCP and SRES scenarios and GCM models were utilized for each case study.

For the two future years, the focus of the data collection was on obtaining data that would pertain to the moderate and high climate scenarios. Such data was extracted from GCM results that depicted either moderate or high climate change conditions (both SRES [for wind and freezing rain] and RCP [for flooding] scenarios are used in this analysis) over a 10 to 20 year time frame centered around 2020 and 2040. The precise definitions of the moderate and high climate change scenarios varied by extreme event and depended on data availability (see Concept Note below).

CONCEPT NOTE – Climate Data, Models and Scenarios

Climate data describing the weather intensity was required to estimate the economic impacts of climate-related extreme events for specific return periods. The metrics used to quantify weather intensity for each case study were the following:

- The HRM:
  - Storm Surge Flooding: flood depth, measured in meters
  - Extreme Wind: peak wind gust, measured in meters per second
- Mississauga:
  - Storm Water Flooding: rainfall intensity, measured in millimeters per hour
  - Freezing Rain: ice thickness and average wind speed, measured in millimeters and meters per second, respectively

Climate data utilized for the **baseline climate change scenario** were based on historical data measured at weather stations within or adjacent to each community. Climate data sets were collected across a historic period leading up to the baseline year and this data informed the weather intensity (using the above metrics) as a function of return period.

Climate data utilized for the **future climate change scenarios** stemmed from general circulation models (GCMs) that simulated widely accepted greenhouse gas emission trajectories (i.e. climate change scenarios) spanning this century. The climate data output relied upon in this analysis originated from climate models and climate change scenarios from several sources where the most recently available and widely acceptable models and climate change scenarios were used. GCM climate data outputs were downscaled to local community conditions. The GCM models, climate change scenarios (representing either a high or moderate climate change scenario), and down-scaled modelling and data sources that generated the climate data output for each case study were as per the bullets below.

- The HRM:
  - Storm Surge Flooding:
    - Climate change scenarios: High climate change – RCP8.5; Moderate climate change – RCP4.5;
    - Climate models: See Church et al. (2013).[46]
    - Downscaled model source: James et al. (2014).[47]
  - Extreme Wind:
    - Climate change scenarios: High climate change – SRES A2; Moderate climate change – SRES B1;

[46] Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, 2013a. Sea Level Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[47] James, T.S., Henton, J.A., Leonard, L.J., Darlington, A., Forbes, D.L., Craymer, M. 2014. Relative Sea-level Projections in Canada and the Adjacent Mainland United States. Natural Resources Canada, Geological Survey of Canada, Open File 737, [Accessed 10.10.2014] http://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/fulle.web&search1=R=295574.

- Climate models: CGCM3.1/T63, CNRM-CM3, CSIRO Mk3.0, ECHAM5, ECHO-G, GFDL CCM2, GISS-ER and MIROC3.2.[48]
- Downscaled model source: Cheng et al. (2014).[49]

- Mississauga:
  - Storm Water Flooding:
    - Climate change scenarios: High climate change – RCP8.5; Moderate climate change – RCP4.5;
    - Climate model: CanESM2.[50]
    - Downscaled model source: IDF CC Tool.[51]
  - Freezing Rain:
    - Climate change scenarios: High climate change – SRES A2; Moderate climate change – SRES B2;
    - Climate models: CGCM1, and CGCM2;[52]
    - Downscaled model source: Cheng et al. (2007).[53]

See Appendix A and B sections *Climate and Weather Data and Scenarios* for further insight into how this data was employed in this analysis.

3.2.1.3 Establishing Baseline Damage Estimates

In this study, the impact of the climate-related extreme events is measured as the difference in the EAD between the baseline climate change scenario and the moderate and high climate change scenarios for each of 2020 and 2040. The first step in estimating the EAD attributed to climate change is therefore establishing baseline EAD estimates for each climate-related extreme event.

Climate and socio-economic projections were used to establish baseline conditions in each of the case study communities. The baseline conditions were used to estimate the baseline EAD. **The baseline EAD are defined as the expected damages due to climate-related extreme events in each of the communities given current and projected (i.e. 2020 and 2040) socio-economic conditions and today's climate.** The resulting baseline EAD estimates for 2020 and 2040 were used to compare the EAD estimates for 2020 and 2040 under the future climate change scenario where the difference

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[48] CGCM3.1/T63: Canadian Centre for Climate Modelling and Analysis (CCCma) Coupled Global Climate Model, version 3.1 (T63 spectral resolution); CNRM-CM3: Centre National de Recherches Meterologiques Coupled Global Climate Model, version 3; CSIRO Mk3.0: Commonwealth Scientific and Industrial Research Organization Mark, version 3.0; ECHAM5, ECHO-G: ECHAM and the Global Hamburg Ocean Primitive Equation; GFDL CCM2: Geophysical Fluid Dynamics Laboratory Climate Model, version 2.0; GISS-ER: Goddard Institute for Space Studies Model E-R; and MIROC3.2: Model for Interdisciplinary Research on Climate, version 3.2 (medium resolution). Data output from these models was attained from: PCMDI, About theWCRPCMIP3 multi-model dataset archive. [Available online at http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php.]
[49] Cheng, C. S., Lopes, E., Fu, C., Huang, Z., 2014. Possible Impacts of Climate Change on Wind Gusts under Downscaled Future Climate Conditions: Updated for Canada. Journal of Climate 27(3):1255-1270.
[50] CanESM2: Canadian Earth System Model. See Chylek, P., Li, J., Dubey, M.K., Wang, M., Lesins, G., 2011. Observed and model simulated 20th century Arctic temperature variability: Canadian Earth System Model CanESM2. Atmospheric Chemistry and Physics Discussions 11:22893-22907.
[51] IDF CC Tool for deriving rainfall Intensity-Duration-Frequency Cures for future climate scenarios. Version 1.0.3863. [Accessed December 1, 2014] http://www.idf-cc-uwo.ca/.
[52] CGCM1: 1st generation Canadian GCM; CGCM2: 2nd generation Canadian GCM. See Environment Canada, 2014, [Climate Change] Models. [Accessed 02.02.2015] http://ec.gc.ca/ccmac-cccma/default.asp?lang=En&n=4A642EDE-1.
[53] Cheng, C.S., Auld, H., Li, G., Klassen, J., Li, Q. (2007) Possible impacts of climate change on freezing rain in south-central Canada using downscaled future climate scenarios. Natural Hazards and Earth System Sciences 7:71-87.

between the climate scenarios is the EAD that is attributed to climate change. The following steps were taken to estimate the baseline EAD for 2020 and 2040:

1. Establish a spatially referenced inventory of today's community assets and their associated values.
2. From the current conditions (step 1) forecast a spatially referenced inventory of community assets and their associated values for 2020 and 2040 drawing on population growth projections and future land-use plans.
3. Establish the spatial distribution of today's climate-related extreme events for a single event of a given magnitude.
4. For each of 2020 and 2040, overlay the asset distribution (step 2) with the distribution of the extreme event (step 3) to identify the assets damaged under the particular event given the particular magnitude.
5. Calculate the damage costs (quantity of assets damaged multiplied by the value of those assets and losses due to business interruptions, where applicable) associated with the extreme event for all affected assets.
6. Determine an associated probability of occurrence based on the frequency and magnitude level of the given extreme event.
7. Repeat steps 1 through 6 for extreme events of varying severities and probabilities.
8. Plot the resulting damage probability points and quantify the area under the curve; the area under the curve is the EAD under baseline conditions.

The result of completing the steps above is an estimate of the EAD due to climate-related extreme events under baseline conditions for 2020 and 2040 assuming today's climate and projected socio-economic changes. It is the baseline EAD estimates from which damages resulting from the moderate and high climate change scenarios are benchmarked to determine the EAD that is attributed to climate change (described below).

3.2.1.4 Establishing High and Moderate Climate Damage Estimates

A similar process to that described above was used to establish EAD estimates for each of the future climate change scenarios. For each of 2020 and 2040, the following steps describe the process for estimating EAD under the moderate and high climate change scenarios:

1. Use the baseline spatially referenced inventory of community assets and their associated values for 2020 and 2040 (an outcome of establishing the baseline conditions described above).
2. Forecast the spatial distribution of climate-related extreme events for an event of a given magnitude under moderate and high climate change scenarios.

3. Overlay the asset distribution (step 1) with the distribution of the extreme event (step 2) under each climate change scenario to identify the assets damaged under the particular event given the particular magnitude.
4. Calculate the damage costs (quantity of assets damaged multiplied by the value of those assets and losses due to business interruptions, where applicable) associated with the extreme event for all affected assets.
5. Determine an associated probability of occurrence based on the frequency and magnitude level of the given extreme event.
6. Repeat steps 1 through 5 for extreme events of varying magnitudes and probabilities under each climate change scenario.
7. Plot the resulting damage probability points and quantify the area under the curve; the area under the curve is the EAD for the future climate scenarios.

The result of completing the steps above is an estimate of EAD due to climate-related extreme events for 2020 and 2040 under moderate and high climate change scenarios. As is described below, the direct impact of the climate-related extreme event under consideration that is attributed to climate change is equal to the difference between the EAD estimates under the moderate and high climate change scenarios and the EAD estimates for the baseline conditions.

3.2.1.5 Calculating the Direct Impact Attributed to Climate Change

To calculate the EAD that is attributed to climate change for each time frame (2020 and 2040) under each climate change scenario, the following steps were taken:

1. Calculate the area under the damage probability curve for baseline conditions in 2020.
   - This is the EAD in 2020 under today's climate conditions.
2. Calculate the area under the damage probability curve for baseline conditions in 2040.
   - This is the EAD in 2040 under today's climate conditions.
3. Calculate the area under the damage probability curve under moderate climate change for 2020.
   - This is the EAD in 2020 under a moderate climate change pathway.
4. Calculate the area under the damage probability curve under moderate climate change for 2040.
   - This is the EAD in 2040 under a moderate climate change pathway.
5. Subtract the area under the baseline probability curve from the damage probability curve under moderate climate change for 2020.
   - This is the EAD in 2020 that is attributed to climate change under a moderate climate change pathway.
6. Subtract the area under the baseline probability curve from the damage probability curve under moderate climate change for 2040.

- This is the EAD in 2040 that is attributed to climate change under a moderate climate change pathway.

7. Calculate the area under the damage probability curve under high climate change for 2020.
   - This is the EAD in 2020 under a high climate change pathway.
8. Calculate the area under the damage probability curve under high climate change for 2040.
   - This is the EAD in 2040 under a high climate change pathway.
9. Subtract the area under the baseline probability curve from the damage probability curve under high climate change for 2020.
   - This is the EAD in 2020 that is attributed to climate change under a high climate change pathway.
10. Subtract the area under the baseline probability curve from the damage probability curve under high climate change for 2040.
    - This is the EAD in 2040 that is attributed to climate change under a high climate change pathway.

By completing the steps identified above, EAD estimates for 2020 and 2040 across baseline, moderate and high climate change scenarios can be compared and the portion of EAD attributed to climate change under moderate and high climate change scenarios in relation to the baseline climate change scenario estimated.

As a complement to EAD estimates, it is useful and informative to consider damage estimates for particular climate-related extreme events of a given magnitude (e.g. the expected impact for a 1 in 100 year flood event). These are presented along with EAD results in the case study sections of this report. The expected cumulative impact of a climate-related extreme event is also presented as a means to demonstrate the potential cost of extreme events over a period of time.

3.2.2 Measuring the Secondary Impacts of Climate-related Extreme Events

Once the direct impacts from climate-related extreme events were estimated (as per the approach described above), the secondary impacts (indirect and induced) resulting from the ripple effect of the direct impacts on the economy at large were analyzed. To calculate secondary impacts, direct impact estimates were aggregated into appropriate economic sectors and were used to shock a series of models capable of measuring secondary impacts.

This sub-section describes the approaches employed to estimate the secondary impacts of the climate-related extreme events. For each of the case study communities, the secondary impacts of the climate-related extreme events were estimated using three approaches:

- **Readily available and published Statistics Canada multipliers:** These multipliers provide a common platform for all users regardless of their degree of knowledge and comfort with secondary impact modelling approaches.
- **Input-output tables calibrated to each city and time period:** This approach provides increasingly custom multipliers and hence a somewhat more sophisticated approach than the multiplier approach identified above.
- **A stylized computable general equilibrium model:** Relative to the two approaches above, this approach is the most sophisticated in nature and would be employed by analysts with a relatively high degree of knowledge and comfort with secondary impact modelling approaches. This approach is consistent with the model used by Natural Resources Canada for other climate change vulnerability case studies.[54]

The specific steps taken to conduct the secondary impact modelling under each of these approaches are described in the sub-sections below. First, an overview of the modelling approaches employed and their strengths and weaknesses is presented.

3.2.2.1 An Overview of General Equilibrium Models

General equilibrium (GE) models are the standard tool used to calculate the secondary impacts associated with a direct impact to an economy. Impacts to one industry are not isolated and GE models are designed to identify inter-industry linkages and economic interdependence. Broadly speaking, two

[54] Assessing potential biophysical and socioeconomic impacts of climate change on forest-based communities: a methodological case study. 2008. Williamson, T.B.; Price, D.T.; Beverly, J.; Bothwell, P.M.; Frenkel, B.; Park, J.; Patriquin, M.N. Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta. Information Report NOR-X-415E. 136 p. http://cfs.nrcan.gc.ca/publications?id=29156

classes of GE models exist: input-output (I-O) models and computable general equilibrium (CGE) models.[55]

Input-output models are a quantitative economic technique that represents the interdependencies between the agents (i.e. industries, households, and government) of a defined regional economy. Input-output models are relatively simple allowing widespread application, but they are also less theoretically grounded in economics compared to CGE models.[56] The biggest advantage of the I-O approach is that Statistics Canada maintains a well-developed I-O database and produces multipliers and tables at provincial and national scales.[57] Input-output techniques have been in use for decades and are universally accepted with most countries maintaining such databases.

Multipliers are based on I-O model interactions and are also used to measure secondary impacts. Provincial and national multipliers are readily available from Statistics Canada and are often used to determine indirect and induced impacts without needing to build a formal I-O model.[58] However, their ability to be customized to a specific community is limited and without the detailed I-O tables, it is not possible to tease out geographic areas of particular interest. While the I-O multipliers provide the ability to produce quick estimates of the order of magnitude of secondary impacts, the main disadvantage of this approach is that they do not include any behavioural economic responses to changes. Labour and capital are fixed as sector-specific and there are no potential movements across sectors and no potential responses to price changes. For example, a negative impact in an industry may result in the dismissal of staff and potentially a decline in wage rates. In the I-O context, there are no offsetting effects of the dismissed staff being hired in other industries and price changes are not considered.

Computable general equilibrium models are similar to I-O models, but can be more flexible in terms of the treatment of a variety of assumptions including the mobility of labour and capital across industries. These models have a firm grounding in economic theory (i.e. unlike I-O models, they are able to incorporate behavioural responses of economic agents to price changes). While CGE models have most often been used in the past at a provincial or larger scale of analysis, the occurrence of community-level CGE models has become more common in the literature.[59,60,61,62] Computable general equilibrium models are

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[55] A framework for assessing vulnerability of forest-based communities to climate change. 2007. Williamson, T.B.; Price, D.T.; Beverly, J.; Bothwell, P.M.; Parkins, J.R.; Patriquin, M.N.; Pearce, C.; Stedman, R.C.; Volney, W.J.A. Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, Edmonton, Alberta. Information Report NOR-X-414E. 50 p. http://cfs.nrcan.gc.ca/publications?id=27507

[56] Burnett, P., Cutler, H., and Thresher, R. (2007). The impact of tourism for a small city: A CGE approach. Journal of Regional Analysis and Policy 37(3): 233-242.

[57] Statistics Canada Input-Output Multipliers. http://www5.statcan.gc.ca/olc-cel/olc.action?objId=15F0046X&objType=2&lang=en&limit=0

[58] Statistics Canada Input-Output Multipliers. http://www5.statcan.gc.ca/olc-cel/olc.action?objId=15F0046X&objType=2&lang=en&limit=0

[59] Patriquin, M.; Alavalapati, J.; Wellstead, A.; White, W. 2002. A comparison of impact measures from hybrid and synthetic techniques: a case study of the Foothills Model Forest. Annals of Regional Science 36: 265-278.

not without their criticism, however. For example, the increased complexity and data requirements often make the CGE framework costly and impractical at small geographic scales. The increased complexity is a particular concern that may limit the applicability of CGE methods at a municipal scale. Another key criticism of this approach is that there are no readily agreed upon specifications, meaning a wide range of specifications are possible creating a wide variation in model results. In response to the criticism of complexity, a number of hybrid I-O / CGE modelling approaches have been developed.[63] This is the case for example with what is referred to as *stylized CGE models*. Stylized CGE models are largely based on the same information as the I-O tables, but offer more flexibility in terms of the treatment of a number of key variables such as labour and wages, sector outputs, and rental rates of capital. For example, the CGE specification used in this study allows labour to migrate between industries in response to direct impacts.

The economic impact estimates that are derived from I-O models are generally thought to be larger than those derived from CGE models. The main reason for this is that I-O models are by nature linear and unidirectional, meaning that there are no offsetting effects in terms of the movement of labour and capital between industries. Computable general equilibrium models are generally thought to produce more modest impact estimates since offsetting impacts, depending on the model specification, can be considered. For instance, if labour is released from one industry due to the closure of a business, a CGE model could consider the movement of all or part of the released labour to another industry, whereas the I-O model would not.

Both GE modelling approaches are used in the scenario analysis to provide estimates of economic indicators such as gross output, gross domestic product (GDP) and employment. Gross output is defined as the value of sales including value added and all intermediate goods used in the production process. Gross domestic product is the value added component of gross output representing the value of production in a defined time period. In other words, GDP is the value of gross output less the intermediate goods in the production process. One typical measure of GDP is the sum of payments to primary factors of production (land, labour and capital) plus taxes net of subsidies. In this study, employment is measured as the number of full-time equivalent (FTE) jobs. Output, GDP, and employment were selected as the outputs for this study, as they are the main components in the multiplier framework and most weather-related impacts are expressed in the media relative to GDP. The secondary impact results for GDP are

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[60] Lantz, V. and Yigezu, Y. (2003). An economic impact analysis of market and policy changes in New Brunswick Fundy Model Forest community. Forestry Chronicle 79(5): 957-966.
[61] Burnett, P., Cutler, H., and Thresher, R. (2007). The impact of tourism for a small city: A CGE approach. Journal of Regional Analysis and Policy 37(3): 233-242.
[62] Schwarm, W. and Cutler, H. (2003). Building small city and town SAMs and CGE models. Review of Urban and Regional Development Studies 15(2): 132-46.
[63] Patriquin, M.; Alavalapati, J.; Wellstead, A.; White, W. 2002. A comparison of impact measures from hybrid and synthetic techniques: a case study of the Foothills Model Forest. Annals of Regional Science 36: 265-278.

presented in the case study sections of this report (Sections 6 and 7). Employment and gross output results for the secondary impact results are contained in Appendices D-E.

3.2.2.2 Modelling Secondary Impacts

Given the range of GE modelling tools available for estimating secondary impacts and the relative strengths and criticisms of each (described above), to demonstrate the relative sensitivity of the secondary impact estimates, three modelling approaches were used in this study:

- The use of readily available and published Statistics Canada multipliers
- The use of I-O tables calibrated to each city and time period
- The use of community-level stylized CGE models

The use of these three approaches provides a range of results reflecting varying levels of sophistication (with Statistics Canada's multipliers being the least sophisticated and CGE models being the most sophisticated) and also accessibility (with Statistics Canada's multipliers and I-O tables being readily available and CGE models being less common). The development of region-specific I-O and stylized CGE models for each case study community required down-scaling the most recently available provincial I-O tables produced by Statistics Canada.[64] The process of scaling down the I-O data to a regional level involved comparing readily available labour force data at the municipal level with that at the provincial level and adjusting coefficients based on the relative difference in labour force productivity between the province and the community.[65] The 2011 I-O tables for each community were projected forward and re-balanced to 2020 and 2040 using socio-economic forecasts of population, labour force and GDP by industry. These future socio-economic conditions were considered part of the baseline scenario (i.e. given historical climate change) against which the moderate and high climate change impact scenarios were compared.

The community-level stylized CGE models were calibrated to the years 2020 and 2040 using the I-O tables described above, along with additional parameters collected from the literature and through discussions with relevant experts in the communities.

Direct damage impact estimates aggregated across sectors were applied to the stylized CGE models and the I-O models by shocking the models to generate estimates of secondary impacts on gross output, GDP and employment. Note that given the municipal nature of the impacts, the multipliers used in this study consider only the 'within province' impacts of the home province for each case study community.

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[64] Statistics Canada Provincial Input-Output Tables. http://www5.statcan.gc.ca/olc-cel/olc.action?objId=15F0042X&objType=2&lang=en&limit=0
[65] Patriquin, M.; Alavalapati, J.; Wellstead, A.; White, W. 2002. A comparison of impact measures from hybrid and synthetic techniques: a case study of the Foothills Model Forest. Annals of Regional Science 36: 265-278.

CONCEPT NOTE – Secondary Impact Modelling Outputs

Outputs from secondary impact modelling exercises can be expressed as being derived from **Type I multipliers**, which express the sum of direct and indirect impacts, or **Type II multipliers**, which express the sum of direct, indirect and induced impacts.

In this report, secondary impact estimates for the case study communities are based on Type II multipliers and hence encompass direct, indirect and induced impacts.

3.2.3 The Sum of Direct and Secondary Impacts

The final step in the case study impact analysis was to sum the direct and secondary impacts to get a bottom line estimate of the impact of climate-related extreme events for each of the case study communities. Note that the sum of the direct and secondary impact estimates should not be interpreted as a *total* impact estimate. Total implies a full and all-encompassing assessment of impacts, which was not the focus of the current study. The focus of this study is on the direct and secondary impacts of select climate-related extreme events on community assets and business interruptions given data availability.

CONCEPT NOTE – Comparing Direct and Secondary Impact Results

In this study, the **direct impact** results, when presented alone, are measured as changes to **gross output**. The **direct and secondary impact** results, when presented together, are measured as changes to **gross domestic product**. This is done to avoid double counting when considering direct and secondary impacts combined.

3.3 Community Impact Assessment Tool

The steps and calculations described above were undertaken to estimate the direct and secondary impacts of climate-related extreme events in two case study communities. The analysis is housed in a spreadsheet tool – the CIAT – which is designed to provide a replicable framework that others can employ to estimate the impact of climate-related extreme events in their communities. The CIAT contains the calculations required to estimate the direct and secondary impacts of the three climate-related extreme events considered in this analysis: flooding (CIAT-Flood), extreme wind (CIAT-Wind) and freezing rain (CIAT-Freezing Rain).

Going forward, analysts can employ the CIAT, along with a community engagement process, to estimate the direct and secondary impacts of climate-related extreme events in their community. In the sections that follow, the approaches and results of applying the CIAT and community engagement in the two case study communities are presented.

4. Case Study Analysis – The Halifax Regional Municipality

This section of the report provides details on the Halifax Regional Municipality (HRM) case study. A summary of the case study findings for the HRM is presented at the outset of the section. This is followed by details pertaining to the case study including those related to the approaches employed and the results of the impact analysis. Impacts are measured as direct and secondary impacts (indirect and induced impacts) as defined in the *Approach* section and the *Glossary of Terms* contained in this report. Technical information, as in detailed data and analytical assumptions, is contained in Appendix A. Impacts are discussed in terms of their present value and monetary values are 2013 constant Canadian dollars unless otherwise stated.

4.1 Key Findings

The case study analysis for the HRM focused on the climate-related extreme events of storm surge flooding and extreme wind. The analysis revealed the following key findings (see Section 4.8 for a summary of all findings):

1. **Greater direct impacts under the climate change scenarios:** For the moderate and high climate change scenarios, increases in direct impacts (measured as changes in gross output between scenarios) were found over time and in relation to the baseline scenario for both storm surge flooding and extreme wind events. By measuring changes relative to a baseline scenario, factors such as normal community growth are accounted for – allowing the analysis to isolate the climate-related impacts. Comparing the baseline scenario with the moderate and high scenarios revealed the following:
    - **Building stock, sector output and re-construction costs drive baseline increases:** From 2020 to 2040, the direct impacts to gross output for the baseline scenario increased (132% for flooding and 43% for wind) due to increases in sector output, new building stock and the cost of re-construction over the same time period.
    - **Impacts of moderate climate change relative to baseline:** From 2020 to 2040, the direct gross output impacts for the moderate climate change scenario increased relatively more than the increase under the baseline scenario; the increase in impacts under the moderate climate change scenario relative to the baseline scenario was found to be 59% greater for flooding and 5% greater for wind. These increases are attributed to climate change.
    - **Impacts of high climate change relative to baseline:** From 2020 to 2040, the direct gross output impacts for the high climate change scenario increased relatively more than the increase under the baseline scenario; the increase in impacts under the high climate change

scenario relative to the baseline scenario was found to be 85% greater for flooding and 46% greater for wind. These increases are attributed to climate change.

2. **Relative increase in flood impacts between 2020 and 2040 substantially larger than the increase in wind impacts between 2020 and 2040:** Under the high climate change scenario, between 2020 and 2040 the estimated direct and secondary gross domestic product impacts from climate-related storm surge increased by a factor of seven (from $400 thousand to $3.1 million). In comparison, impacts from extreme wind were estimated to increase threefold (from $2.8 million to $8.4 million) over the same time period.
3. **Secondary impacts comparable across modelling approaches:** The magnitude of the secondary impacts (i.e. the indirect and induced impacts) resulting from storm surge flooding and extreme wind were found to be comparable across the three approaches to modelling secondary impacts employed in this analysis.
4. **Climate change driving increases in cumulative impacts over time:** The cumulative sum of direct and secondary impact estimates attributed to climate change for storm surge flooding could reach over $35 million of gross domestic product ($2013) by 2040. Even more dramatic, the cumulative sum of direct and secondary impact estimates attributed to climate change from extreme wind could reach over $140 million of gross domestic product ($2013) by 2040.
5. **Extreme events more costly with high climate change:** Impacts from specific climate-related events can be compared across climate change scenarios to demonstrate the difference in impacts resulting from varying climate assumptions. For example, measured in terms of gross domestic product, a 1 in 25 year storm surge event occurring in 2040 under a high climate change scenario is estimated to be $22 million ($2013) more costly than a 1 in 25 year event occurring in the same year under today's climate conditions. This increased cost is the result of storm surges occurring more frequently with greater flood depths. In the case of extreme wind, a 1 in 25 year event occurring in 2040 under a high climate change scenario is estimated to be $16 million ($2013) more costly than a 1 in 25 year event occurring in 2040 under today's climate conditions. This increased cost is the result of extreme wind events occurring more frequently with greater wind speeds.

4.2 Scope of the Impact Analysis

Before presenting the detailed case study results it is necessary to acknowledge that the impact analysis completed for storm surge flooding and extreme wind in the HRM are not *full* assessments of the *total* cost associated with these climate-related extreme events. To be clear, the bullets below state that which is, and is not, included in the case study impact analysis for the HRM.

The HRM case study analysis **DOES:**

- Cover direct and secondary impacts resulting from damage to building structures and their contents for the climate-related storm surge flooding.

- Cover direct and secondary impacts resulting from damages to building structures, electricity restoration and from business interruptions from power outages for climate-related extreme wind.
- Cover the geographic region of Halifax Harbour and Bedford Basin from a storm surge flooding perspective.

The HRM case study analysis **DOES NOT:**

- Cover damage to personal property due to fallen trees or tree limbs because of lack of data to support such an analysis.
- Cover economic activity lost due to road, rail, airport and other transportation closures because of a lack of data and the potential for double counting of costs related to business interruptions from power outage.
- Cover all coastal areas located within the HRM (as noted above, the analysis is limited to Halifax Harbour and Bedford Basin)
- Examine the impacts of all possible climate-related extreme events.

4.3 Case Study Outline

This sub-section builds upon the *Background* and *Approach* sections of the report with an explicit focus on the HRM. More specifically, in the sub-sections below the following information is presented:

- **Background:** Provides a brief overview of climate-related extreme events in the HRM.
- **Approaches:** Presents details on the approaches employed to forecast socio-economic variables, complete the community engagement process and quantify direct and secondary impacts for two climate-related extreme events.
- **Results:** Contains results for direct and secondary impact estimates as well as cumulative and event-specific impact estimates.

4.4 Background: Climate-related Extreme Events in the Halifax Regional Municipality

The HRM is a geographically large and diverse area, encompassing an area roughly the size of Prince Edward Island, with a mix of urban and rural settlements, forest, and agriculture. As is the case with other regions of Canada, a wide range of climate-related extreme events are experienced in the HRM, including heavy snow and rainfalls, winter thaws and ice storms, gale to hurricane force winds, high waves and storm surges.[66] Events such as these have caused significant damage in recent years.

[66] Dillon Consulting and de Romilly and de Romilly Ltd., 2007, Climate Change Risk Management Strategy for Halifax Region Municipality.

Hurricanes, including Juan (2003), have caused significant loss of economic activity, as well as natural and cultural heritage in the HRM region. In 2009, Hurricane Bill dumped between 60 and 70 mm of rain with overland wind gusts of 87 km/h. Offshore wind gusts measured 130 km/h and 200 km offshore a maximum wave height of 26.4 metres was realized. The rain and winds knocked out power to 40,000 residents. Tropical storm Irene (2011) knocked out power for 51,000 in Nova Scotia. The HRM spent an estimated $24 million dealing with the aftermath of Hurricane Juan and filed a disaster assistance claim with the federal government in the amount of $17.2 million to help cover those costs. At the same time, hurricanes, snow and rain are not the only hazards in the HRM. In 2008, a brush fire ravaged a wooded area east of Halifax destroying two homes and forcing 5,000 residents to evacuate.

From the list of extreme events experienced in the HRM, it was necessary to identify two events that would be the focus of the impact analysis. This was done, in part, through an engagement process with local community representatives. The community engagement process as well as other approaches to conducting the impact analysis in the HRM are described in the sub-section below.

4.5 Case Study-Specific Approaches

The following sections provide detailed information on the approaches used to assess impacts from climate-related extreme events in the HRM. The section begins with a description of the socio-economic forecasting that was undertaken. This is followed by an overview of the HRM community engagement process. Pertinent details related to the establishment of baseline conditions for the HRM are then provided along with the analytical approaches for estimating the direct impact of each climate-related extreme event.

4.5.1 Socio-economic Forecasting

Socio-economic forecasting plays an important role in the estimation of direct and secondary impacts from climate-related extreme events. In particular, and as is discussed in the *Approach* section of this report, expected impacts are a function of the damages resulting from an extreme event, the probability of the event occurring, and the socio-economic conditions of the community under consideration. In the context of the current analysis, population, gross domestic product (GDP) and labour force were forecasted for the HRM and used to establish baseline economic conditions for 2020 and 2040. The process by which these variables were forecasted and the resulting trends in their values to 2020 and 2040 are described below.

Population: Population forecasts for the HRM for 2020 and 2040 were employed in the estimation of direct impacts from the climate-related extreme events under consideration by informing future asset development assumptions. For the HRM, the *Regional Plan* informed the population projections and growth assumptions required to establish the baseline conditions for 2020 and 2040.[67] The most recent update to regional forecasts of population, housing and employment provide these values to the year 2026[68] and a recent assessment for the five-year plan review extended these forecasts to 2031.[69]

According to HRM forecasts, a low-growth scenario would have the population and employment of Halifax growing 0.5% and 0.2% annually, respectively, resulting in a population that would reach about 440,000 by 2040. In contrast, a high growth scenario would have annual growth rates of twice those in the low scenario, and result in a projected population of 540,000 in 2040.

Gross Domestic Product: GDP projections for the HRM are employed in the analysis of secondary impacts of the climate-related extreme events to establish the baseline economic structure for 2020 and 2040. Estimates for GDP for 2020 and 2040 by sector at the HRM level are based on historical provincial GDP data trends by sector. The HRM-specific GDP baseline was estimated by comparing sector labour and income at the municipal level to provincial labour and income data. Since labour income is a major component of GDP and is readily available for most municipalities, it provides a basis on which to develop scaled-down GDP estimates. Statistics Canada GDP data covering the years 1997 to 2013 (CANSIM Table 379-0030) was scaled to the community level and projected forward in a linear fashion. This process resulted in the following key GDP projections for the HRM (details in Table 3 below):

- The total estimated GDP for Halifax is projected to increase 51% by 2040.
- The only sector-specific downward trend is in the arts, entertainment and recreation sector.
- The highest rate of change (101% by 2040) is in the administrative and support, waste management and remediation (the industry responsible for cleaning up contaminated buildings, sites, soil and water) sectors.
- Retail trade and the construction sector also have high projected growth rates of 76% and 72%, respectively.

[67] Halifax Regional Municipality, October 2014. Halifax Regional Municipal Planning Strategy. [Accessed 15.11.2014] http://www.halifax.ca/planning/documents/Halifax_MPS.pdf.
[68] Altus Group Economic Consulting. 2009. Employment, population and housing projections, Halifax Regional Municipality: An update. Report prepared for Planning and Development Services, Halifax Regional Municipality.
[69] Stantec 2013. Quantifying the Costs and Benefits to HRM, Residents and the Environment of Alternative Growth Scenarios. Report prepared for the Halifax Regional Municipality.

Table 3. Halifax Regional Municipality gross domestic product projections by sector

Sector	Baseline GDP ($2013M)	2020 GDP ($2013M)	2040 GDP ($2013M)	% Change to 2020	% Change to 2040
Crop and animal production	30.4	34.7	42.1	14%	39%
Forestry and logging	5.7	6.5	7.9	14%	39%
Fishing, hunting and trapping	32.0	36.6	44.4	14%	39%
Support activities for agriculture and forestry	2.2	2.5	3.0	14%	39%
Mining, quarrying, and oil and gas extraction	424.7	476.1	466.4	12%	10%
Utilities	322.8	329.2	345.7	2%	7%
Residential construction	117.0	144.4	201.6	23%	72%
Non-residential building construction	58.5	72.2	100.8	23%	72%
Engineering construction	113.2	139.8	195.1	23%	72%
Repair construction	477.7	589.6	823.2	23%	72%
Other activities of the construction industry	205.4	253.5	353.9	23%	72%
Manufacturing	783.7	817.7	909.0	4%	16%
Wholesale trade	691.4	798.2	1,041.2	15%	51%
Retail trade	966.8	1,211.5	1,702.1	25%	76%
Transportation and warehousing	660.5	694.7	735.0	5%	11%
Information and cultural industries	928.5	1,117.4	1,489.8	20%	60%
Finance, insurance, real estate, rental and leasing and holding companies	3,884.0	4,606.1	6,193.0	19%	59%
Professional, scientific and technical services	1,297.7	1,580.6	2,182.5	22%	68%
Administrative and support, waste management and remediation services	463.4	631.5	932.9	36%	101%
Educational services	1,400.9	1,604.4	2,070.7	15%	48%
Health care and social assistance	2,204.6	2,632.8	3,582.3	19%	62%
Arts, entertainment and recreation	168.8	164.4	145.9	-3%	-14%
Accommodation and food services	357.7	391.8	445.9	10%	25%
Other services (except public administration)	379.9	450.8	575.8	19%	52%
Other federal government services	1,412.3	1,502.5	1,783.7	6%	26%
Other provincial and territorial government services	532.5	566.5	672.5	6%	26%
Other municipal government services	233.7	248.6	295.1	6%	26%
Other aboriginal government services	4.7	5.0	6.0	6%	26%
Total	18,160.5	21,109.8	27,347.4	16%	51%

Labour force: Labour force projections for the HRM are employed in the analysis of secondary impacts of the climate-related extreme events to downscale provincial input-output data for the HRM in both 2020 and 2040. Estimates for the labour force for 2020 and 2040 by sector at the HRM level are based on historical Statistics Canada labour force data (CANSIM Table 282-0061 for the period of 1987 to 2013). This process resulted in the following key labour force projections for the HRM (details in Table 4 below):

- The total labour force is expected to increase by approximately 22% by 2040.
- Labour force declines are expected in the utilities, manufacturing, and public administration sectors.
- The largest percent increase is projected in the business, building, and other support services sector (~58%).

Table 4: Halifax Regional Municipality labour force projections by sector (# of full-time equivalent jobs)

Sector	Baseline LF	2020 LF	2040 LF	% Change to 2020	% Change to 2040
Agriculture [111-112 1100 1151-1152]	410	411	409	0.3%	-0.2%
Forestry, fishing, mining, quarrying, oil and gas [21 113-114 1153 2100]	1,735	2,746	2,348	58.3%	35.3%
Utilities [22]	1,330	959	1,259	-27.9%	-5.4%
Construction [23]	13,210	14,387	17,455	8.9%	32.1%
Manufacturing [31-33]	10,285	9,769	10,139	-5.0%	-1.4%
Trade [41 44-45]	34,260	35,350	40,192	3.2%	17.3%
Transportation and warehousing [48-49]	9,620	10,308	11,246	7.2%	16.9%
Finance, insurance, real estate and leasing [52-53]	14,500	14,893	16,391	2.7%	13.0%
Professional, scientific and technical services [54]	15,635	20,577	22,888	31.6%	46.4%
Business, building and other support services [55-56]	11,725	18,684	18,477	59.3%	57.6%
Educational services [61]	18,365	20,161	23,855	9.8%	29.9%
Health care and social assistance [62]	26,410	30,177	35,370	14.3%	33.9%
Information, culture and recreation [51 71]	6,450	7,308	8,355	13.3%	29.5%
Accommodation and food services [72]	15,165	17,799	20,254	17.4%	33.6%
Other services [81]	13,700	17,106	18,157	24.9%	32.5%
Public administration [91]	28,390	24,415	22,574	-14.0%	-20.5%
Total	221,190	245,048	269,368	10.8%	21.8%

4.5.2 Community Engagement Process

A community-based advisory group was assembled to guide and inform the project. This group was comprised of the HRM staff representing multiple departments, including emergency management, planning, infrastructure and transportation planning, risk management, facility development, finance and economic development, environment, and the Chief Administrative Office. Halifax Water, the local water and sewer utility, the Halifax Port Authority, and the provincial Climate Change Directorate also participated. The advisory group's core roles were to inform the project scope and design, to provide local knowledge and data, and to review the results.

The focal points of the community engagement process were two advisory group meetings. Meeting #1 built an understanding on the project approach and goals, and saw participants identify and select the climate-related extreme events they wished to be addressed in the economic analysis. The group worked through a discussion of multiple climate-related extreme events while considering diverse evaluation criteria.

Preliminary discussions in the lead-up to Meeting #1 with the HRM staff revealed a high likelihood that storm surge flooding and extreme wind would be considered priority climate-related extreme events. However, these climate-related extreme events needed to be confirmed through the advisory group discussion. At the meeting, a proposal was made to the group that the project focus on storm surge flooding and extreme wind as priority climate-related extreme events.[70] These two climate-related extreme events can occur individually or as components of hurricane events.

The project team then asked four questions of the group:

1. Are storm surge flooding and extreme wind appropriate choices for analysis?
2. What other climate-related extreme events are important to the HRM?
3. How would you prioritize the climate-related extreme events relative to each other?
4. What factors contribute to the relative importance of each?

Other climate-related extreme events that were discussed, as they are important for the HRM, include additional impacts related to hurricanes such as wave run-up and forest blow-down (subsequently increasing forest fire risk). Drought, exotic pests and extreme precipitation (snow, rain, freezing rain) were also discussed. The group collectively determined that storm surge flooding and extreme wind were the appropriate events for this project, as there was a strong link to climate change, and the nature of the climate-related extreme events were such that they promoted broad citizen engagement. After the climate-related extreme events were selected, the participants discussed the multiple and diverse impacts, direct and secondary, that result from each of climate-related extreme events.

Following Meeting #1, the project team continued to work with the HRM liaison to secure data for the analysis. This process was iterative and the project team was in frequent contact with the city to clarify and interpret data, obtain new data and address gaps, and provide updates on progress.

[70] In this context, 'priority climate-related extreme events' refer to establishing priority within the context of this project. This is not meant to be interpreted as an assessment or relative ranking of damage or vulnerability caused by different climate-related extreme events.

As the project progressed towards preliminary results, the advisory group was reconvened for Meeting #2. At this meeting, the project team tested the assumptions used in the analysis, explained what the analysis currently included and excluded, and gauged reaction to preliminary model outputs. The advisory group confirmed many assumptions, identified and helped address outstanding gaps, and provided important context for project reports. Following meeting #2, the project team was able to complete the analysis of the expected impacts from climate-related extreme events for the HRM case study. The first step in undertaking the impact analysis was to establish the baseline conditions.

4.5.3 Establishing the Baseline Conditions

As is described in the *Approach* section of this report, to estimate the direct impacts of climate-related extreme events, the spatial distribution of the assets in the case study community was overlaid with the spatial distribution of the extreme event. Damage costs result from the assets that are located within the spatial distribution of the extreme event. They are measured in relation to both baseline and future climate conditions for the projected (2020 and 2040) distribution and value of assets on the landscape. The baseline climate condition is considered to be the climate of the recent past while the future climate condition is based on one of two climate change scenarios (moderate and high).

The estimated distribution of assets on the landscape is driven by projected changes in population in the case study community (see the socio-economic forecasting section above). The projected change in population for 2020 and 2040 was used to derive estimates for new building requirements for the same years. Present day citywide and sector-specific building footprints (which were derived through GIS analysis) were divided by the current population to estimate sector-specific building requirements per person. Applying these sector-specific building requirements per person to the projected population for 2020 and 2040 resulted in estimates of the amount of building growth required for the same years.

Building requirements for 2020 and 2040 were than allocated to the HRM landscape across “opportunity areas.” Opportunity areas describe geographic locations that have been identified for future development. These areas were established through available information in HRM regional plan documents[71] and through discussion with HRM planning staff. New building requirements for 2020 and 2040 were assigned to these areas for residential, industrial, commercial and institutional buildings.

The location of buildings (existing and new) by sector (residential, industrial, commercial and institutional) for 2020 and 2040 describe the distribution of assets on the landscape. To calculate the damage costs to the sub-set of assets that intersect with the extreme events requires assigning values to the affected assets. Building structure values were derived from construction cost values per unit area (gross floor

[71] http://www.halifax.ca/regionalplanning/FinalRegPlan.php

space) and were projected for 2020 and 2040 based on historical construction cost trends.[72] These values were employed as estimates of the cost of rebuilding/refurbishing a damaged building. Building content values were estimated using the HAZUS building structure to building content value ratios[73] for the general categories of residential, industrial, commercial and institutional buildings (for example, based on the HAZUS ratios, the building structure to contents value ratio for residential buildings was assumed to be 2:1). The building and content value estimates were employed in the estimation of direct impacts from each of the climate-related extreme events under consideration for the moderate and high climate change scenarios.

4.5.4 Estimating the Direct Impact of Storm Surge Flooding

To estimate the direct impact of storm surge flooding, the spatial distribution and value of assets for the baseline conditions (derived through the means described above) was overlaid with the spatial distribution of storm surge flooding. The overlap between the two spatial distributions was used to estimate which building assets are flooded, what percentage of buildings are flooded, and how high the flood water reaches in each affected building. Given the degree of flooding for each building affected by storm surge, damage costs for the affected buildings were estimated.

The estimation of flood damage costs employed in this analysis generally followed procedures developed by the U.S. Army Corps of Engineers.[74] In accordance with these procedures, damage costs are based on depth-damage curves that depict the percent of damage that results at various flood depths (Figure 8).

[72] AltusGroup, 2014. Construction Cost Guide, [Accessed October 20, 2014], http://www.altusgroup.com/research/construction-cost-guide/ .
[73] HAZUS, 2010. Multi-hazard Loss Estimation Methodology, Flood Model. Technical Manual, Federal Emergency Management Agency, Jessup, Maryland.
[74] USACE 2011. Coastal Storm Risk Management: National Economic Development Manual. U.S. Army Corps of Engineers, Institute for Water Resources, IWR Report 2011-R-09.

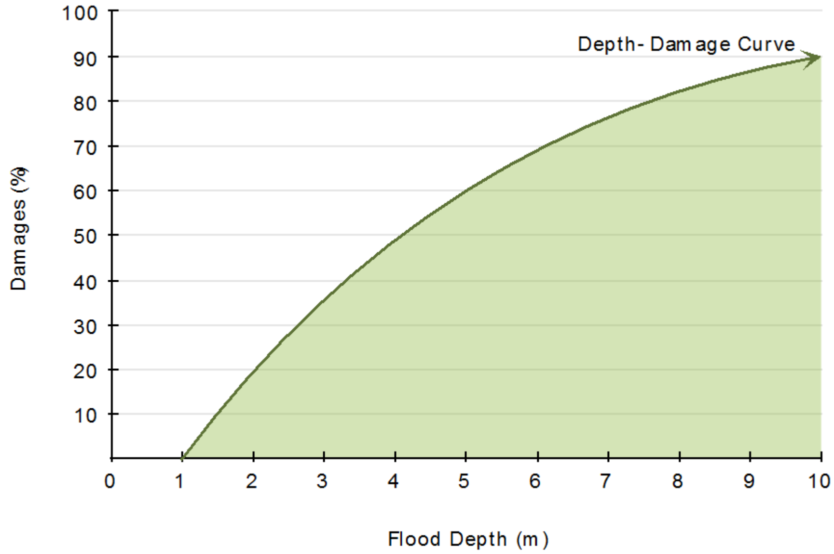


Figure 8: Hypothetical depth-damage curve

Thus, in the context of the HRM, percent damage estimates from the depth-damage curve relationship were assigned to the value of the affected buildings and their contents by matching building attributes with the available depth-damage curves. A total of 35 damage curves were used to assess the damages to the affected buildings based on the calculated flood depths at each building: 20 related to structural damages and 15 related to content / inventory / equipment. This process was completed for a range of flood depths and each flood depth was allocated a probability. This same process was repeated for the moderate and high climate change scenarios and the flood depths versus probability estimates changed accordingly (for details on the climate data pertaining to the flood impact analysis see Appendix A) to capture the changes driven by climate change.

4.5.5 Estimating the Direct Impact of Extreme Wind

The primary hazard with extreme wind is damage caused to buildings and power outages from damaged electricity transmission lines. The literature related to extreme winds provides guidance on the possible approaches to estimating wind-related damages. Recent research has focused on establishing peak gust speed – damage relationships. There is a growing body of literature exploring these relationships for a range of building materials.[75,76,77,78] With these peak gust speed – damage relationships, as is described

[75] Unanwa, C. O., McDonald, J. R., Mehta, K. C., & Smith, D. A. (2000). The development of wind damage bands for buildings. Journal of Wind Engineering and Industrial Aerodynamics, 84(1), 119-149.
[76] Khanduri, A. C., & Morrow, G. C. (2003). Vulnerability of buildings to windstorms and insurance loss estimation. Journal of wind engineering and industrial aerodynamics, 91(4), 455-467.
[77] Heneka, P., Hofherr, T., Ruck, B., & Kottmeier, C. (2006). Winter storm risk of residential structures--model development and application to the German state of Baden-Württemberg. Natural Hazards & Earth System Sciences, 6(5).
[78] Stewart, M. G., Wang, X., & Willgoose, G. R. (2012). Indirect cost and benefit assessment of climate adaptation strategies for extreme wind events in Queensland. Published by CSIRO.

below, the process for quantifying damages is similar to that employed for damage from storm surge flooding.

In the case of extreme wind, the spatial distribution and value of assets for the HRM was overlaid with the spatial distribution of peak gust speeds across several return periods. In keeping with the detailed and comprehensive approach employed by Steward et al (2012),[79] our analysis of damages from extreme wind relates peak gust speeds with percent building damages taking into consideration the probability of different peak gust speeds occurring. Damage curves for peak gust speeds of different probabilities[80] were assigned to affected buildings taking into consideration building attributes (e.g. sector - residential, commercial, and number of stories – 1 to 3 stories, 4 to 10 stories) (see Appendix A for additional details on the data pertaining to this analysis). This allowed for the estimation of direct impacts resulting from a range of wind speeds. To establish costs under the baseline, moderate and high climate change scenarios, these calculations are repeated for peak gust speeds attributed to each scenario.

4.6 Storm Surge Flooding Impact Results

In the sub-sections below the results of the impact analysis for storm surge flooding in the HRM are presented, beginning with estimates of direct impact. Secondary impacts are then presented. The direct and secondary impacts presented here represent the opportunity cost of direct, indirect and induced spending – spending that could have been directed elsewhere in the economy were it not for the need to respond to the damages from storm surge flooding. Estimates for cumulative impacts as well as event-specific impacts are also included below. This is followed by a sensitivity analysis and a discussion of key data and analytical limitations.

4.6.1 Direct Impact

The direct impact estimates presented here are measured as impacts to gross output (which means they are not directly comparable with the secondary impact results presented below which measure impacts to GDP).[81] Future climate change is likely to significantly increase impacts due to storm surge flooding events in the HRM, assuming no adaption measures are taken. Taking into consideration damages to fixed assets (i.e. buildings and their contents), by 2020, it is estimated that the expected annual damage (EAD) attributed to climate change will increase by 13% (moderate climate change) to 19% (high climate change) relative to the corresponding baseline scenario. By 2040, EAD increases by 42% (moderate

[79] Stewart, M. G., Wang, X., & Willgoose, G. R. (2012). Indirect cost and benefit assessment of climate adaptation strategies for extreme wind events in Queensland. Published by CSIRO.
[80] Unanwa, C.O., McDonald, J.R., Mehta, K.C., Smith, D.A., 2000. The development of wind damage bands for buildings. *Journal of Wind Engineering and Industrial Aerodynamics* 84:119-149.
[81] As per the concept note in the Approach section, direct impacts are first measured as gross output to fully account for intermediate and value added inter-industry linkages in the input-output multiplier. The impacts are then translated to the more commonly reported metric of gross domestic product that highlights the impact on the value of production in the particular year of interest.

climate change) to 62% (high climate change) relative to the baseline scenario. In terms of the absolute direct impact on gross output, the EAD attributed to future climate change increases from $310 thousand to $450 thousand in 2020 and from $2.3 million to $3.4 million in 2040 (from moderate to high climate change scenarios).

The underlining reason for the increases in the direct impact attributed to climate change is the gradual sea level rise expected to take place over many centuries.[82] This analysis assumes sea level rises by 4 cm (with moderate climate change) and 6 cm (with high climate change) by 2020 and 15 cm (with moderate climate change) and 20 cm (with high climate change) by 2040.[83] This seemingly small increase in sea level leads to a significant increase in EAD (Figure 9). Since by the end of this century, relative sea level rise increases are expected to be 60 to 77 cm in Halifax (under RCP4.5 and RCP8.5, respectively),[84] the EAD attributed to climate change is likely to steadily increase in the absence of adaptation strategies.

[82] Warren, F.J. and Lemmen, D.S. (2014): Synthesis; in Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation, (ed.) F.J. Warren and D.S. Lemmen; Government of Canada, Ottawa, ON, p. 1-18.
[83] Daigle, R.J., 2014. Sea-level rise and coastal flooding estimates for Chignecto Isthmus and Halifax Harbour. Based on IPCC 5th Assessment Report.
[84] James, T.S., Henton, J.A., Leonard, L.J., Darlington, A., Forbes, D.L., Craymer, M. 2014. Relative Sea-level Projections in Canada and the Adjacent Mainland United States. Natural Resources Canada, Geological Survey of Canada, Open File 737, [Accessed 10.10.2014] http://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/fulle.web&search1=R=295574.

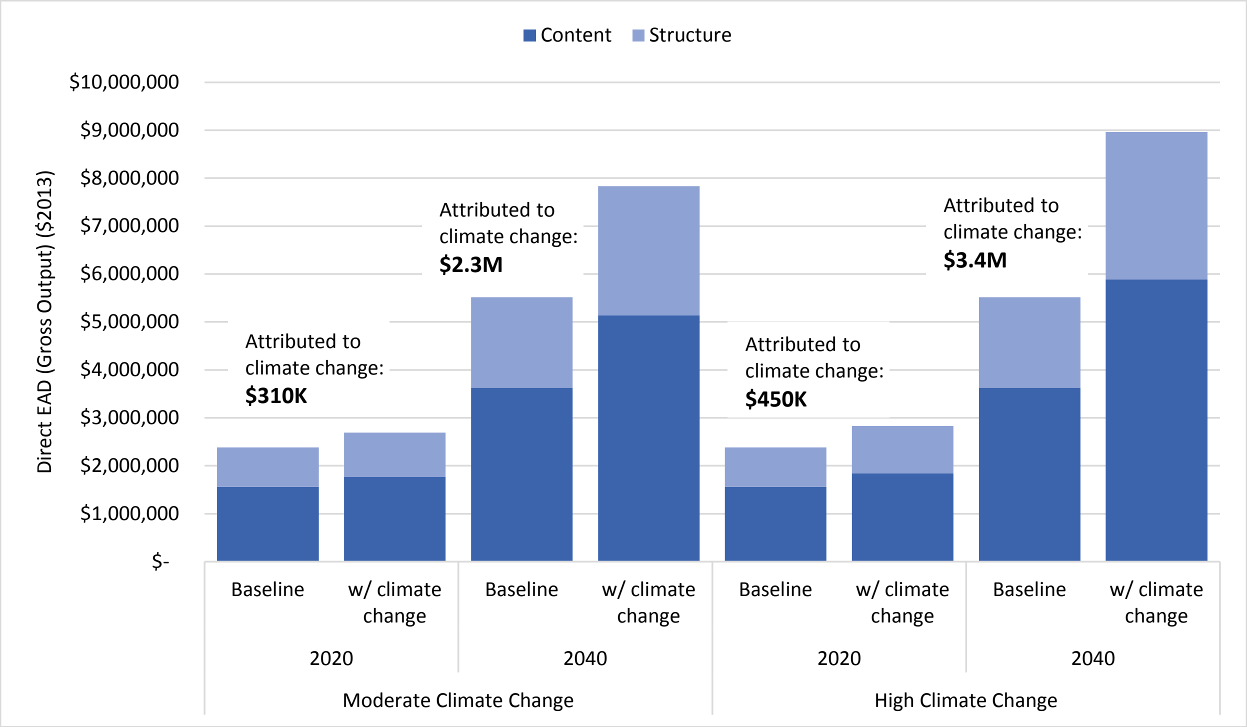


Figure 9: **Direct expected annual damage (sum of content and structure) (in terms of gross output) due to storm surge flooding in the Halifax Regional Municipality**

Figure 10 shows direct impact estimates, measured as gross output, by sector. Commercial buildings take on the majority of the impact in the region where the share of gross output impact to commercial buildings remains quite stable across climate scenarios: 82% to 83% in 2020 and 86% to 87% in 2040. The building class with the next level of impact is residential (~10% in 2020 and ~8% in 2040). This is followed by industrial (~6% in 2020 and ~5% in 2040) and then institutional (0.6-0.7% in 2020 and 0.3-0.5% in 2040).

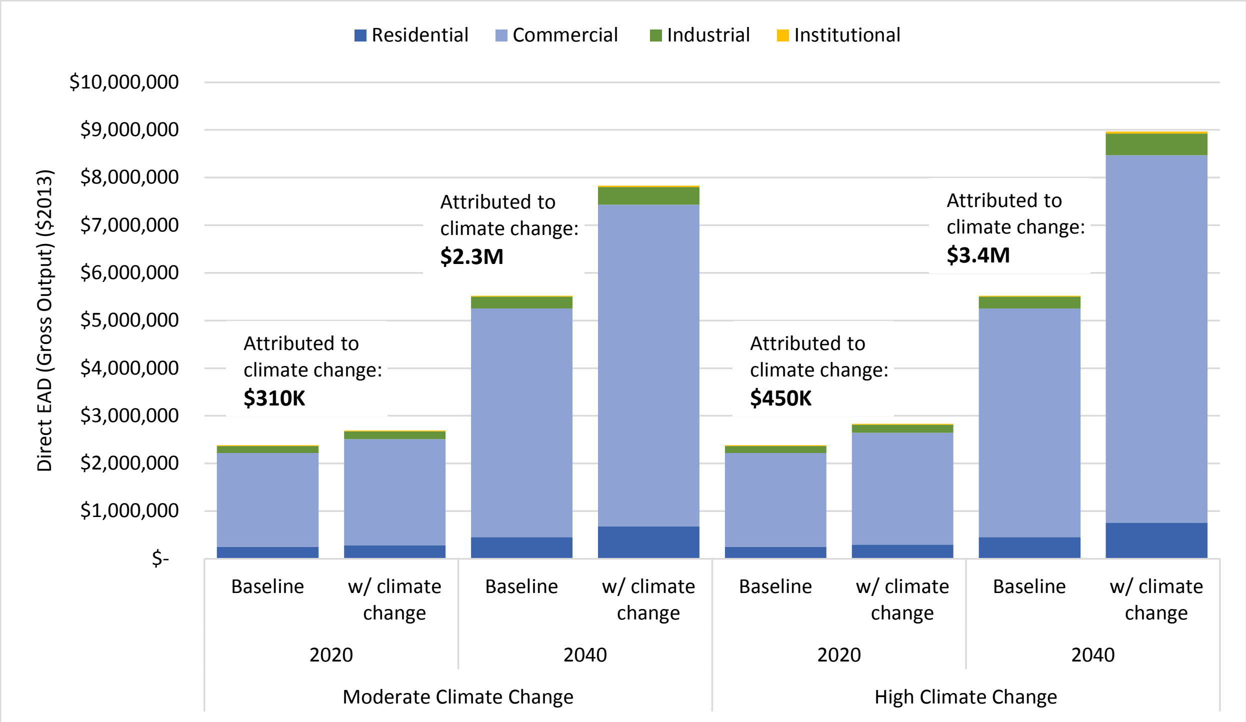


Figure 10: Direct expected annual damage (in terms of gross output) due to storm surge flooding by building sector for the Halifax Regional Municipality

In terms of the breakdown between contents and structure by sector, impacts to the residential sector are dominated by structural damage (~60% due to structural damage). In the other sectors, damage is dominated by the contents of the building: commercial ~68% due to content damage; industrial ~71% due to content damage; and institutional ~95% due to content damage. In other words, aside from residential buildings, contents represent a greater proportion of the value of damage compared to structure.

The direct impact results can also be examined according to damage to new buildings (buildings developed in the future years on presently designated opportunity areas – areas designated for future development – not including new buildings that replace existing buildings) versus existing buildings (Figure 11). The impact divide between existing and new buildings in 2020 is relatively constant across the climate scenarios; impacts range from 72% to 73% for existing buildings and 27% to 28% for new buildings. New buildings were found to exhibit a greater share of the total building impacts by 2040, accounting for 53% to 58% of the impact while existing buildings account for the remaining 42% to 47%. New building developments dominate the total impacts in 2040 due to assumptions (obtained through the community engagement process) related to new building developments taking place in flood prone land.

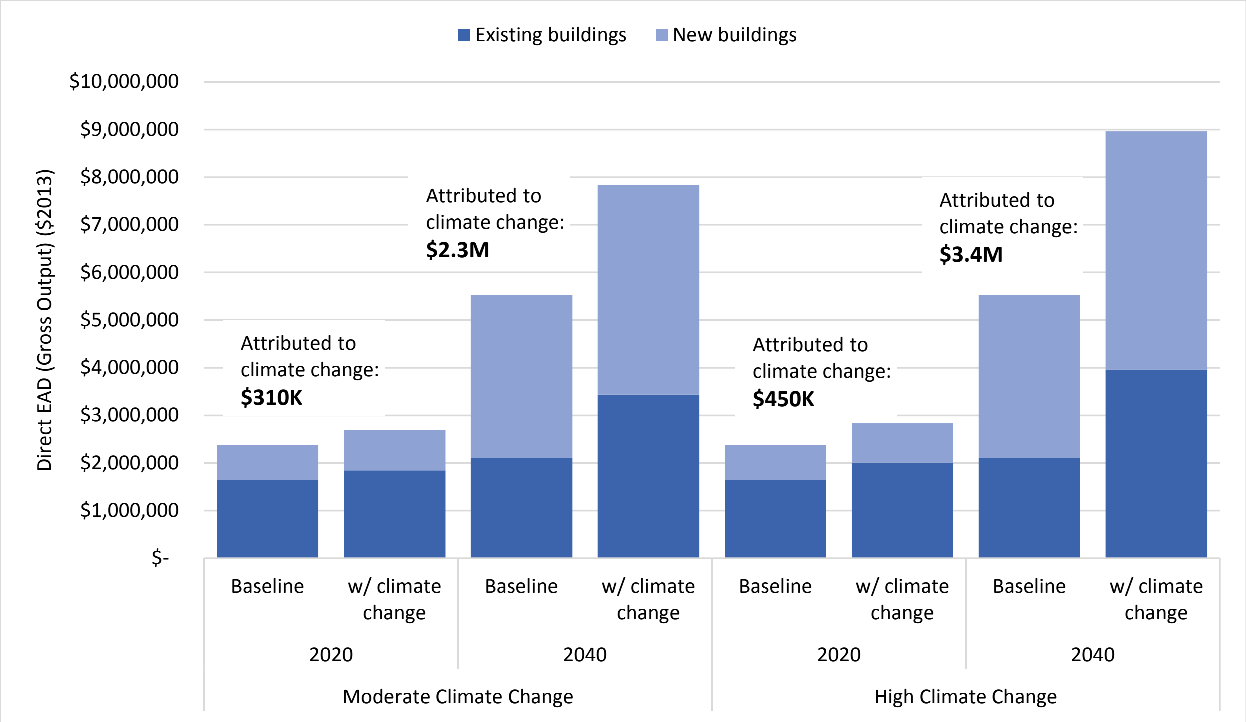


Figure 11: Direct expected annual damage (in terms of gross output) due to storm surge flooding distinguishing between existing and new buildings for the Halifax Regional Municipality

4.6.2 Secondary Impacts

The secondary impact estimates presented here are measured as impacts to GDP and take into consideration damage to fixed assets (i.e. buildings and their structure). They are not directly comparable with the gross output estimates presented above for direct impacts. The results presented in this section were derived using the input-output basic Type II multiplier approach. Additional information on how secondary impacts were calculated is contained in Appendix C. The Type II approach considers both the indirect and induced impacts and was chosen as the approach on which to focus these results as it is considered the most accessible (i.e. because it is based on published provincial Statistic Canada multipliers) of the approaches and the one most likely to be employed by community impact analysis tool users. The series of figures presented in this section depict the sum of direct and secondary impacts. Additional graphs for output and employment are located in Appendix D-E.[85]

Figure 12 presents estimates for the direct and secondary impacts of storm surge flooding on GDP in the HRM for the baseline and future climate change scenarios in 2020 and 2040.

[85] Employment impacts are generally quite small using the EAD concept and given the high amount of output per worker that is representative of the Canadian economy.

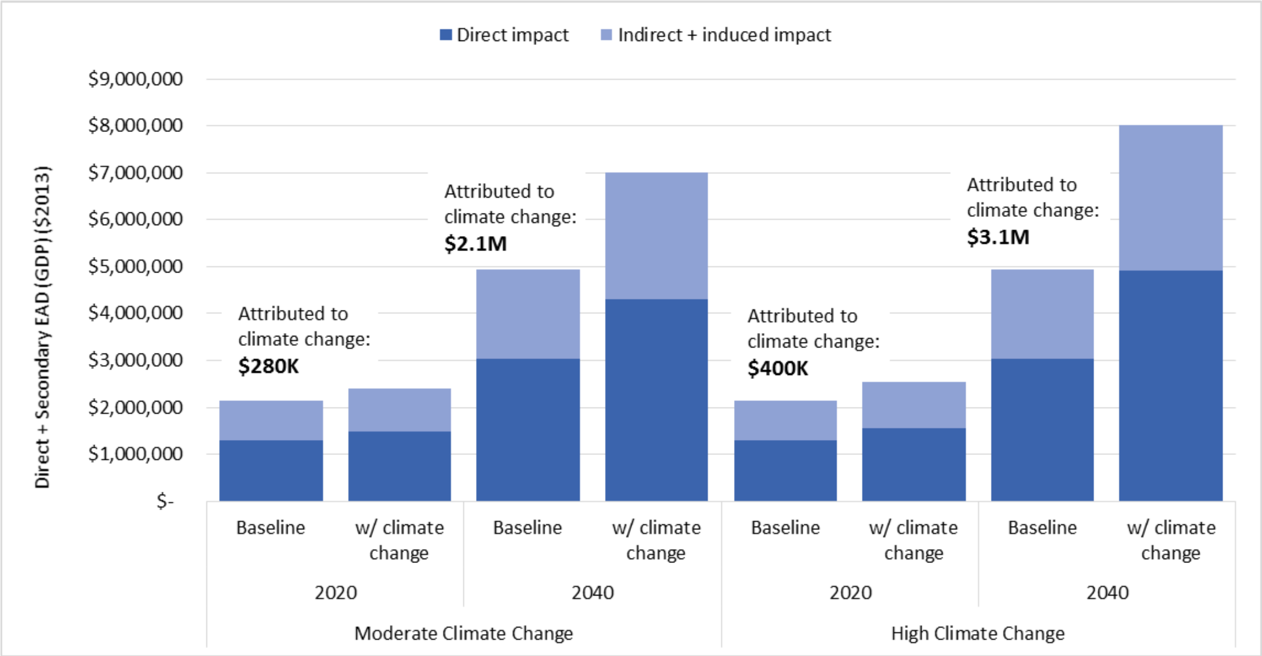


Figure 12: **Direct and secondary (indirect and induced) expected annual damage (in terms of gross domestic product) due to storm surge flooding in the Halifax Regional Municipality**

As is demonstrated in the figure above, the indirect and induced impacts were a significant component of the sum of the impact on GDP. The sum of direct and secondary impacts attributed to climate change in 2020 is $280 thousand, increasing to $2.1 million in 2040 under the moderate climate change scenario. In the case of the high climate scenario, the sum of direct and secondary impacts attributed to climate change in 2020 is $400 thousand, increasing to $3.1 million in 2040.

As is noted in the *Approach* section, several approaches to modelling secondary impacts were employed in this study. Table 5 below highlights the range of EAD estimates across modelling approaches attributed to climate change for direct and secondary impacts combined measured as gross domestic product (GDP). In general, the order of magnitude of the EAD estimates are comparable across the modelling techniques for any given climate change scenario. As expected, the CGE model results are for the most part smaller, reflecting the offsetting effect of labour mobility across industries not considered in the I-O models. The basic I-O Type II multiplier results (the results focused on above) generally provide a midpoint among the estimates derived from the various techniques.

Table 5. Sum of direct and secondary expected annual damages to assets (A) as measured by impacts to GDP from storm surge attributed to climate change under moderate (M) and high (H) climate change scenarios ($2013 Millions)

			Basic I-O Type I	Basic I-O Type II	Custom I-O Type I	Custom I-O Type II	CGE
2020	A	M	$0.22	$0.28	$0.17	$0.24	$0.16
		H	$0.32	$0.40	$0.24	$0.35	$0.23
2040	A	M	$1.7	$2.1	$1.3	$1.8	$1.2
		H	$2.5	$3.1	$1.9	$2.7	$1.8

Table 5 warrants the following observations:

- The percent difference between the moderate climate change scenario and the high climate change scenario is in the order of 40% across methods.
- The expected annual damages from storm surge attributed to climate change increased by approximately 7 times from 2020 to 2040.
- The CGE model results generally showed the smallest impacts, but the results from all methods yielded similar orders of magnitude.
- Focusing on the basic multiplier (Type II) results, the percent difference between the moderate and high climate change scenarios is 44% in 2020 and 49% in 2040 and the expected annual damages increased by more than 7 fold under both the moderate and high climate change scenarios.

4.6.3 Cumulative Impacts

To demonstrate the potential impacts of climate-related extreme events across climate change scenarios, is useful to consider the cumulative EAD over the timeframe of the analysis (i.e. from the baseline year of 2015 to 2040). Figure 13 demonstrates the cumulative impact measured as the sum of the direct and secondary EAD estimates for flooding in the HRM that is attributed to climate change, measured by gross output and GDP. The results reflect the use of basic I-O Type II multipliers. These results depict the overarching trend in EAD as a consequence of climate change; they do not show the scenario-specific direct and secondary EAD.[86]

[86] This trend line was built using a best-fit 2nd order polynomial equation by fitting the three known points of EAD that is attributed to climate change for the baseline year (2015, which has zero EAD attributed to climate change by definition) and the future years, 2020 and 2040.

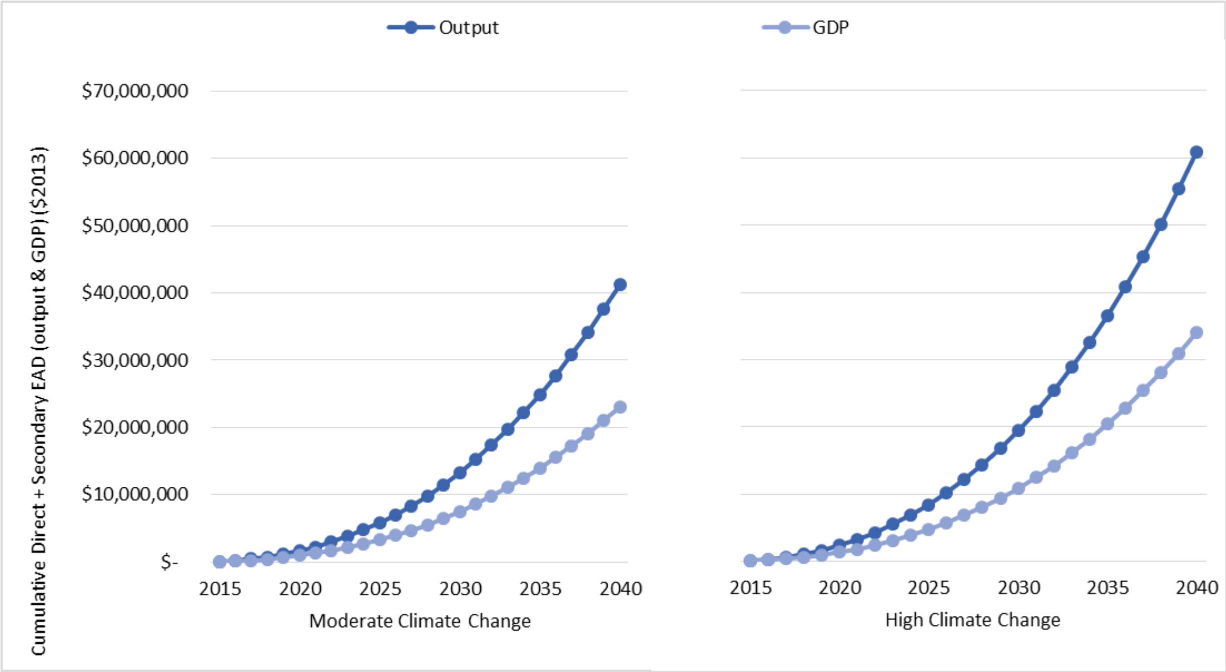


Figure 13: Cumulative average annual direct and secondary expected annual damage of storm surge flooding on gross output and gross domestic product attributed to climate change in Halifax Regional Municipality

The cumulative direct and secondary EAD attributed to climate change for flood events in the HRM was found to increase at exponential rates. The results for both the moderate and high climate change scenarios are shown side-by-side and on the same y-axis scale to show the difference between the two climate change scenarios. By 2020, the direct and secondary EAD (type II, GDP) is expected to be around $920 thousand and $1.3 million for the moderate and high climate change scenarios, respectively. By 2040 this metric is expected to grow considerably, reaching around $23 million and $34 million for the moderate and high climate change scenarios, respectively. This indicates that the EAD due to storm surge flooding will continuously grow higher over the given time horizon. This trend is due to the ongoing future sea level rise that is expected to take place over the same time horizon. Since sea level rise is expected to continue over millennia time scales, the HRM can expect the cumulative EAD attributed to climate change to continue growing at exponential rates, provided little to no adaptation measures are put in place.

4.6.4 Event-Specific Impacts

The expected impacts of climate-related extreme events can also be measured on an event-specific basis. Doing so demonstrates how climate change can influence event probabilities and associated damages. Two examples of estimates for the sum of direct and secondary impacts resulting from storm surge flooding in the HRM are provided below: the expected impacts for a 1 in 25 year flooding event and the expected impacts for a 1 in 100 year flooding event. The results reflect the use of basic I-O Type II multipliers.

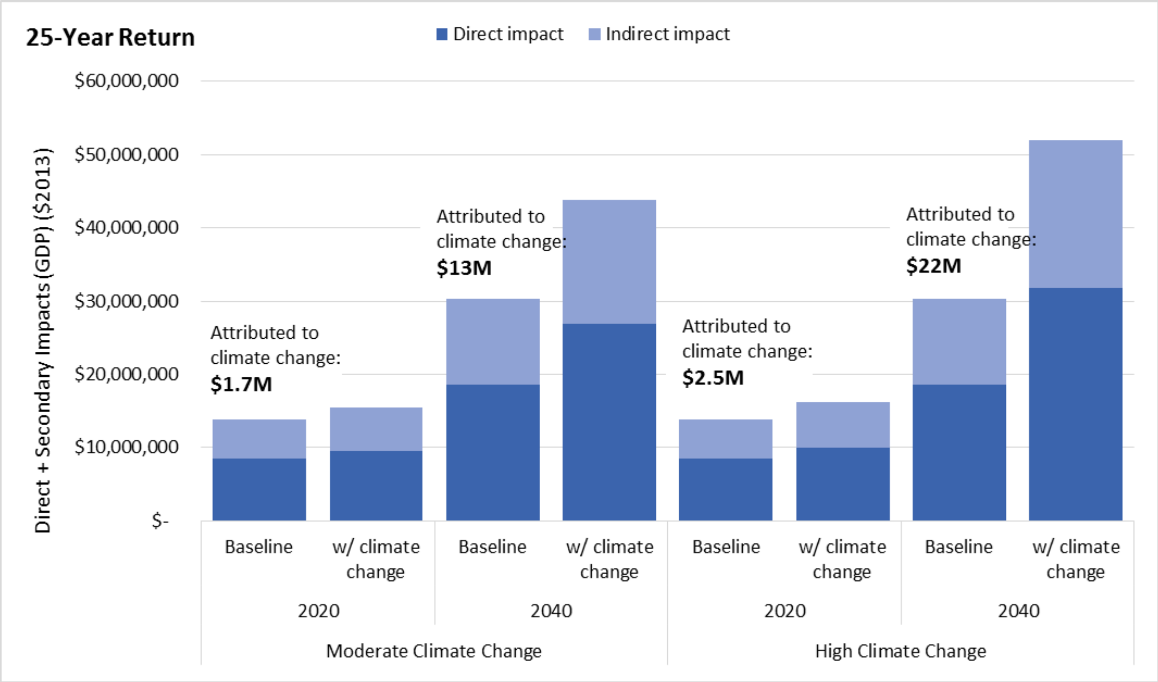


Figure 14: Direct and secondary expected annual damage of a 1 in 25 year storm surge flooding event on gross domestic product in the Halifax Regional Municipality

Figure 14 demonstrates the event-specific impact (direct and secondary) on GDP from a 1 in 25 year storm surge event in the HRM. Under the moderate climate change scenario, the impact attributed to climate change in 2020 is $1.7 million and $2.5 million for the moderate and high climate change scenarios, respectively. The impact increases to $13 million and $22 million in 2040 for the moderate and high climate change scenarios, respectively. This means that by 2020, if a 1 in 25 year storm surge event occurs, then the impacts attributed to climate change are expected to be about $2 million higher than the baseline. By 2040, a 1 in 25 year event would cost an additional $13 million to $22 million as a result of climate change.

Figure 15 illustrates the impact estimates (direct and secondary) for a more extreme flood event in the HRM. In this case, if the 1 in 100 year storm surge event were to occur in 2020, the anticipated impacts would be $2.9 million to $3.7 million with climate change than without. However, a 1 in 100 year event occurring in 2040 would cost an additional $23 million to $29 million as a result of climate change.

In both the 1 in 25 and 1 in 100 year examples, climate change results in storm surge events occurring more frequently and with greater flood depths. This results in an anticipated increase in flood damage costs in 2020 and 2040 relative to the baseline climate scenario.

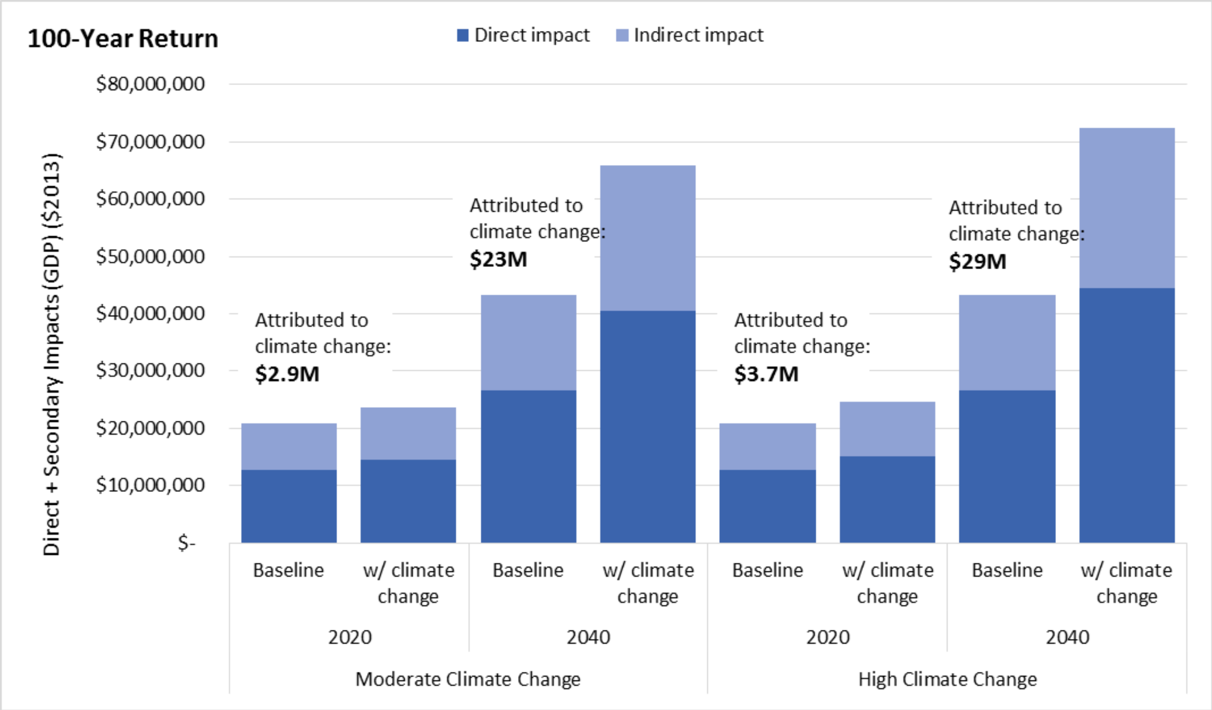
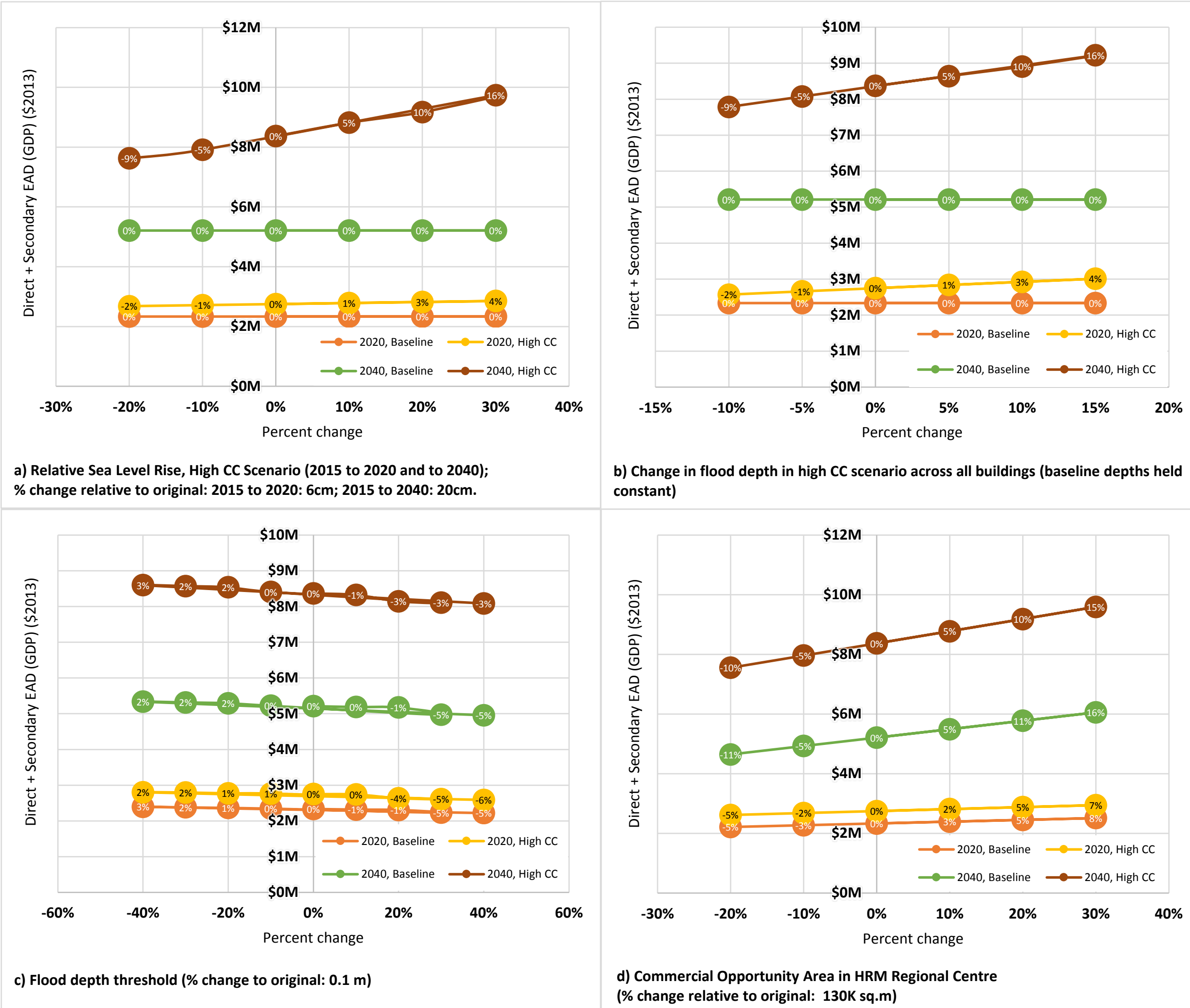


Figure 15: **Direct and secondary expected annual damage of a 1 in 100 year storm surge flooding event on gross domestic product attributed to climate change in the Halifax Regional Municipality**

4.6.5 Sensitivity Analysis

The sensitivity graphs (Figure 16) cover four key parameters used in the flood event analysis for the HRM. Each of the parameters has been plotted in a sensitivity graph demonstrating how the direct and secondary EAD in terms of GDP change as each parameter varies by a given percentage. The results reflect the use of basic I-O Type II multipliers.



a) Relative Sea Level Rise, High CC Scenario (2015 to 2020 and to 2040); % change relative to original: 2015 to 2020: 6cm; 2015 to 2040: 20cm.

b) Change in flood depth in high CC scenario across all buildings (baseline depths held constant)

c) Flood depth threshold (% change to original: 0.1 m)

d) Commercial Opportunity Area in HRM Regional Centre (% change relative to original: 130K sq.m)

Figure 16: Sensitivity graphs for four parameter sets (see individual captions under each sub-plot)

Figure 16a) shows how the sum of direct and secondary EAD changes as a function of changes in the assumed relative sea-level rise for the high climate change scenario. The original values assumed for relative sea-level rise for the high climate change scenario were 6 cm and 20 cm for 2020 and 2040, respectively; this rise in sea-level describes how much the sea that surrounds the coast of the HRM is expected to increase from 2015 to 2020 and from 2015 to 2040. The EAD estimate changes faster in 2040 than in 2020 as relative sea level rise increases; this is sensible since the change in sea-level rise is larger as a function of the percentage change in the original relative sea-level rise value from 2015 to 2040 when compared to 2015 to 2020. For 2040, the direct and secondary EAD changes by about 0.5% for each percent change in relative sea-level rise, making it an important parameter to consider given the degree of uncertainty surrounding what the relative sea-level rise will be in these future years.[87] In 2020, the EAD changes much more slowly, by about 0.1% for each percent change in relative sea-level rise.

Figure 16b) depicts how the sum of direct and secondary EAD changes as a function of changes in the assumed flood depth versus return period for the high climate change scenario across all buildings while the baseline flood depth versus return period across all buildings is held constant. For example, if a flood depth for a 100 year return period event under the high climate change scenario was originally 1 m, a 10% change in this parameter would increase this depth to 1.1 m. The percentage change in this sensitivity parameter changes the flood depth of every building accounted for in this analysis (both new and existing). The change in direct and secondary EAD as this parameter changes is found to be identical to that found in Figure 16a). This is reasonable given that flood depth versus return period across buildings is directly proportional to the relative rise in sea-level.

Figure 16c) describes the sum of direct and secondary EAD as a function of changes in the assumed flood depth threshold, which was originally assumed to be 0.1 m. The flood depth threshold of 0.1 m was used as a boundary between a flood depth that does and does not create damage to building structure and contents. If a flood depth for a given return period and scenario is above this number, then damage to the building is dictated by the best available flood damage curve. If the flood depth is below this flood depth threshold, then the damage to a building was assumed to be negligible. The change in the sum of direct and secondary EAD as a function of changing flood depth threshold is fairly gradual and nearly linear: 0.09% to 0.11% for each percent change in the flood depth threshold.

Lastly, Figure 16d) illustrates how the sum of direct and secondary EAD changes as a function of changing the total available opportunity area in the HRM regional centre that was assumed to be earmarked for commercial development (~130 thousand square meters). As this area increases, the sum of the direct and secondary EAD is expected to also increase significantly. The underlining reason why the EAD increases as a function of this parameter, is because the greater area available for commercial development allows the HRM to more closely meet the assumed new commercial development demand. In other words, the default assumptions surrounding building demand and saturated building density do not allow the HRM to fulfill the expected future building demand, so as this area increases, more commercial buildings are assumed to be developed. This leads to greater EAD due to flooding events because there are more buildings within the flood zone that can be exposed to flood damage.

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[87] James, T.S., Henton, J.A., Leonard, L.J., Darlington, A., Forbes, D.L., Craymer, M. 2014. Relative Sea-level Projections in Canada and the Adjacent Mainland United States. Natural Resources Canada, Geological Survey of Canada, Open File 737, [Accessed 10.10.2014] http://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/fulle.web&search1=R=295574.

4.6.6 Limitations

While the impact estimates presented above capture a large portion of anticipated impacts associated with storm surge, a few limitations should be noted. While the impact assessment was scoped to focus on damage to fixed assets (i.e. buildings and their contents), due to data limitations, not all impacts could be captured. The following impacts are not captured in the storm surge flooding impact assessment for the HRM:

- Damage to roads from erosion and disruption caused by associated road closures.
- Damage to rail lines.
- Power outages caused by flooding, which are expected to be minimal and localized.[88]

Data on whether existing buildings have been constructed to withstand storm surge exposure was not available. Impacts will be overestimated to the extent that exposed buildings are resilient to storm surge. On the other hand, wave run-up typically associated with storm surge events was not captured in this analysis, which would lead to an underestimate of the impacts.

The analysis is also limited by the geographic scope of the assessment. Due to data limitations it was only possible to assess the core urban and parts of the suburban areas of the HRM. As mentioned above, HRM is a large regional municipality that includes a number of smaller coastal communities with potential exposure to storm surge impacts. Attempts were made to include at least one or two examples of rural coastal communities. However, existing data could not support such an assessment.

Direct impact estimates for storm surge flooding assume that all of the buildings damaged from a flood event will be repaired/rebuilt to their undamaged pre-flood condition. In reality, future sea level rise could create a situation where several parcels of land with existing buildings will be permanently underwater and land abandonment could be a necessary adaptation (an outcome that is likely to occur outside the timeframe considered in this analysis). Although the scope of this study does not consider any adaptation strategies, permanent land abandonment due to sea encroachment on once dry habitable land is a possibility.

4.7 Extreme Wind Impact Results

In the sub-sections below the results of the impact analysis for extreme wind in the HRM are presented, beginning with estimates of the direct impacts. Secondary impacts are then presented. The direct and secondary impacts presented here represent the opportunity cost of direct, indirect and induced spending – spending that could have been directed elsewhere in the economy were it not for the need to respond to the damages from extreme wind. Estimates for cumulative impacts as well as event-specific impacts

[88] According to community advisors participating in the community engagement process.

are also included below. This is followed by a sensitivity analysis and a discussion of key data and analytical limitations.

4.7.1 Direct Impact

The direct impact estimates presented here are measured as impacts to gross output (which means that they are not directly comparable with the secondary impacts presented below which measure impacts to GDP).[89] The results of the HRM extreme wind analysis are presented in the figures below.[90] Taking into consideration damages to building assets (i.e. structures), the cost of electricity restoration, and economic losses due to business interruptions (due to wind-induced power outages), the findings indicate that future climate change is likely to increase the impacts due to extreme wind events in the HRM. By 2020, the EAD to gross output attributed to climate change was found to increase by 13% (moderate climate change) to 21% (high climate change) relative to the baseline scenario. In 2040, the EAD to gross output increases by 16% (moderate climate change) to 49% (high climate change) relative to the baseline scenario. In terms of absolute direct impacts, the EAD to gross output attributed to future climate change increases from $2.2 million to $3.6 million in 2020 to $3.7 million to $11 million in 2040 (with the ranges representing the difference between the moderate and high climate scenarios).

The increase in direct impact is driven, in part, by increases in peak gust speeds for the extreme events with return periods that are 25 years and higher. In other words, extreme wind events are occurring more frequently. In addition, larger extreme wind events with longer return periods, which have stronger wind speeds, tend to be more significantly impacted by climate change. For instance, the increase in peak gust speed varies from 0.3% to 0.6% for a 1 in 25 year event under moderate climate change, the increase in peak gust speed varies from 1.5% to 1.8% for a 1 in 25 year event under high climate change; the increase in peak gust speed varies from 3.6% to 5.2% for a 1 in 200 year event under moderate climate change; and the increase in peak gust speed varies from 4.4% to 6.5% for a 1 in 200 year event under high climate change. Given the trend in peak gust speed over return periods and climate change scenarios, a small increase in peak gust speed amounts to a considerably larger increase in direct impacts. Figure 17 demonstrates the trend in direct impacts due to climate-related extreme wind in the HRM.

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[89] As per the concept note in the Approach section, direct impacts are first measured as gross output to fully account for intermediate and value added inter-industry linkages in the input-output multiplier analysis. The impacts are then translated to the more commonly reported metric of gross domestic product that highlights the impact on the value of production in the particular year of interest.

[90] The analysis was based on the mean direct impact between the lower and upper damage bands which represent the lowest and highest relative building structure damage as a function of peak gust speed across building types: 1-3 story residential buildings; 1-3 story commercial/industrial buildings; 1-3 story institutional buildings; and 4-10 story mid-rise buildings.

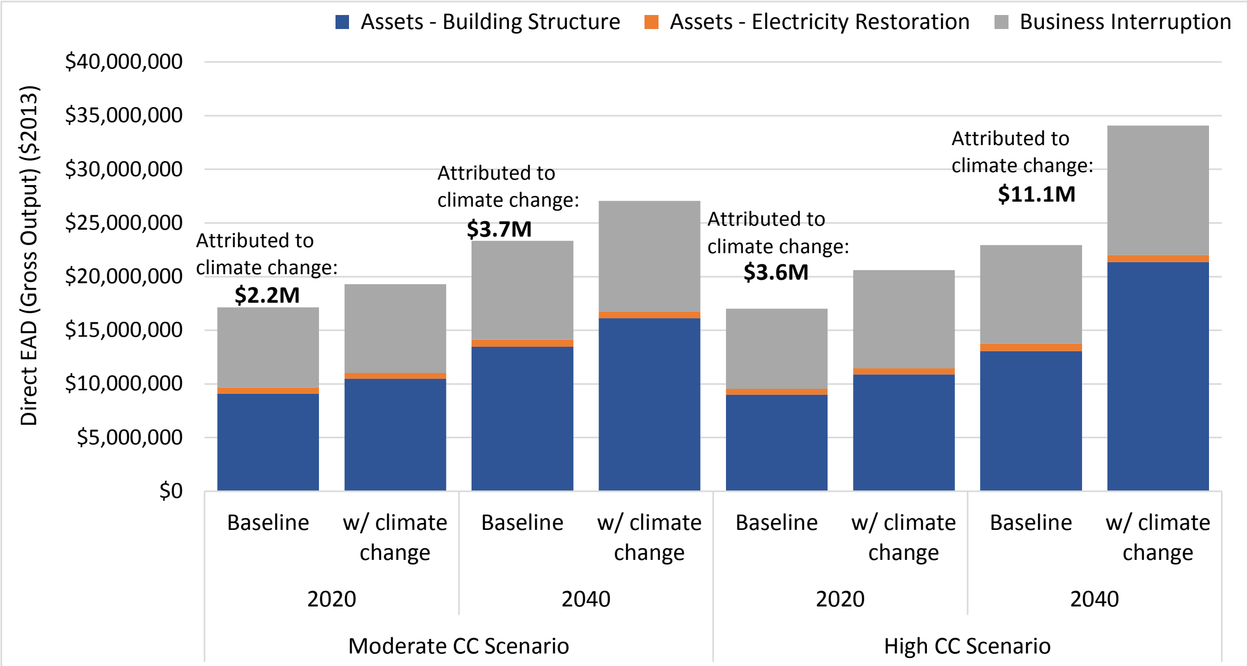


Figure 17: **Direct expected annual damage (in terms of gross output) due to extreme wind in the Halifax Regional Municipality divided between building structure, electricity restoration and business interruption.**

As was noted above, the impacts in this case study include those to building assets (i.e. structures), electricity restoration, and business interruption (due to wind-induced power outages). Across all scenarios and time periods, the impact to building assets represents around 57% (range of 43% to 63%) of the direct EAD impacts considered, while impacts to electricity restoration and business interruption represented around 2.7% (range of 2.0% to 3.2%) and 41% (range of 35% to 45%) of direct and secondary EAD, respectively.

The direct impact split between the aggregated building types indicates (Figure 18) that low-rise residential buildings experience the greatest proportion of the impact (accounting for 47% to 53% of the building-related impacts). This split in impact is largely driven by the share of footprint attributed to low-rise residential buildings: 56% of total building footprint in the baseline year and 60% and 54% of the total building footprint by 2020 and 2040, respectively.

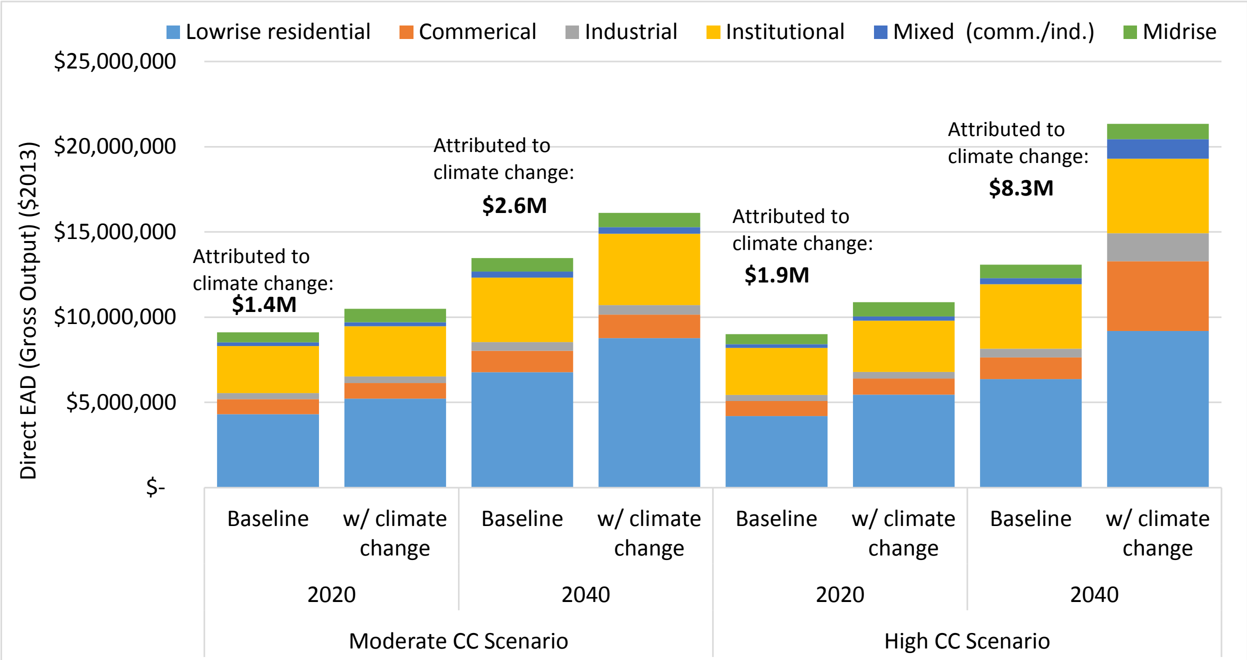


Figure 18: **Direct expected annual damage (in terms of gross output) due to extreme wind in the Halifax Regional Municipality divided between building type**

The direct impact split between existing and new buildings in 2020 is relatively constant across the climate change scenarios ranging from 93% to 94% for existing buildings and 6% to 7% for new buildings (Figure 19). As would be expected, the share of new buildings in the estimated total building impact is larger by 2040, accounting for about 16% of the impact in that year, while existing buildings account for the remaining 84%.

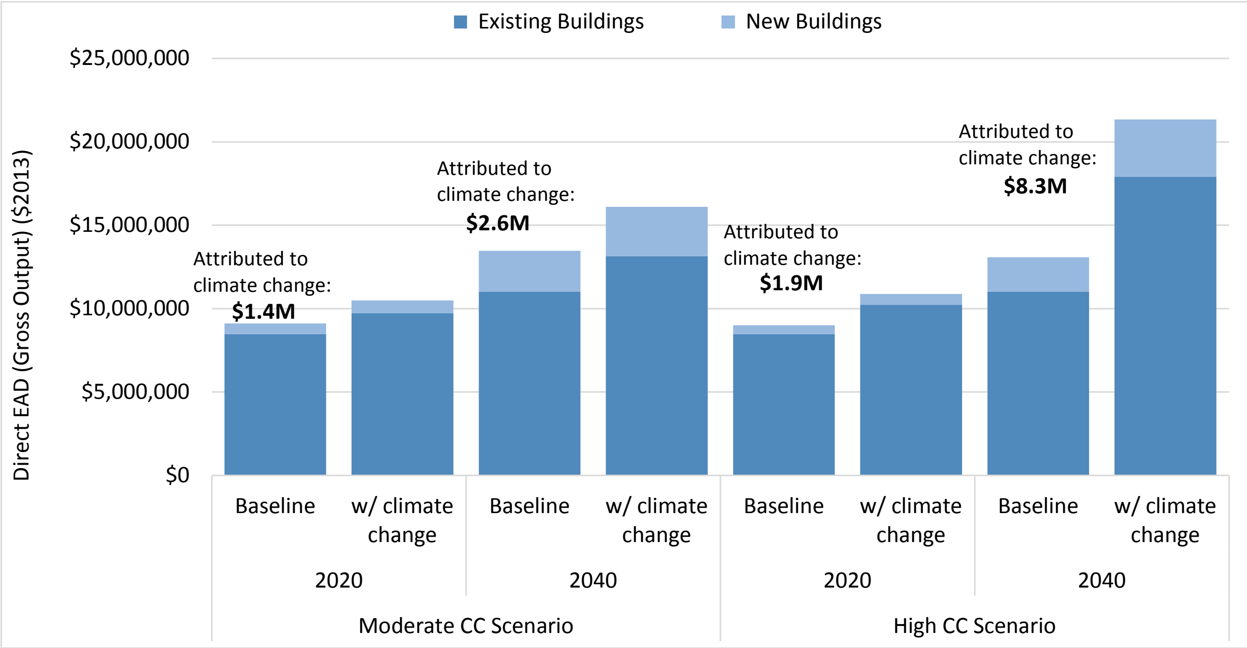


Figure 19: Direct expected annual damage (in terms of gross output) due to extreme wind in the Halifax Regional Municipality divided by existing versus new buildings

The damage curves applied in this analysis originate from Unanwa et al. (2000).[91] It is worth noting that even for the longest return period considered (200 years), the peak gust speed (42.4 m/s to 44.6 m/s) for the HRM does not register any damages when applying the lower damage bands from Unanwa et al. (2000) across all building types. As Unanwa et al. (2000) point out, the lower damage bands are representative of the impacts to the best built buildings within each building category and the upper damage bands are representative of the building structures of least quality. Damage fractions for the upper damage band do not begin to register damage to buildings until a peak gust speed of 35m/s to 39m/s (depending on the building type) is reached. According to the peak gust return periods used in this analysis, the upper damage band shows non-zero impacts at return periods of 25 years and higher. Given the range of peak gust speeds across the return periods (~30m/s to 45m/s), the associated building damage fraction on the upper damage band ranges from 0% to 5.4% of total building value. This indicates that extreme wind impacts to individual buildings in the HRM are relatively minor, but given the extensive geographic coverage of the buildings that intersect with extreme wind, when taken together, the impacts become noticeable.

[91] Unanwa, C. O., McDonald, J. R., Mehta, K. C., & Smith, D. A. (2000). The development of wind damage bands for buildings. Journal of Wind Engineering and Industrial Aerodynamics, 84(1), 119-149.

4.7.2 Secondary Impacts

The secondary impact estimates presented here are measured as impacts to GDP and take into account damages to buildings, the cost of electrical restoration and lost economic output due to business interruptions (resulting from power outages). They are not directly comparable with the gross output estimates presented above for direct impacts. They were derived using the input-output basic Type II multiplier approach. Additional information on how secondary impacts were calculated is contained in Appendix C. The Type II approach considers both the indirect and induced impacts and was chosen as the approach on which to focus these results as it is considered the most accessible (i.e. because it is based on published provincial Statistic Canada multipliers) of the approaches and the one most likely to be employed by community impact analysis tool users. Figure 20 presents the sum of direct and secondary GDP impact estimates for extreme wind in the HRM for the baseline and future climate change scenarios for 2020 and 2040 for impacts to assets. Additional graphs for output and employment are located in Appendix D-E.[92]

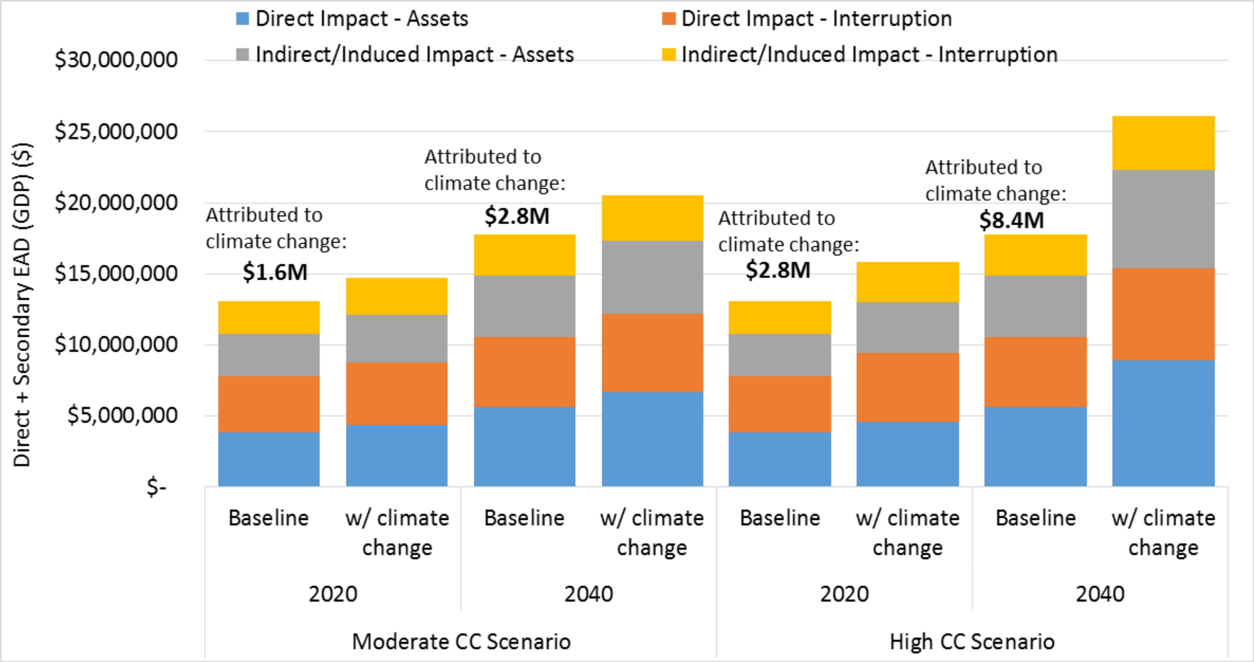


Figure 20: **Direct and secondary expected annual damage (in terms of gross domestic product) due to extreme wind in the Halifax Regional Municipality**

In 2020, under moderate climate change, the sum of direct and secondary impacts from extreme wind attributed to climate change is $1.6 million of GDP. In 2040, under moderate climate change, the sum of direct and secondary impacts from extreme wind attributed to climate change is an estimated $2.8 million

[92] Employment impacts are generally quite small using the EAD concept and given the high amount of output per worker that is representative of the Canadian economy.

of GDP. Under high climate change, the sum of direct and secondary impacts from extreme wind attributed to climate change is $2.8 million of GDP in 2020 and increases substantially to $8.4 million of GDP in 2040.

As is noted in the *Approach* section, several approaches to modelling secondary impacts were employed in this study. Table 6 below highlights the range of the EAD estimates across modelling approaches attributed to climate change for direct and secondary impacts combined measured as GDP. In general, the order of magnitude of the EAD estimates are comparable across the modelling techniques for any given climate change scenario and impact type (i.e. asset versus business interruption). As expected, the CGE model results are for the most part smaller, reflecting the offsetting effect of labour mobility across industries not considered in the I-O models. The basic I-O Type II multiplier results (the results focused on above) generally provide a midpoint among the estimates derived from the various techniques.

Table 6: Summary of the expected annual damage from extreme wind to gross domestic product attributed to climate change ($2013 Millions)

			Basic I-O Type I	Basic I-O Type II	Custom I-O Type I	Custom I-O Type II	CGE
2020	A	M	$0.78	$0.97	$0.85	$1.21	$0.78
		H	$1.09	$1.35	$1.19	$1.69	$1.09
	BI	M	$0.55	$0.67	$0.45	$0.61	$0.33
		H	$1.18	$1.42	$0.95	$1.29	$0.70
2040	A	M	$1.49	$1.84	$1.63	$2.36	$1.63
		H	$4.78	$5.93	$5.23	$7.58	$5.24
	BI	M	$0.77	$0.92	$0.63	$0.87	$0.48
		H	$2.03	$2.44	$1.67	$2.30	$1.28

A = Asset, BI = Business Interruption, M = Moderate climate change, H = High Climate change

The following observations are warranted in light of the results presented in the Table 6:

- The expected annual damages to assets from extreme wind attributed to climate change increased under the moderate climate change scenario from 2020 to 2040, but showed a threefold increase under the high climate change scenario. The expected annual damage in the form of business interruption attributed to climate change over the same period generally increased, 1.4 to 1.7 times under the moderate and high climate change assumptions, respectively.
- Focusing on the Basic Multiplier (Type II) results, the percent difference between the moderate and high climate change scenarios is in the order of 18% in 2020 for assets, relative to the baseline conditions. This gap widened to over 300% in 2040. Business interruption varied by 113% from the moderate to high climate change assumptions in 2020, increasing to 164% in 2040.

4.7.3 Cumulative Impact

To demonstrate the potential impacts of climate-related extreme events across climate change scenarios, is useful to consider the cumulative EAD over the timeframe of the analysis (i.e. from the baseline year of 2015 to 2040). Figure 21 demonstrates the cumulative impact measured as the sum of the direct and secondary EAD estimates for extreme wind events in the HRM attributed to climate change and measured by gross output and GDP. The results reflect the use of basic I-O Type II multipliers. These results depict the overarching trend in EAD as a consequence of climate change; they do not show the scenario-specific direct and secondary EAD.[93]

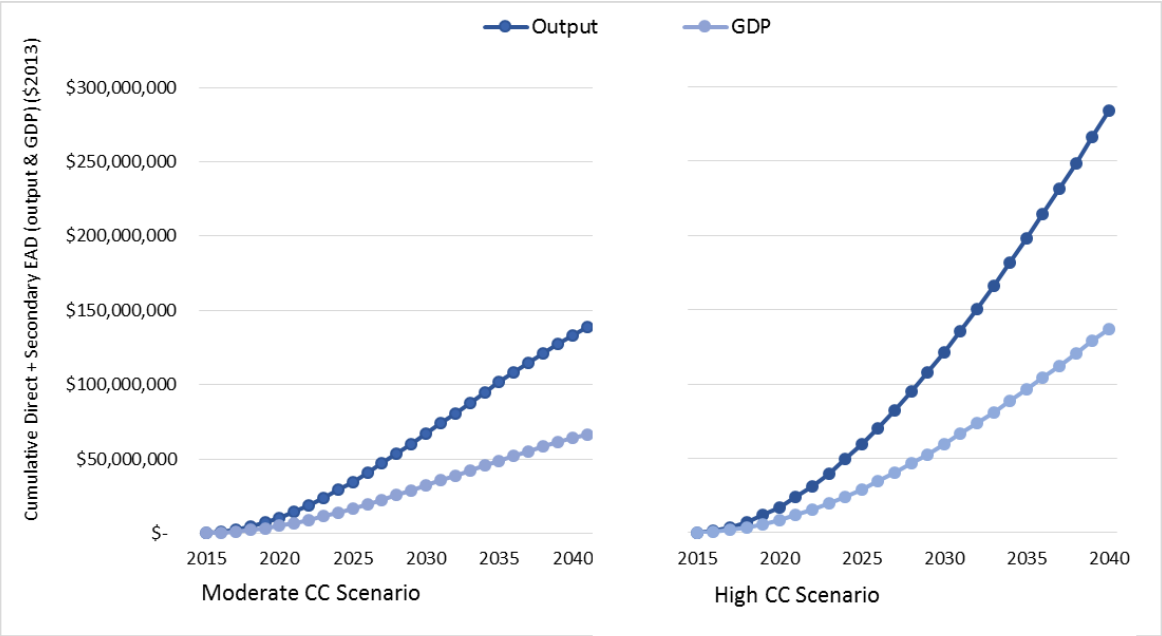


Figure 21: **Cumulative direct and secondary expected annual damage (in terms of gross output and gross domestic product) due to extreme wind in the Halifax Regional Municipality**

The cumulative direct and secondary EAD attributed to climate change for extreme wind events in the HRM was found to increase at exponential rates initially, slowly taper off to increase at a more linear trend by 2020-2025 and begin to increase at a decreasing rate by 2040 for the moderate climate change scenario. The results for both the moderate and high climate change scenarios are shown side-by-side and on the same y-axis scale to show the difference between the two climate change scenarios. By 2020, the direct and secondary EAD is expected to be around $5.1 million and $8.5 million for the moderate and high climate change scenarios, respectively. By 2040, this metric is expected to grow considerably, reaching around $64 million and $140 million for the moderate and high climate change scenarios,

[93] This trend line was built using a best-fit 2nd order polynomial equation by fitting the three known points of EAD that is attributed to climate change for the baseline year (2015, which has zero EAD attributed to climate change by definition) and the future years, 2020 and 2040.

respectively. According to findings in Cheng et al. (2014)[94] it is likely that the trend in cumulative EAD that is attributed to climate change will gradually level off throughout the latter half of this century.

Since EAD expresses impacts statistically by accounting for the probability any given event will occur in any given year, we can use the cumulative EAD estimates to communicate anticipated impacts over a specified time period. For instance, a series of extreme wind events, which could consist of a couple large events or a number of smaller events, are anticipated to cause an additional $64 million to $140 million in impacts (sum of direct and secondary GDP) over the next 25 years as a result of climate change.

4.7.4 Event-Specific Impacts

The expected impacts of climate-related extreme events can be measured on an event-specific basis. Doing so demonstrates how climate change can influence event probabilities and their associated damages. Two examples of estimates for impacts (direct and secondary) resulting from extreme wind events in the HRM are provided below: the expected impacts of a 1 in 25 year extreme wind event and the expected impacts of a 1 in 100 year extreme wind event. The results reflect the use of basic I-O Type II multipliers.

[94] Cheng, C. S., Lopes, E., Fu, C., Huang, Z., 2014. Possible Impacts of Climate Change on Wind Gusts under Downscaled Future Climate Conditions: Updated for Canada. Journal of Climate 27(3):1255-1270.

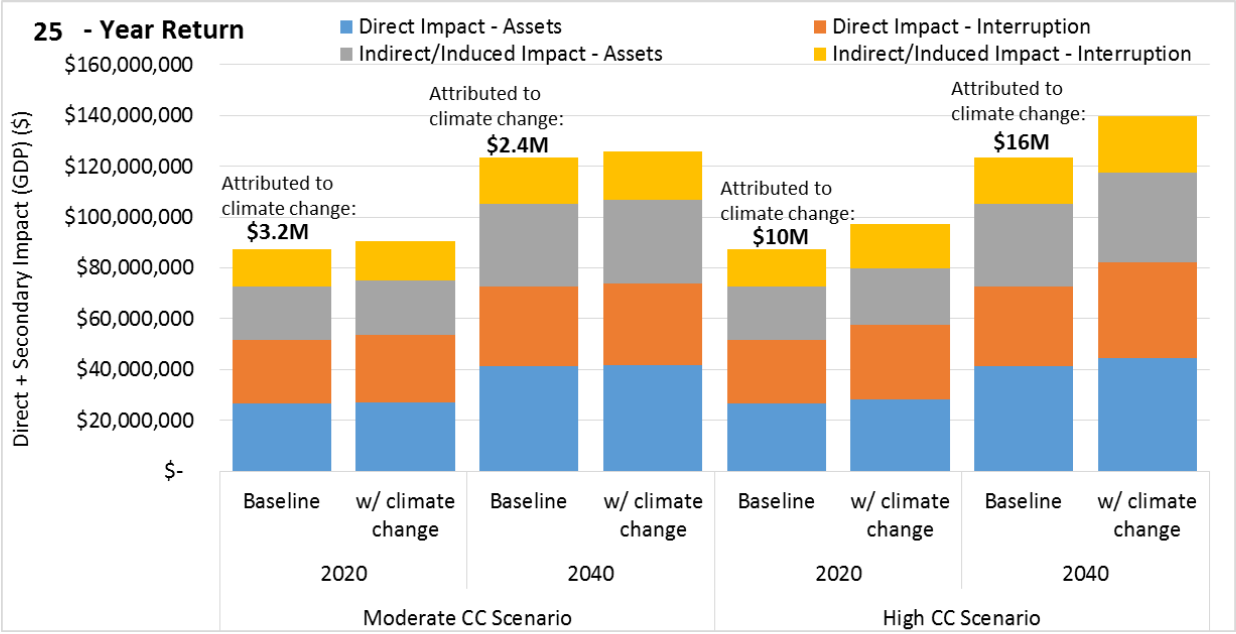


Figure 22: **Direct and indirect expected annual damage (in terms of gross domestic product) of a 1 in 25 year extreme wind event in the Halifax Regional Municipality**

The direct and secondary impact on GDP attributed to climate change in 2020 for a 1 in 25 year extreme wind event is estimated at $3.2 million and $10 million for the moderate and high climate change scenarios, respectively. The impact attributed to climate change then decreases[95] to $2.4 million and $16 million in 2040 for the moderate and high climate change scenarios, respectively. This means that by 2020, if a 1 in 25 year extreme wind event occurs, then the impacts attributed to climate change are expected to be about $3.2 million to $10 million higher than the baseline. By 2040, a 1 in 25 year event would cost an additional $2.4 thousand to $16 million as a result of climate change.

Figure 23 illustrates the direct and secondary impacts on GDP for a more extreme wind event in the HRM. In this case, if a 1 in 100 year extreme wind event were to occur in 2020, then the anticipated impacts would be $120 million to $160 million more with climate change than without. However, a 1 in 100 year event occurring in 2040 would cost an additional $220 million to $330 million, relative to the baseline, as a result of climate change.

In both the 1 in 25 and 1 in 100 year examples, climate change results in extreme wind events occurring more frequently and with greater wind speeds. This results in an anticipated increase in wind damage costs in 2020 and 2040 relative to the baseline climate scenario.

[95] This decrease in impact attributed to climate change is a direct result of the future wind speed data sets utilized to calculate the Gumbel distributions (peak gust speed versus return periods). See Appendix A for additional details on the Gumbel distribution and the source of the climate data employed in this analysis.

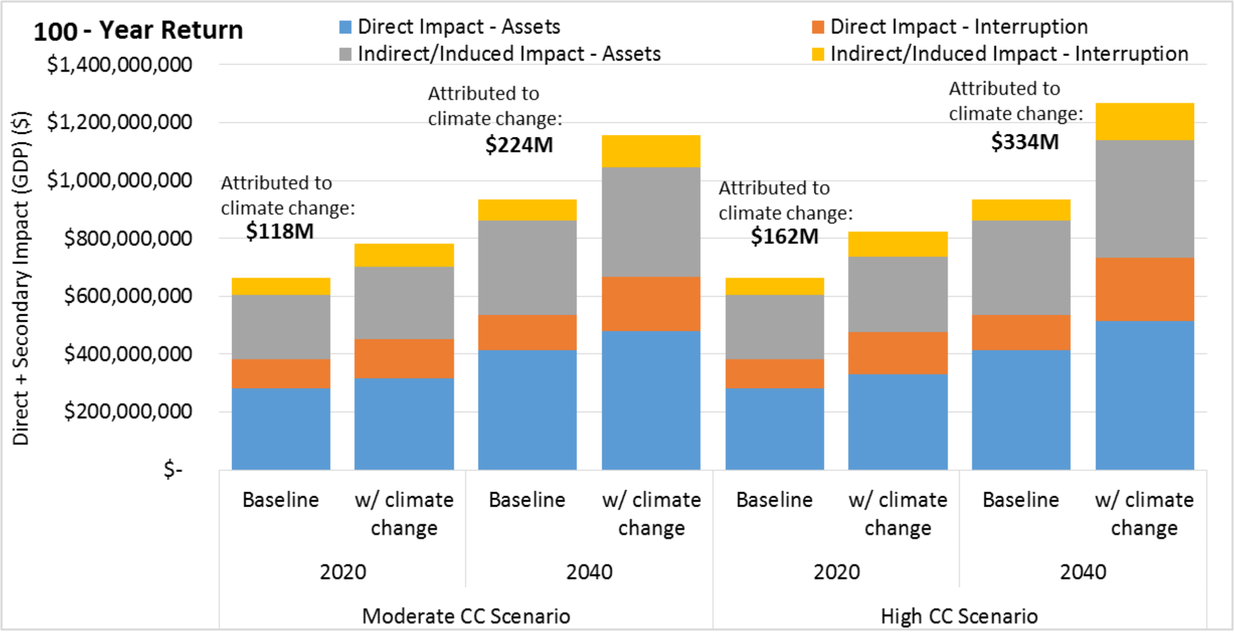
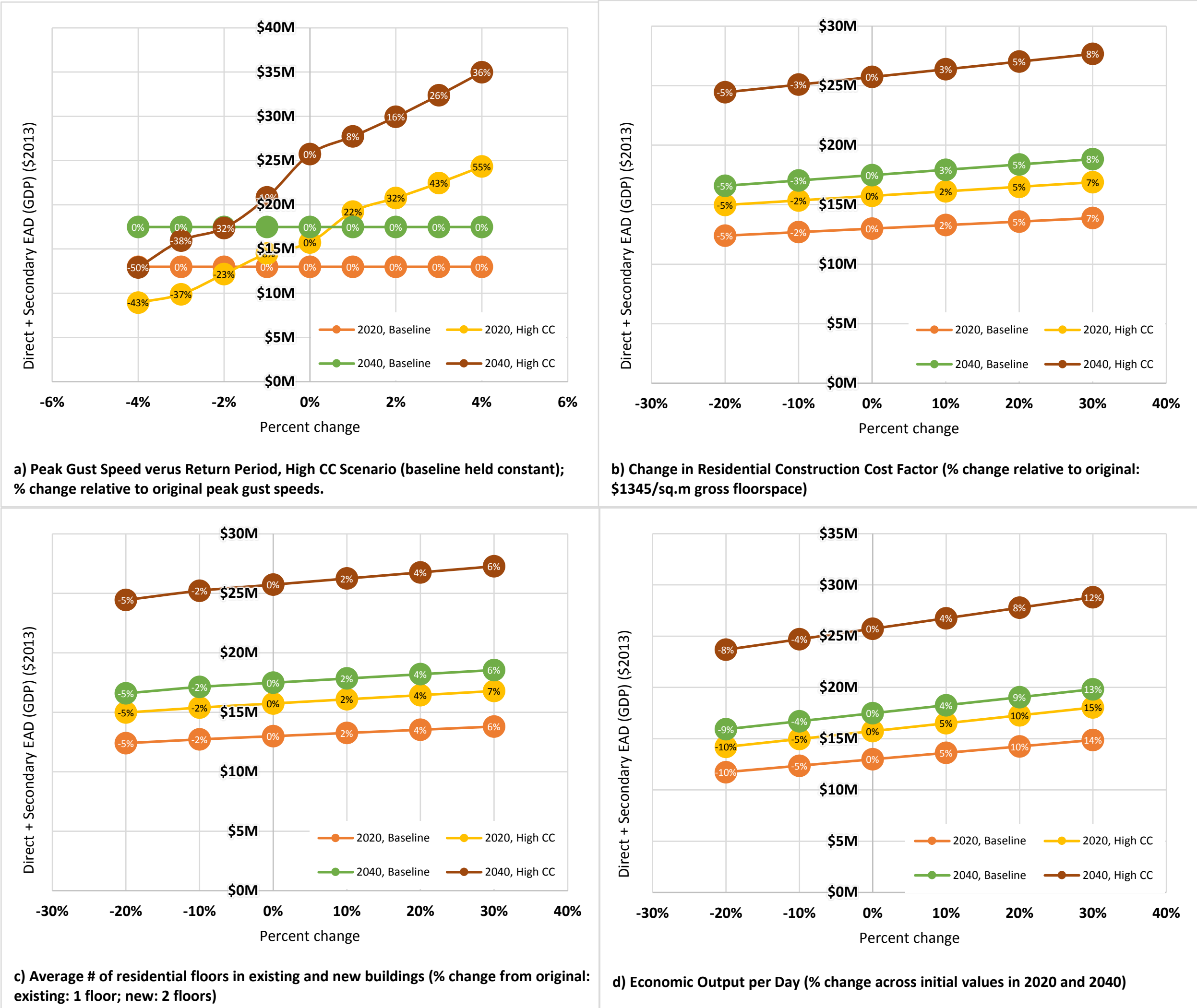


Figure 23: Direct and indirect expected annual damage (in terms of gross domestic product) of a 1 in 100 year extreme wind event in the Halifax Regional Municipality

4.7.5 Sensitivity Analysis

The sensitivity graphs (Figure 24) cover four key parameters used in the extreme wind event analysis for the HRM. Each of these parameters has been plotted in a sensitivity graph demonstrating how the direct and secondary EAD (in terms of GDP) changes as each parameter varies by a given percentage. The results reflect the use of basic I-O Type II multipliers.



a) Peak Gust Speed verus Return Period, High CC Scenario (baseline held constant); % change relative to original peak gust speeds.

b) Change in Residential Construction Cost Factor (% change relative to original: $1345/sq.m gross floorspace)

c) Average # of residential floors in existing and new buildings (% change from original: existing: 1 floor; new: 2 floors)

d) Economic Output per Day (% change across initial values in 2020 and 2040)

Figure 24: Sensitivity graphs for four parameter sets (see individual captions under each sub-plot)

Figure 24a) shows how the sum of the direct and secondary EAD changes as a function of changing the assumed peak gust speeds versus return period for the high climate change scenario while keeping the baseline peak gust speeds versus return period constant. Altering the assumed peak gust speeds by a few percentages has a significant impact on the EAD estimates. For example, if the assumed peak gust speeds for the high climate change scenario in 2020 and 2040 are reduced by just 2%, then the direct and secondary EAD becomes less than the EAD for the baseline scenario (there is about a 13% change in EAD for each percent change in peak gust speed versus return period for the high climate change scenario).

Figure 24b) depicts how the sum of the direct and secondary EAD changes as a function of changing the low-rise residential construction cost factor, which was initially assumed to be $1,345 per square meter of gross floor space. As the figure shows, there is a gradual linear change in EAD as this construction cost factor changes (there is a 0.2% change in EAD for each percent change in the construction cost factor). Since low-rise buildings absorb about half of the total building-related EAD, this means that the construction cost factors of the other buildings will lead to even smaller changes in the EAD as these parameters change. Thus, the principal results are quite robust in terms of changing the construction cost factors.

Figure 24c) indicates the relationship between the sum of direct and secondary EAD and the assumed average number of floors in existing and new low-rise residential buildings. In this case, the initial assumptions were one and two floors, for existing and new low-rise residential buildings, respectively. As the average number of floors increases, the assumed gross floor space within each low-rise residential building increases proportionally, which in turn leads to a higher EAD impact since a building will be valued higher in terms of re-construction/repair costs. As Figure 24c) shows, there is a gradual linear change in EAD as the number of floors changes (there is a 0.2% change in EAD for each percent change in the average number of floors in residential buildings).

Lastly, Figure 24d) illustrates how the sum of direct and secondary EAD changes as a function of changing the total HRM-wide daily economic output across all sectors for 2020 and 2040. Given that this parameter only affects business interruption impacts and that business interruption impacts account for about 40% of the overall EAD, the change in EAD as a function of changing daily economic output is significant but gradual: there is ~0.4% change in EAD for each percent change in daily economic output across sectors in the HRM for 2020 and 2040.

4.7.6 Limitations

A key limitation of the extreme wind results for HRM stems from the application of the wind damage curves taken from Unanwa et al. (2000).[96] Using the Unanwa et al. data, an upper and a lower damage curve was applied to each of the four building types thus determining a range of direct impact estimates. However, the direct impact estimates stemming from the lower band damage curves resulted in zero impact; this means the peak gust speeds in Halifax, even for the longest return period, resulted in no damage when the lower band was applied. Impacts based on the upper band damage curve assume all buildings are of the least quality. Since buildings in Halifax have a range of resilience to wind, the estimated direct impacts assumed an average between the lower (zero impact) and the upper damage bands. An improvement in this analysis would be to account for the resilience of buildings on a building by building basis. This would allow the application of either the lower or upper damage bands to each building according to the resilience of the particular building.

[96] Unanwa, C.O., McDonald, J.R., Mehta, K.C., Smith, D.A., 2000. The development of wind damage bands for buildings. *Journal of Wind Engineering and Industrial Aerodynamics* 84:119-149.

4.8 Impact Analysis Summary

The case study analysis for the HRM focused on the climate-related extreme events of storm surge flooding and extreme wind. Table 7, provides a summary of the direct and secondary impacts (focused on the Type II impacts to GDP) attributed to climate change due to each climate-related event type across each future year and compared between each climate change scenario.

Table 7: Summary of Impacts Attributed to Climate Change in the HRM Case Study (M = Million; K = thousand; all values in $2013)

	Storm Surge Flooding				Wind			
	Moderate climate change		High climate change		Moderate climate change		High climate change	
Year	EAD	Cum. EAD	EAD	Cum. EAD	EAD	Cum. EAD	EAD	Cum. EAD
2020	$280K	$920K	$400K	$1.3M	$2.6M	$5.1 M	$2.8M	$8.5M
2040	$2.1M	$23M	$3.1M	$34M	$2.8M	$64M	$8.4M	$140M
1 in 25 yr event	$1.7M (2020) $13M (2040)		$2.5M (2020) $22M (2040)		$3.2M (2020) $2.4M (2040)		$10M (2020) $16M (2040)	
1 in 100 yr event	$2.9M (2020) $23M (2040)		$3.7M (2020) $29M (2040)		$120M (2020) $220M (2040)		$160M (2020) $330M (2040)	

5. Case Study Analysis – The City of Mississauga

This section of the report provides details on the City of Mississauga (Mississauga) case study. A summary of the case study findings for Mississauga is presented at the outset of the section. This is followed by details pertaining to the case study approaches and the results of the impact analysis. Impacts are measured as direct and secondary impacts (indirect and induced impacts) as are defined in the *Approach* section and the *Glossary of Terms* contained in this report. Technical information, as in detailed data and analytical assumptions, is contained in Appendix B. Impacts are discussed in terms of their present value and monetary values are 2013 constant Canadian dollars unless otherwise stated.

5.1 Key Findings

The case study analysis for Mississauga focused on the climate-related extreme events of storm water flooding and freezing rain. The analysis revealed the following key findings (see Section 4.8 for a summary of all findings):

1. **Greater direct impacts under the climate change scenarios:** For the moderate and high climate change scenarios, increases in direct impacts (measured as changes in gross output between scenarios) were found over time and in relation to the baseline scenario for both freezing rain and storm water flooding. By measuring changes relative to a baseline scenario, factors such as normal community growth are accounted for – allowing the analysis to isolate the climate-related impacts. Comparing the baseline scenario with the moderate and high scenarios revealed the following:
    - **Cost of re-construction and sector output driving baseline increases:** From 2020 to 2040, the direct impacts to gross output for the baseline scenario increased (38% for storm water flooding and 14% for freezing rain) due to increases in the value of buildings, the cost of re-construction and sector output over the same time period.
    - **Impacts of moderate climate change relative to baseline:** From 2020 to 2040, the direct gross output impacts for the moderate climate change scenario increased more than the increase under the baseline scenario; the increase in impacts under the moderate climate change scenario relative to the baseline scenario was found to be 30% greater for freezing rain and 10% greater for storm water flooding. These increases are attributed to climate change.
    - **Impacts of high climate change relative to baseline:** From 2020 to 2040, the direct gross output impacts for the high climate change scenario increased relatively more than the increase under the baseline scenario; the increase in impacts under the high climate change scenario relative to the baseline scenario was found to be 30% greater for freezing rain and 4% greater for storm water flooding. These increases are attributed to climate change.

2. **Business interruption dominates freezing rain impacts:** The majority of the direct gross output impact resulting from freezing rain is due to business interruptions. More than 80% of the estimated impact is due to business interruptions while 17% is attributed to tree-related impacts. Costs associated with power restoration were found to be relatively minimal (0.4%), which is to be expected given that approximately 65% of the power lines in Mississauga are underground.
3. **Residential homes hit the hardest during storm water flood events:** Almost all of the buildings located in the flood zone (96% or 645 of 674 buildings) were found to be residential detached buildings. Because of this, the residential sector accounts for about 87% of the direct impact estimates in 2020 and 2040.
4. **Secondary impacts are comparable across modelling approaches:** The magnitude of the secondary impacts (i.e. the indirect and induced impacts) resulting from freezing rain and storm water flooding were found to be comparable across the three approaches to modelling secondary impacts employed in the analysis.
5. **Climate change driving increases in cumulative impacts over time:** The cumulative sum of direct and secondary impact estimates attributed to climate change for freezing rain could reach over $30 million of gross domestic product ($2013) by 2040. Similarly, for storm water flooding, the cumulative sum of direct and secondary impact estimates attributed to climate change could reach $70 million of gross domestic product ($2013) by 2040.
6. **Extreme events more costly with high climate change:** Impacts from specific climate-related events can be compared across climate change scenarios to demonstrate the difference in impacts resulting from varying climate change assumptions. For example, measured in terms of gross domestic product, a 1 in 25 year freezing rain event occurring in 2040 under a high climate change scenario is estimated to be $15.7 million (2013$) more costly than a 1 in 25 year event occurring in the same year under today's climate conditions. This increased cost is the result of freezing rain events occurring more frequently during the winter months. In the case of storm water flooding, a 1 in 25 year event occurring in 2040 under a high climate change scenario is estimated to be $12 million (2013$) more costly than a 1 in 25 year event occurring in 2040 under today's climate conditions. This increased cost is the result of more frequent heave rainfall events causing greater flood depths.

5.2 Scope of the Impact Analysis

Before presenting the detailed case study results it is necessary to acknowledge that the impact analysis completed for storm water flooding and freezing rain in Mississauga are not *full* assessments of the *total* cost associated with these climate-related extreme events. To be clear, the bullets below state that which is, and is not, included in the case study impact analysis for Mississauga.

The Mississauga case study analysis **DOES:**

- Cover direct and secondary impacts to building structures and contents from climate-related storm water flooding.
- Cover direct and secondary impacts resulting from business interruptions from power outages from freezing rain events.
- Cover direct and secondary impacts resulting from damage to trees from freezing rain events.
- Cover direct and secondary impacts associated with restoring electrical infrastructure from freezing rain events.

The Mississauga case study analysis **DOES NOT:**

- Cover flood damages caused by urban storm water drainage backup
- Cover damage to personal and commercial property from fallen trees.
- Cover business interruptions from road closures.
- Cover road maintenance costs from freezing rain events.
- Cover the cost of delays and disruptions at the airport.
- Cover costs arising from other climate-related extreme events.

5.3 Case Study Outline

This sub-section builds upon the *Background* and *Approach* sections of the report with an explicit focus on Mississauga. More specifically, in the sub-sections below the following information is presented:

- **Background:** Provides a brief overview of climate-related extreme events in Mississauga.
- **Approaches:** Describes details on the approaches employed to forecast socio-economic variables, complete the community engagement process and quantify the direct and secondary impacts of two climate-related extreme events.
- **Results:** Presents the results for direct and secondary impact estimates as well as cumulative impacts and event-specific impact estimates.

5.4 Background: Climate-related Extreme Events in Mississauga

Mississauga has a moderate climate, with possible high summer temperatures accompanied by high humidity. The average July and August temperature is 20ºC, but can reach above 30ºC. Winters in Mississauga can be cold, with temperatures most often below the freezing mark. Brief periods of warmer temperatures can also occur throughout the winter season. Snowfall in Mississauga is relatively low.

Climate-related extreme events in Mississauga include freezing rain, high precipitation (snow or rain), high winds, extreme heat, and extreme highs or lows in lake levels. The Great Lakes have a modifying influence on the local climate, including moderation of extreme heat from winds. However, Mississauga is shielded from lake effect snow. Climate in the Greater Toronto Area (GTA) (including Mississauga) is affected by large-scale circulation patterns, including el Niño and the North Atlantic Oscillation.[97]

Annual and seasonal temperatures have increased across the GTA. The combination of urbanization and climate change has led to significant temperature increases in the GTA from both 1970-2000 and from the shorter time period of 1989-2000. A number of recent climate-related extreme events have highlighted both climate and infrastructure vulnerability in the GTA, including extreme rain and flooding (2005, 2009, 2013), and freezing rain (2013), all of which can cause significant damages. The July 8, 2013 rainfall event has been touted as Toronto's most expensive disaster with costs estimated close to $1 billion.[98] The December 22, 2013 freezing rain event triggered the City of Mississauga to approve $12.5 million of non-budget funding to cover the tree removal and clean-up costs,[99] while the insurance claims across Ontario were estimated to be $179 million.[100]

Extreme rainfall over short periods of time is becoming a new normal for southern Ontario and the GTA. What has made these storms particularly damaging is the intensity of the rainfall, which in some cases far exceeds current design standards.[101] The table below (Table 8) highlights a number of storms in recent years in and around the GTA and how they compare to the current 100 year design standard (established based on the Hurricane Hazel event in 1954). In the last 10 years, the region has seen 6 storms all exceeding the 100 year design storm standard.

Table 8: Summary of recent extreme rainfall event for southern Ontario

Extreme Rainfall Event	Total Rainfall Amount (mm)	Duration (hr)	1 Hr Max. Intensity (mm/hr)
Peterborough (Trent U), July 14-15, 2004	250	16.5	87.2
Toronto (Finch Ave), August 19, 2005	153.4	12.5	116.6
Hamilton (Stoney Creek), July 25-26, 2009	135.5	35	60.8
Mississauga (Cooksville), August 4, 2009	68	1	68
West-Central GTA (Pearson), July 8, 2013	126	3	96
Burlington, August 4, 2014	192	3	80
Hurricane Hazel, 15 October, 1954	285	48	52.5
100 Year Design Storm	118	24	50

From the list of extreme weather events experienced in Mississauga, two were identified as the focus of the impact analysis. This was done, in part, through an engagement process with local community

[97] Moughsin and Gough (2009). Trend analysis of long-term temperature time series in the Greater Toronto Area (GTA).
[98] Environment Canada (2014). Canada's Top Weather Stories for 2013: Toronto's Torrent. http://www.ec.gc.ca/meteo-weather/default.asp?lang=En&n=5BA5EAFC-1&offset=3&toc=show
[99] City of Mississauga Corporate Report to Council. Ice Storm Recovery Update – Parks and Forestry. April, 23, 2014
[100] Personal communication, Chris Rol, Senior Policy Advisor, Insurance Bureau of Canada.
[101] Design standards result from the minimum legal requirements to which buildings have to be constructed and a developers choice on the degree to which those requirements may or may not be exceeded.

representatives. The community engagement process as well as the approaches used to conduct the impact analysis for Mississauga are described in the sub-section below.

5.5 Case Study-Specific Approaches

The following sections provide detailed information on the approaches used to assess the impacts from climate-related extreme events in Mississauga. The section begins with a description of the socio-economic forecasting that was undertaken. This is followed by an overview of the Mississauga community engagement process. Pertinent details related to establishing baseline conditions for Mississauga are then provided along with the analytical approaches for estimating the direct and secondary impacts of each climate-related extreme event.

5.5.1 Socio-economic Forecasting

Socio-economic forecasting plays an important role in the estimation of direct and secondary impacts from climate-related extreme events. In particular, and as is discussed in the *Approach* section of this report, expected impacts are a function of the damages resulting from an extreme event, the probability of the event occurring, and the socio-economic conditions of the community under consideration. In the context of the current analysis, population, gross domestic product (GDP) and labour force were forecasted for Mississauga and used to establish baseline economic conditions for 2020 and 2040. The process by which these variables were forecasted and the resulting trends in their values to 2020 and 2040 are described below.

Population: Population forecasts for Mississauga for 2020 and 2040 were employed in the estimation of direct and secondary impacts from the climate-related extreme events under consideration by informing future asset development assumptions. Under Ontario planning policy, Mississauga is obligated to plan on the basis of long-term population, housing and employment forecasts. Forecasts of these variables are currently provided to 2051 although the present municipal plan has a horizon to the year 2031.[102]

The analysis relied on Mississauga's long-term economic forecasts to inform assumptions about how assets will change into the future. Municipal projections span a range of low and higher growth assumptions, to take into account different amounts of intensification that would result from different numbers and sizes of households being accommodated within the municipal boundary.

The most conservative projection would have Mississauga's population reaching about 864,000 by 2040, which amounts to about 15% growth from present. A higher projection would mean population growth of 20%. The majority of this growth will be accommodated by new apartment units rather than single- or

[102] Hemson Consulting Limited. 2013. Long range forecasts: City of Mississauga 2011-2015. www.mississauga.ca/data

semi-detached dwellings, while the majority of employment growth will be accommodated in higher density forms by new major offices.

Gross Domestic Product: Gross domestic product projections for Mississauga are employed in the analysis of the secondary impacts of the climate-related extreme events to establish the baseline economic structure for 2020 and 2040. Estimates for GDP for 2020 and 2040 by sector for Mississauga are based on historical provincial GDP data by sector. The Mississauga-specific GDP baseline was estimated by comparing sector labour and income at the municipal level to provincial labour and income data. Since labour income is a major component of GDP and readily available for most municipalities, it provides a basis upon which to develop scaled-down GDP estimates. Statistics Canada GDP data covering the years 1997 to 2013 (CANSIM Table 379-0030) was scaled to the community level and projected forward in a linear fashion. This process resulted in the following key GDP projections for Mississauga (details in Table 9 below):

- The total estimated GDP for Mississauga is projected to increase 57% by 2040.
- Downward trends are projected for the mining, quarrying, and oil and gas extraction sector and the manufacturing sector.
- The highest rate of change (91% by 2040) is in the information and cultural industries sector.
- The administrative and support, waste management and remediation services sector, and the retail trade sector also have high projected growth rates of 78% each.

Table 9: Mississauga gross domestic product projections by sector

Sector	Baseline GDP ($2013M)	2020 GDP ($2013M)	2040 GDP ($2013M)	% Change to 2020	% Change to 2040
Crop and animal production	73.6	79.4	95.6	8%	30%
Forestry and logging	2.4	2.6	3.1	8%	30%
Fishing, hunting and trapping	1.3	1.4	1.6	8%	30%
Support activities for agriculture and forestry	2.1	2.3	2.8	8%	30%
Mining, quarrying, and oil and gas extraction	141.7	116.6	70.8	-18%	-50%
Utilities	326.8	367.5	464.3	12%	42%
Residential construction	374.7	457.4	637.9	22%	70%
Non-residential building construction	128.7	157.1	219.1	22%	70%
Engineering construction	151.2	184.5	257.3	22%	70%
Repair construction	701.4	856.1	1,194.0	22%	70%
Other activities of the construction industry	331.3	404.3	563.9	22%	70%
Manufacturing	3,713.7	3,427.0	2,349.3	-8%	-37%
Wholesale trade	2,704.7	3,346.1	4,785.6	24%	77%
Retail trade	1,964.3	2,469.9	3,493.4	26%	78%
Transportation and warehousing	1,702.2	1,978.2	2,555.3	16%	50%
Information and cultural industries	1,511.8	1,968.5	2,883.0	30%	91%
Finance, insurance, real estate, rental and leasing and holding companies	8,705.5	10,709.1	14,837.7	23%	70%
Professional, scientific and technical services	3,742.1	4,719.7	6,602.9	26%	76%
Administrative and support, waste management and remediation services	938.9	1,196.0	1,668.2	27%	78%
Educational services	1,634.3	1,946.5	2,653.4	19%	62%
Health care and social assistance	3,052.4	3,643.8	4,946.0	19%	62%
Arts, entertainment and recreation	189.7	220.3	270.4	16%	43%
Accommodation and food services	579.3	635.6	732.5	10%	26%
Other services (except public administration)	660.5	812.7	1,089.3	23%	65%
Other federal government services	241.4	283.5	387.6	17%	61%
Other provincial and territorial government services	277.7	326.2	446.0	17%	61%
Other municipal government services	636.2	747.1	1,021.6	17%	61%
Other aboriginal government services	-	-	-	0%	0%
Total	34,489.9	41,059.4	54,232.5	19%	57%

Labour Force: Labour force projections for Mississauga are also employed in the analysis of the secondary impacts of the climate-related extreme events to downscale provincial data to Mississauga for both 2020 and 2040. Estimates of labour force for 2020 and 2040 by sector at the Mississauga level are based on historical Statistics Canada labour force data projected forward in a linear fashion (CANSIM Table 282-0061 for the period of 1987 to 2013). This process resulted in the following key labour force projections for Mississauga, measured as the number of full-time equivalent jobs - FTE (details in Table 10 below):

- The total labour force is expected to increase by approximately 45% by 2040.
- Labour force declines are expected in the agriculture, mining, quarrying, oil and gas extraction, utilities, and manufacturing sectors.
- The largest percent increase is projected in the business, building, and other support services sector (~81%).

Table 10: Mississauga labour force projections by sector

Sector	Baseline (#FTE)	2020 (#FTE)	2040 (#FTE)	% Change to 2020	% Change to 2040
Agriculture [111-112 1100 1151-1152]	800	807	791	0.9%	-1.1%
Forestry, fishing, mining, quarrying, oil and gas [21 113-114 1153 2100]	875	716	693	-18.2%	-20.8%
Utilities [22]	2,070	1,787	1,593	-13.7%	-23.0%
Construction [23]	20,580	23,059	30,451	12.0%	48.0%
Manufacturing [31-33]	44,595	48,895	44,315	9.6%	-0.6%
Trade [41 44-45]	71,325	85,698	108,310	20.2%	51.9%
Transportation and warehousing [48-49]	26,380	29,573	38,595	12.1%	46.3%
Finance, insurance, real estate and leasing [52-53]	38,410	42,282	54,327	10.1%	41.4%
Professional, scientific and technical services [54]	37,155	44,437	63,055	19.6%	69.7%
Business, building and other support services [55-56]	20,460	26,268	36,933	28.4%	80.5%
Educational services [61]	22,565	26,806	36,085	18.8%	59.9%
Health care and social assistance [62]	29,800	33,193	44,899	11.4%	50.7%
Information, culture and recreation [51 71]	11,340	11,711	15,509	3.3%	36.8%
Accommodation and food services [72]	21,140	25,561	33,493	20.9%	58.4%
Other services [81]	20,625	25,078	31,605	21.6%	53.2%
Public administration [91]	15,040	13,719	15,462	-8.8%	2.8%
Total	**383,160**	**439,588**	**556,117**	14.7%	45.1%

5.5.2 Community Engagement Process

For each of the case study communities, a group of advisors was assembled to provide guidance and information to the project. In Mississauga, this group was comprised of City of Mississauga staff representing planning, economic development, environment, parks planning, forestry, finance, risk management, and transportation and public works departments. The Region of Peel climate change and water and sewer services departments also participated as did the local electrical distribution utility.

The focal points of the community engagement process were two advisory group meetings. Meeting #1 fostered an understanding of the project methods and goals, and facilitated a process for participants to recommend climate-related extreme events for the impact analysis. Meeting #2 focused on key assumptions and data employed in the analysis, identifying options for responding to data gaps, and the presentation of preliminary results. Brief summaries for each of the meetings follow.

Meeting #1 - Selecting climate-related extreme events

Participants were asked to consider several climate-related extreme events in break-out groups before identifying priority events for the project. Among the options considered were extreme precipitation (both snow and rain), freezing precipitation (ice storms), heat waves, flooding and drought.

Through a consensus exercise, the following events emerged: ice storm (identified by two of three groups); flash flood/precipitation (identified by all three groups); extreme wind (identified by one group), extreme heat/cold (identified by two groups). Extreme wind was removed from the list of consideration as it only received one nomination.

A 'paired comparison' exercise[103] including ice storm, extreme rainfall and extreme heat identified freezing rain and extreme rainfall/storm water flooding as the priority events for analysis.

Following Meeting #1, the project team continued to work with the representative from Mississauga to secure data for the analysis. This process was iterative and the project team was in frequent contact with the city representative to clarify and interpret data, obtain new data, address gaps and provide updates on progress.

Meeting #2 – Reviewing assumptions and data

As the project progressed towards preliminary results, the advisory group was reconvened for Meeting #2. At this meeting, the project team tested the assumptions used in the analysis, described the scope of the analysis, and discussed options for the model outputs. The advisory group confirmed many assumptions, identified and helped address outstanding gaps, and provided important context for the project reports. Following meeting #2, the project team was able to complete the analysis of expected impacts from climate-related extreme events for the Mississauga case study. The first step in undertaking the impact analysis was to establish the baseline conditions.

5.5.3 Establishing Baseline Conditions

As is described in the *Approach* section of this report, to estimate the direct and secondary impacts of climate-related extreme events, the spatial distribution of the assets in the case study community was

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[103] Paired comparison: The paired comparison methodology allowed the group to efficiently identify from three options the top two hazards. In pairs, the group voted by show of hands their selection of which extreme event should considered in the research (e.g. Event A compared to B, then A with C, finally B with C). The scoring system applied helps determine the group priority.

overlaid with the spatial distribution of the extreme event. Damage costs result from the assets that are located within the spatial distribution of the extreme event. They are measured in relation to baseline conditions, which describe the current and projected (2020 and 2040) distribution and value of assets on the landscape, for the two climate change scenarios (moderate and high).

The estimated distribution of assets on the landscape are driven by projected changes in population in the case study community (see the socio-economic forecasting section above). The projected change in population for 2020 and 2040 was used to derive estimates for new building requirements for the same years. Present day citywide and sector-specific building footprints (which were derived through GIS analysis) were divided by the current population to estimate sector-specific building requirements per person. Applying these sector-specific building requirements per person to the projected population for 2020 and 2040 resulted in estimates of the amount of building growth required for the same years.

Building requirements for 2020 and 2040 were then allocated to the Mississauga landscape across “opportunity areas.” Opportunity areas describe geographic locations that have been identified for future development. For Mississauga, opportunity areas for new developments were obtained from the city. New building requirements for 2020 and 2040 were assigned to these areas for residential, industrial, commercial and institutional buildings.

The location of buildings (existing and new) by sector (residential, industrial, commercial and institutional) for 2020 and 2040 describe the distribution of assets on the landscape. To calculate the damage costs to the sub-set of assets that intersect with the extreme events requires assigning values to the affected assets. Building structure values were derived from construction cost values per unit area and were projected for 2020 and 2040 based on historical trends.[104] These values were employed as estimates of the cost of re-constructing/refurbishing a damaged building. Building content values were estimated using the HAZUS building structure to building content value ratios[105] for the general categories of residential, industrial, commercial and institutional buildings (for example, based on the HAZUS ratios, the building structure to contents value ratio for residential buildings was assumed to be 2:1). The building and content value estimates were employed in the estimation of direct impacts from each of the climate-related extreme events under consideration for Mississauga for the baseline and moderate and high climate change scenarios.

[104] AltusGroup, 2014. Construction Cost Guide, [Accessed October 20, 2014], http://www.altusgroup.com/research/construction-cost-guide/ .
[105] HAZUS, 2010. Multi-hazard Loss Estimation Methodology, Flood Model. Technical Manual, Federal Emergency Management Agency, Jessup, Maryland.

5.5.4 Estimating the Direct Impacts of Storm Water Flooding

To estimate the direct impacts of storm water flooding, the spatial distribution and value of assets for Mississauga for the baseline conditions (derived through the means described above) was overlaid with the spatial distribution of the storm water flooding. The overlap between the two spatial distributions was used to estimate which building assets are flooded, what percentage of the buildings are flooded, and how high the flood water reaches for each affected building. Given the degree of flooding for each building affected by storm water, damage costs for the affected buildings were estimated.

The estimation of flood damage costs employed in this analysis generally followed procedures developed by the U.S. Army Corps of Engineers.[106] In accordance with these procedures, damage costs are based on depth-damage curves that depict the percent of damage that results at various flood depths (Figure 25).

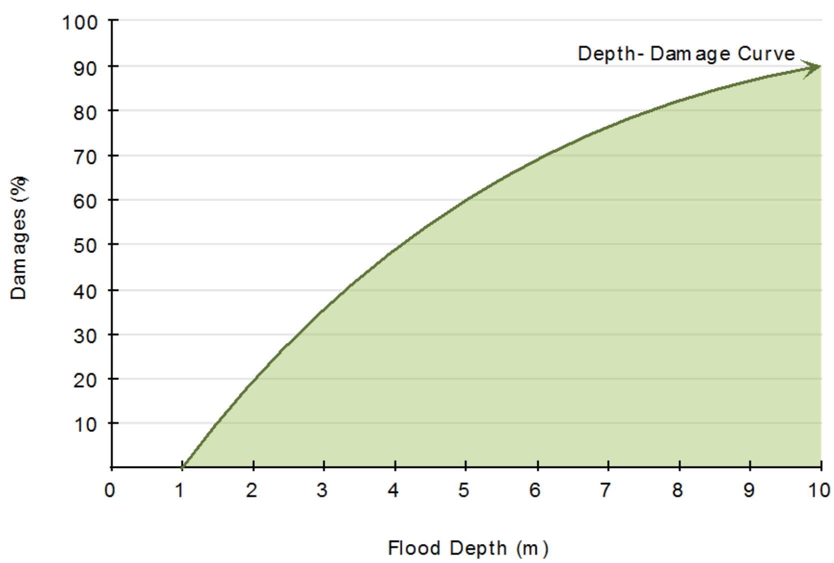

Figure 25: **Hypothetical depth-damage curve**

Thus, in the context of Mississauga, percent damage estimates from the depth-damage curve relationship were assigned to the value of the affected buildings and their content by matching building attributes with the available depth-damage curves. A total of 35 damage curves were used to assess the damages to the affected buildings based on the calculated flood depths at each building: 20 related to structural damages and 15 related to content / inventory / equipment. This process was completed for a range of flood depths and each flood depth was allocated a probability. This same process was repeated for both moderate and high climate change scenarios and the flood depths versus probability estimates changed

[106] USACE 2011. Coastal Storm Risk Management: National Economic Development Manual. U.S. Army Corps of Engineers, Institute for Water Resources, IWR Report 2011-R-09.

accordingly (for details on the climate data pertaining to the flood impact analysis see Appendix B) to capture anticipated changes driven by climate change.

5.5.5 Estimating the Direct Impact of Freezing Rain

Research related to freezing rain identifies a number of different potential impacts to various assets. Most damage is caused by the accumulation of ice on trees and power lines which break or topple. In doing so they can cause damage to buildings and property. Business can also be disrupted by power outages associated with freezing rain events.

The analysis of the damage from freezing rain involved applying the 'Sperry-Piltz Ice Accumulation' (SPIA) index that links ice thickness to power disruption-related impacts. The index is typically used for risk management and winter storm preparedness purposes. However, it can be utilized to link ice thickness to potential power disruption-related damages based on sector-specific productivity and population data, essentially creating an ice thickness – impact curve at the community level that captures business interruptions arising from prolonged power outages. For the current analysis, the index was used to inform the creation of a damage curve for freezing rain storms. Table 11 describes the SPIA Index.[107]

[107] The Sperry-Piltz Index. www.spia-index.com.

Table 11: Sperry-Piltz utility ice damage index[108]

Ice Index	Radial Ice Amount (inches)	Wind (mph)	Damage and Impact Descriptions
1	< 0.25	15-25	Some localized utility interruptions possible, typically lasting only 1 or 2 hours maximum.
	0.25-0.50	< 15	
2	< 0.25	>= 25	Scattered utility interruptions expected, typically lasting less than 8-12 hours maximum.
	0.25-0.50	15-25	
	0.50-1.00	< 15	
3	0.25-0.50	>= 25	Numerous utility interruption, with some damage to main feeder lines expected with outages lasting from 1-3 days.
	0.50-0.75	15-25	
	0.75-1.00	<15	
4	0.50-0.75	>= 25	Prolonged & widespread utility interruptions, with extensive damage to main distribution feeder lines and possibly some high voltage transmission lines. Outages expected to last more than 3 to 5 days.
	0.75-1.00	15-25	
	1.00-1.50	< 15	
5	0.75-1.00	>= 25	Catastrophic damage to entire utility systems. Outages could last from one week to several weeks in some areas.
	1.00-1.50	15-25	
	> 1.50	< 15	

The SPIA index provides a scale from one to five with respect to how extreme a freezing rain event is in terms of power outage duration and spatial distribution. A SPIA score for a given event is determined by knowing a combination of the accumulated ice thickness and the average wind speed during the event. With these datasets, it is possible to estimate annual average citywide power outage duration and relate it to business interruptions in terms of sector-specific economic loss in addition to power line infrastructure restoration costs.

Along with damage costs resulting from impact to power line infrastructure and power outages, damage from climate-related freezing rain events results when ice accumulates on trees. The greater the accumulation of ice on trees, the greater the impact from the freezing rain event. For the purposes of this analysis, a recent publication[109] was used to relate community-wide tree damage (measured as the volume of tree debris that needs to be removed and disposed of) from a freezing rain event to observed ice thickness.

[108] McManus, G.D., Piltz, S.F., Sperry, S., McPherson, R.A., Gartside, A.D., McClain, D., Meyer, T., Fetsch, C., Shafer, M.A. 2009. Development and testing of an ice accumulation algorithm. [Accessed 6.6.2014] http://www.crh.noaa.gov/images/eax/IceDamageIndex/IceUtilityIndexPaper.pdf .
[109] Hauer, R.J., Hauer, A.J., Hartel, D.R., Johnson, J.R., 2011. Rapid assessment of tree debris following urban forest ice storms. Arboricultre & Urban Forestry 37(5):236-246.

Three ways of estimating tree damage were explored in this analysis:

1. A community area factor that estimates the volume of tree debris per square kilometer of the community and per centimetre of ice thickness.[110]
2. A community street distance factor that estimates the volume of tree debris per kilometer of community street distance and per centimetre of ice thickness.[111]
3. A community street distance equation that also estimates the volume of tree debris based on kilometer of street distance and centimetre of ice thickness.[112]

The expected tree damage estimates derived through the approaches identified above are used to estimate the costs associated with tree debris clean up, hazard pruning, tree removal and tree replacement. Through consultation with Mississauga's Parks and Forestry staff unit, cost estimates were verified and an average of the first and second method (i.e. average between community area and street distance factors) was chosen as an appropriate conservative approach to estimate tree debris.

5.6 Storm Water Flooding Impact Results

In the sub-sections below the results of the impact analysis for storm water flooding in Mississauga are presented, beginning with estimates of direct impact. Secondary impacts are then presented. The direct and secondary impacts presented here represent the opportunity cost of direct, indirect and induced spending – spending that could have been directed elsewhere in the economy were it not for the need to respond to the damages from storm water flooding. Estimates for cumulative impacts as well as event-specific impacts are also included below. This is followed by a sensitivity analysis and a discussion of key data and analytical limitations.

5.6.1 Direct Impact

The direct impact estimates presented here are measured as impacts to gross output (which means that they are not directly comparable with the secondary impacts presented below which measure impacts to GDP).[113] Future climate change is likely to significantly increase the impacts to gross output due to storm water flooding events in Mississauga, assuming no adaption measures are taken. Taking into consideration damage to fixed assets (i.e. buildings and their contents), by 2020 it is estimated that the expected annual damage (EAD) attributed to climate change increases by 2.4% (moderate climate change) to 2.5% (high climate change) relative to the corresponding baseline scenario. By 2040, EAD

[110] Community area factor: 365.4 m^3 of tree debris per km^2 of community area per cm ice thickness.
[111] Community street distance factor: 51.8 m^3 of tree debris per km of community street distance per cm ice thickness.
[112] Community street distance equation: Tree debris (m^3) = -99,136 + 311.2 * street distance (km) + 15,031.9 * ice thickness (cm).
[113] As per the concept note in the Approach section, direct impacts are first measured as gross output to fully account for intermediate and value added inter-industry linkages in the input-output multiplier analysis. The impacts are then translated to the more commonly reported metric of gross domestic product that highlights the impact on the value of production in the particular year of interest.

increases by 6% (high climate change) to 13% (moderate climate change) relative to the baseline scenario. In terms of absolute direct impact, the EAD as measured by gross output attributed to future climate change increases from $590 thousand to $1.4 million in 2020 (from high to moderate climate change scenarios) and from $1.9 million to $4.4 million in 2040 (from high to moderate climate change scenarios).

The underlining reason for the increases in direct impact attributed to climate change is that rainfall intensity (i.e. precipitation per unit time) is expected to increase as a consequence of climate change. Generally, this can be explained by a well-established physical law (the Clausius-Clapeyron relation) which says that the water-holding capacity of the atmosphere increases by about 7% for every 1ºC rise in temperature.[114] In fact, basic theory, climate model simulations and empirical evidence all confirm that warmer climates, owing to increased water vapour, lead to more intense precipitation events even when the total annual precipitation is reduced slightly, and with prospects for even stronger events when the overall precipitation amounts increase.[115] The rainfall intensity as a function of return period was found to increase more relative to the baseline climate conditions for the moderate climate change scenario than for the high climate change scenario. This data was extracted directly from the online rainfall intensity-duration-frequency (IDF) tool (see Appendix B for greater details).[116] Given this rainfall IDF data was attained from an online tool with no detailed explanation that described the localized trends of why the moderate CC scenario had higher rainfall intensities relative to the high CC scenario, a scientific reason behind this trend cannot be provided here.[117]

The impacts in this case study include those to Mississauga building assets (both structure and contents) that are within the flood zone of several creeks throughout Mississauga. Impacts to residential buildings is split fairly evenly between structural and contents damage (~53% due to structural damage), whereas the damage to the remaining sectors is dominated by the contents of the building: commercial, ~67% due to content damage; industrial, ~74% due to content damage; and, institutional, ~89% due to content damage.

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[114] Trenberth, K.E., P.D. Jones, P. Ambenje, R. Bojariu, D. Easterling, A. Klein Tank, D. Parker, F. Rahimzadeh, J.A. Renwick, M. Rusticucci, B. Soden and P. Zhai, 2007: Observations: Surface and Atmospheric Climate Change. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

[115] Trenberth, K.E., P.D. Jones, P. Ambenje, R. Bojariu, D. Easterling, A. Klein Tank, D. Parker, F. Rahimzadeh, J.A. Renwick, M. Rusticucci, B. Soden and P. Zhai, 2007: Observations: Surface and Atmospheric Climate Change. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

[116] IDF CC Tool for deriving rainfall Intensity-Duration-Frequency Cures for future climate scenarios. Version 1.0.3863. [Accessed December 1, 2014] http://www.idf-cc-uwo.ca/.

[117] The rainfall IDF data should be updated periodically as climate model data gets updated. For instance, a newer version of IDF data has already been made available since this analysis.

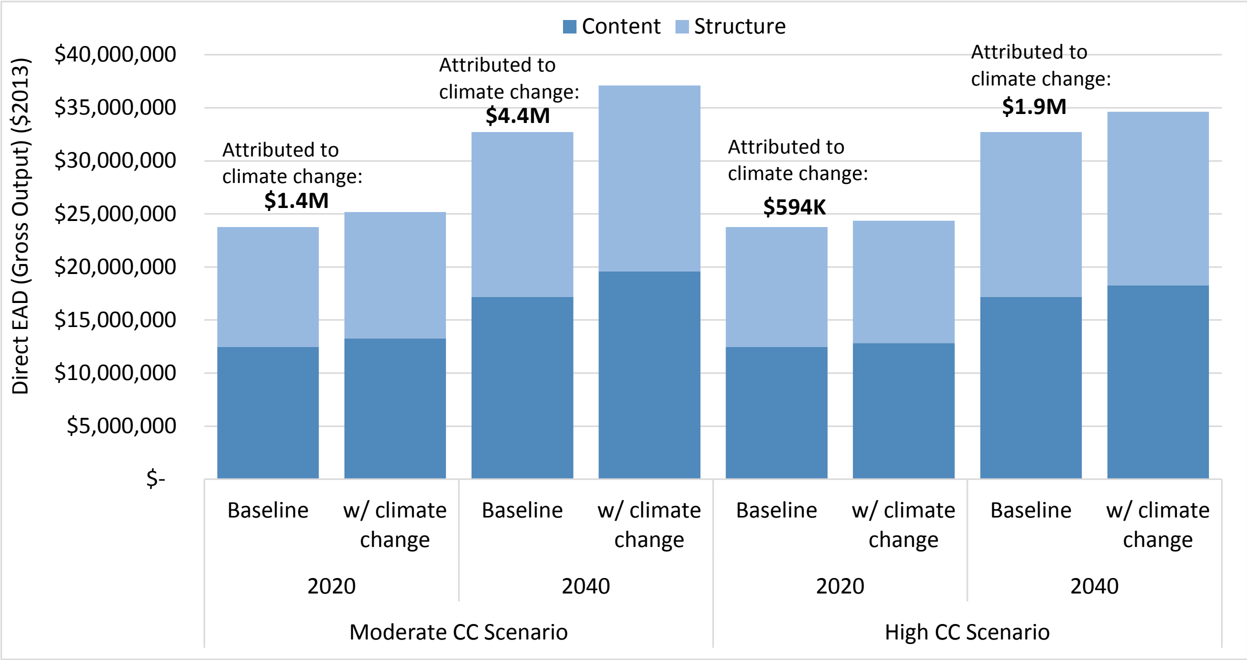


Figure 26: Direct expected annual damage (split between content and structure) (in terms of gross output) due to storm water flooding in Mississauga

Figure 27 shows direct impact to gross output estimates by sector. Within this area of Mississauga it is the residential buildings that take on the majority of the direct impact. The share of total impact to residential buildings remains relatively stable across the future time periods and climate scenarios: 87% in both 2020 and 2040. This relatively high share of impacts to the residential sector is reasonable, given that 96% (645 of 674 buildings) of all existing buildings in this study are residential (all being residential detached homes). The building class that is next hardest hit is the institutional sector (~12% in 2020 and 2040), while the commercial and industrial sectors contribute a relatively small percent to the total impacts (0.5% and 0.05%, respectively).

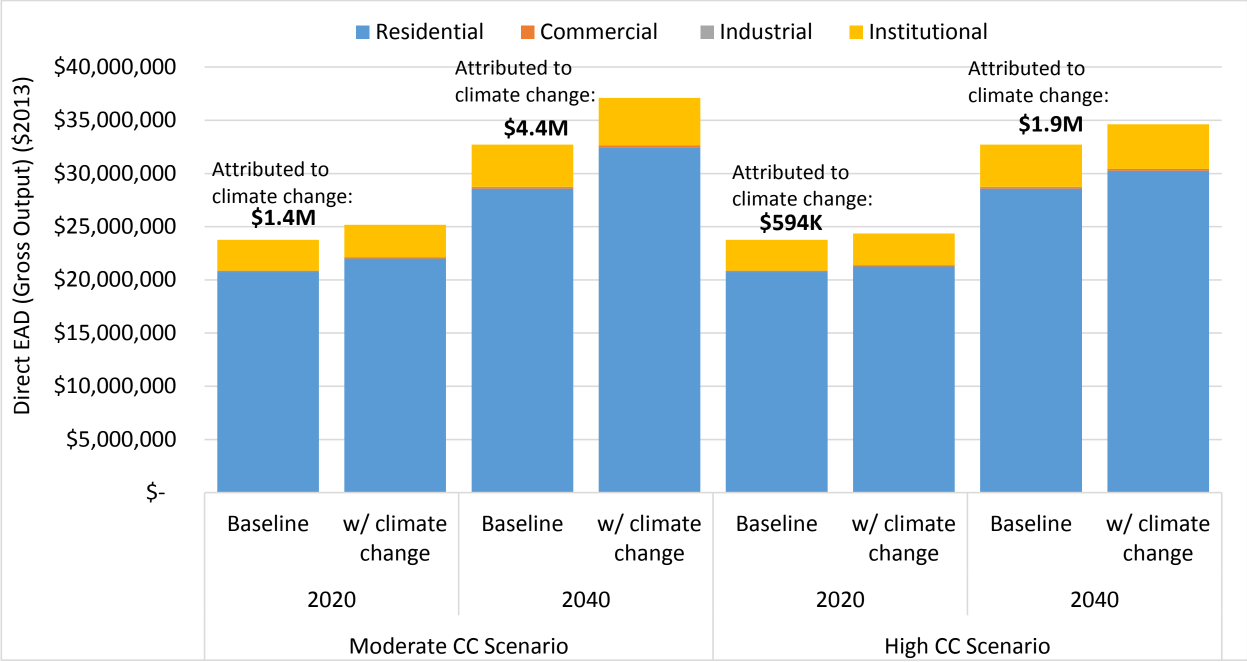


Figure 27: **Direct expected annual damage (in terms of gross output) due to storm water flooding by building sector for Mississauga**

The direct impact results can also be examined according to damage to new buildings (building development in the future years on presently designated opportunity areas – areas designated for future development – not including new buildings that replace existing buildings) versus existing buildings (Figure 28). However, in this analysis no new building development within the focused flood zones was considered,[118] and therefore, 100% of the impacts illustrated in this analysis are attributed to already existing buildings.

[118] Development should generally occur outside of the flood hazard zone as according to the following policy: Ontario Ministry of Affairs and Housing (2014). Provincial Policy Statement under the Planning Act. Effective April 30 2014 [Accessed 02.02.2015] http://www.mah.gov.on.ca/Page10679.aspx .

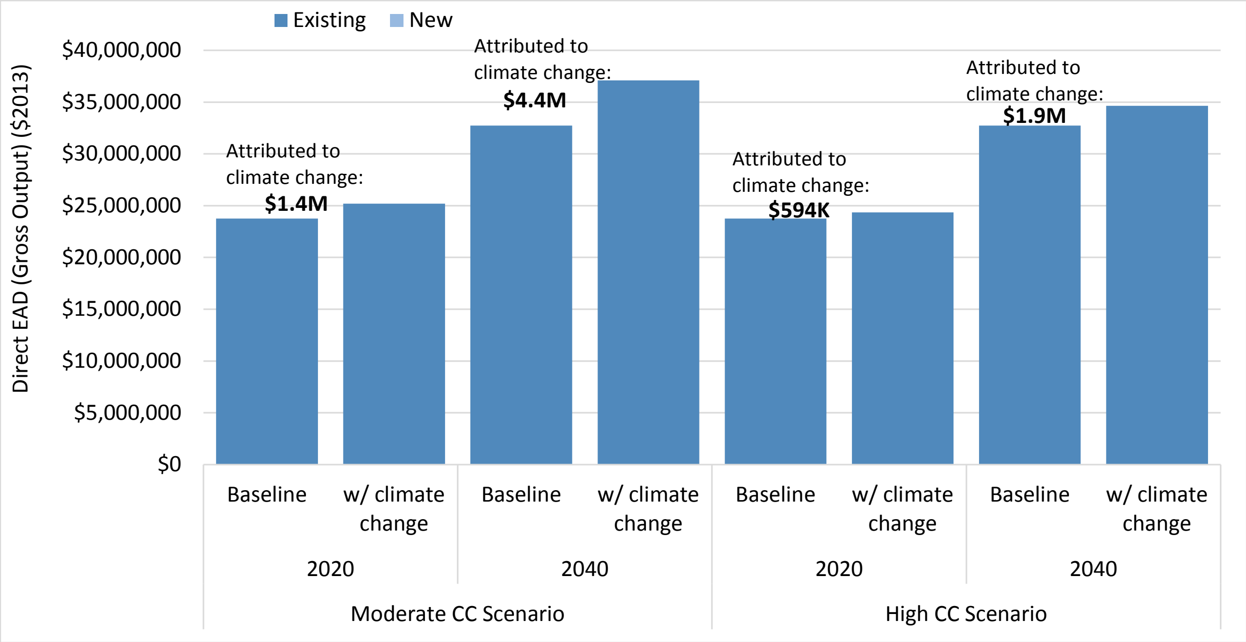


Figure 28: **Direct expected annual damage (in terms of gross output) due to storm water flooding distinguishing between existing and new buildings for Mississauga**

5.6.2 Secondary Impacts

The secondary impact estimates presented here are measured as impacts to GDP and take into account damages to fixed assets (i.e. buildings and their contents). They are not directly comparable with the gross output estimates presented above for direct impacts. They were derived using the input-output basic Type II multiplier approach. Additional information on how secondary impacts were calculated is contained in Appendix C. The Type II approach considers both the indirect and induced impacts and was chosen as the approach on which to focus these results as it is considered the most accessible (i.e. because it is based on published provincial Statistic Canada multipliers) of the secondary impact methods and the one most likely to be employed by community impact analysis tool users. Additional graphs for output and employment are located in Appendix D-E.[119]

Figure 29 presents estimates for the direct and secondary impacts of storm water flooding on GDP in Mississauga for the baseline and future climate change scenarios in 2020 and 2040.

[119] Employment impacts are generally quite small using the EAD concept and given the high amount of output per worker that is representative of the Canadian economy.

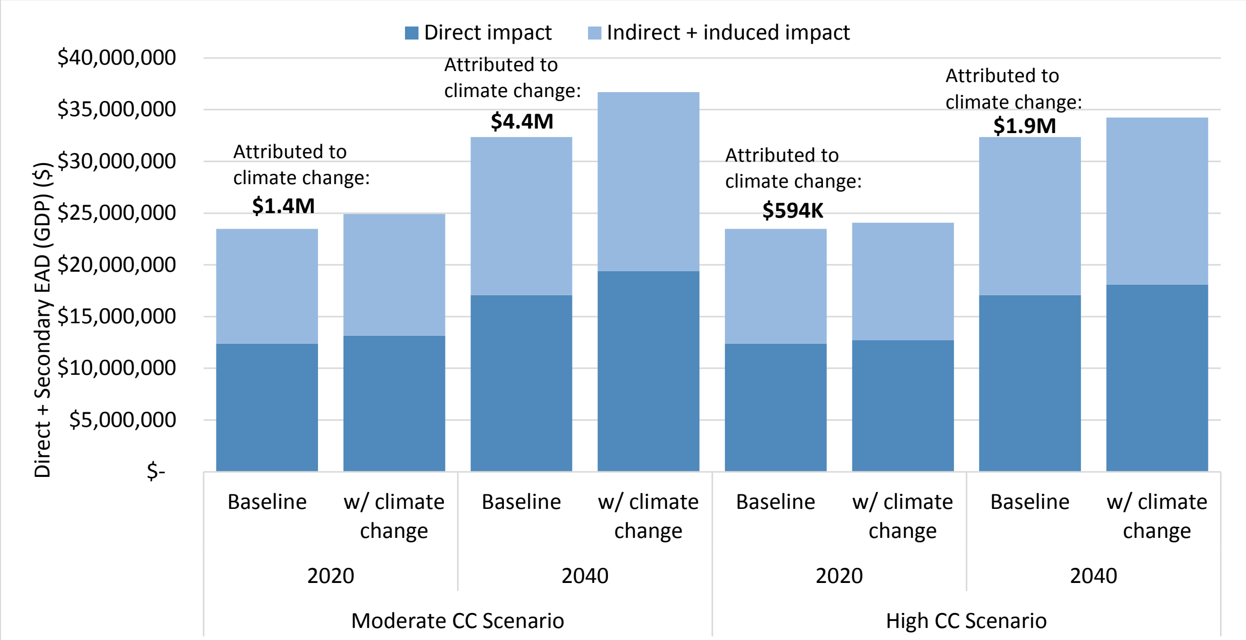


Figure 29: Direct and secondary (indirect and induced) expected annual damage (in terms of gross domestic product) due to storm water flooding in Mississauga

As is demonstrated in the figure above, the province-wide indirect and induced impacts were a significant component of the sum of the impact on GDP. The sum of direct and secondary impacts attributed to climate change in 2020 is $1.4 million, increasing to $4.4 million in 2040 under the moderate climate change scenario. In the case of the high climate scenario, the sum of direct and secondary impacts attributed to climate change in 2020 is $590 thousand, increasing to $1.9 million in 2040.

As is noted in the *Approach* section, several approaches to modelling secondary impact were employed in this study. Table 12 below highlights the range of the EAD estimates across modelling approaches attributed to climate change for direct and secondary impacts combined, measured as GDP. In general, the order of magnitude of the EAD estimates are comparable across the modelling techniques for any given climate change scenario. As expected, the CGE model results are for the most part smaller reflecting the offsetting effect of labour mobility across industries not considered in the I-O models. The basic I-O Type II multiplier results (the results focused on above) generally provide a midpoint among the estimates derived from the various techniques.

Table 12. Expected annual damage to assets (A) as measured by impacts to GDP from storm water attributed to climate change under moderate (M) and high (H) climate change scenarios ($2013 Millions)

			Basic I-O Type I	Basic I-O Type II	Custom I-O Type I	Custom I-O Type II	CGE
2020	A	M	$1.1	$1.4	$1.03	$1.50	$0.68
		H	$0.47	$0.59	$0.43	$0.63	$0.29
2040	A	M	$3.5	$4.4	$3.4	$5.6	$2.2
		H	$1.5	$1.9	$1.5	$2.4	$0.96

Table 12 warrants the following observations:

- The percent difference between the moderate climate change scenario and the high climate change scenario goes from 5% in 2020 to 124% in 2040.
- The expected annual damages from storm surge attributed to climate change increased by approximately 3 to 9 times from 2020 to 2040.
- The CGE model results generally showed the smallest impacts, but all methods yielded similar orders of magnitude of results.

5.6.3 Cumulative Impacts

To demonstrate the potential impacts of climate-related extreme events across climate change scenarios, it is useful to consider the cumulative EAD over the timeframe of the analysis (i.e. from the baseline year of 2015 to 2040). Figure 30 demonstrates the cumulative impacts measured as the sum of the direct and secondary EAD estimates for flooding in Mississauga and attributed to climate change, by gross output and GDP. The results reflect the use of basic I-O Type II multipliers. These results depict the overarching expected trend in EAD as a consequence of climate change, they do not show the scenario-specific direct and secondary EAD.[120]

[120] This trend line was built using a best-fit 2nd order polynomial equation by fitting the three known points of EAD that is attributed to climate change for the baseline year (2015, which has zero EAD attributed to climate change by definition) and the future years, 2020 and 2040.

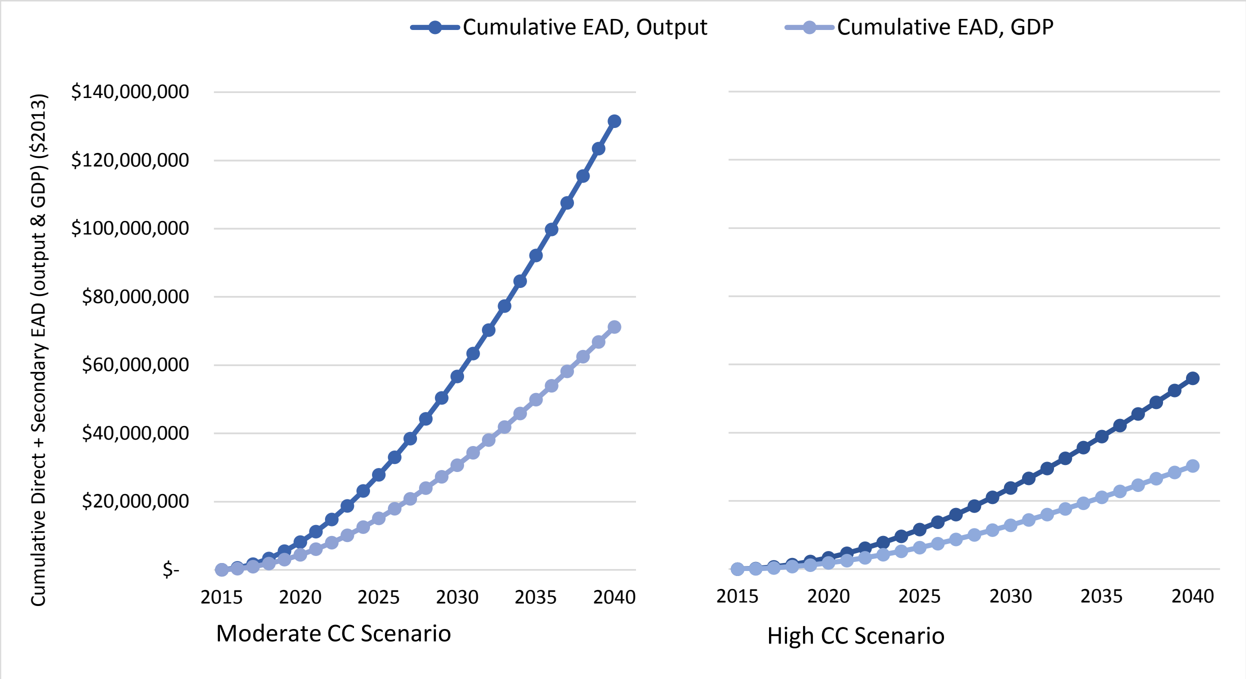


Figure 30: **Cumulative direct and secondary expected annual damage of storm water flooding on gross output and gross domestic product attributed to climate change in Mississauga**

The cumulative direct and secondary EAD attributed to climate change for flood events in Mississauga was found to increase at exponential rates. The results for both the moderate and high climate change scenario are shown side-by-side and on the same y-axis scale to show the difference between the two climate change scenarios. By 2020, the direct and secondary EAD (type II, GDP) was expected to be around $4.4 million and $1.8 million for the moderate and high climate change scenarios, respectively. By 2040 this metric is expected to grow considerably, reaching around $70 million and $30 million for the moderate and high climate change scenarios, respectively.[121] This indicates that the EAD due to storm water flooding will likely continuously grow higher over the given time horizon and this is due to ongoing rising temperatures which generally lead to increasing rainfall intensities.

5.6.4 Event-Specific Impacts

The expected impacts of climate-related extreme events can also be measured on an event-specific basis. This representation demonstrates how climate change can influence event probabilities and associated damages. Two examples of estimates for impacts (direct and secondary) to GDP resulting from flooding in Mississauga are provided below: the expected impacts for a 1 in 25 year storm water flood event and the expected impacts for a 1 in 100 year storm water flood event. The results reflect the use of basic I-O Type II multipliers.

[121] It should be reinforced that this impact is that which is attributed to climate change (i.e. above the baseline impacts).

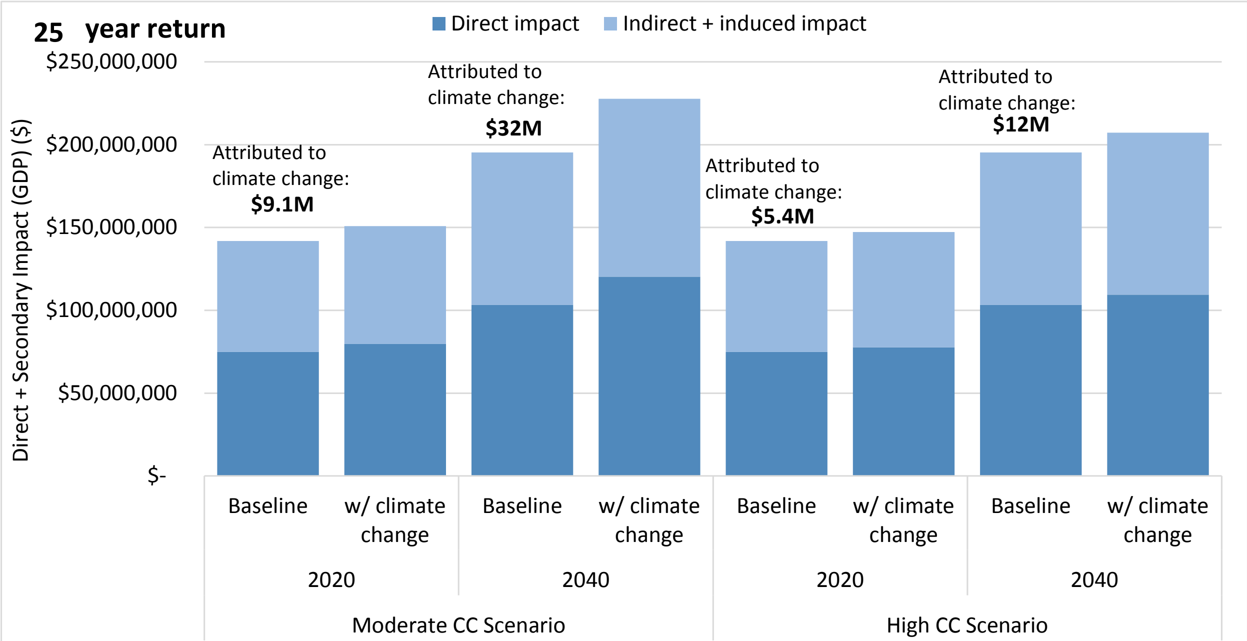


Figure 31: Direct and secondary expected annual damage (in terms of GDP) of a 1 in 25 year storm water flooding event in Mississauga

Figure 31 demonstrates the event-specific impact (direct and secondary) on GDP from a 1 in 25 year storm water flood event in Mississauga. The impact attributed to climate change in 2020 is $9.1 million and $5.4 million for the moderate and high climate change scenarios, respectively. The impact increases to $32 million and $12 million in 2040 for the moderate and high climate change scenarios, respectively. This means that by 2020, if a 1 in 25 year storm water event occurs, then the impacts are expected to be about $5.4 million to 9.1 million higher than the baseline. By 2040, a 1 in 25 year event would cost an additional $12 million to $32 million as a result of climate change.

Figure 32 illustrates the impact estimates (direct and secondary) on GDP for a more extreme flood event in Mississauga. In this case, if the 1 in 100 year flood event were to occur in 2020, then the anticipated impacts would be $4.3 million to $8.7 million higher with climate change than without. However, a 1 in 100 year event occurring in 2040, would cost an additional $11 million to $27 million as a result of climate change.

The underlining reason why the impacts attributed to climate change are higher for the 1 in 25 year event than for the 1 in 100 year event is because a greater proportion of buildings are experiencing changing flood depths that cause a higher rate of change in terms of absolute damage. In general, this is because the damage curves rise steeply throughout relatively small flood depths (i.e. the range of 0.25 to 1 m water depth), and then the damages gradually level-off thereafter. This means that the change in impact due to a 1 in 100 year event between historic and future climate change scenarios is generally smaller on a per building basis than for the 1 in 25 year event. Therefore, although absolute impacts are significantly higher for the 1 in 100 year event the impacts attributed to climate change end up being a little higher for the 1 in 25 year event when compared to the 1 in 100 year event. Regardless, in both cases, climate change results in flood events occurring more frequently and with greater flood depths. This results in an anticipated increase in flood damage costs in 2020 and 2040 relative to the baseline climate scenario.

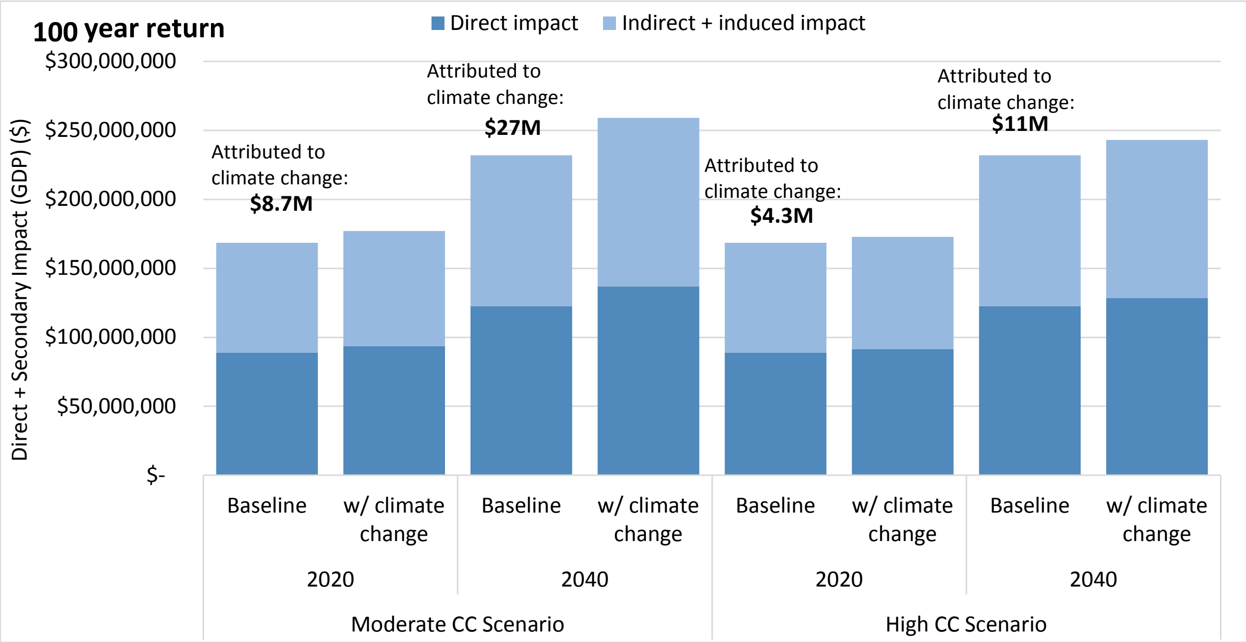


Figure 32: Direct and secondary expected annual damage (in terms of GDP) of a 1 in 100 year storm water flooding event attributed to climate change in Mississauga

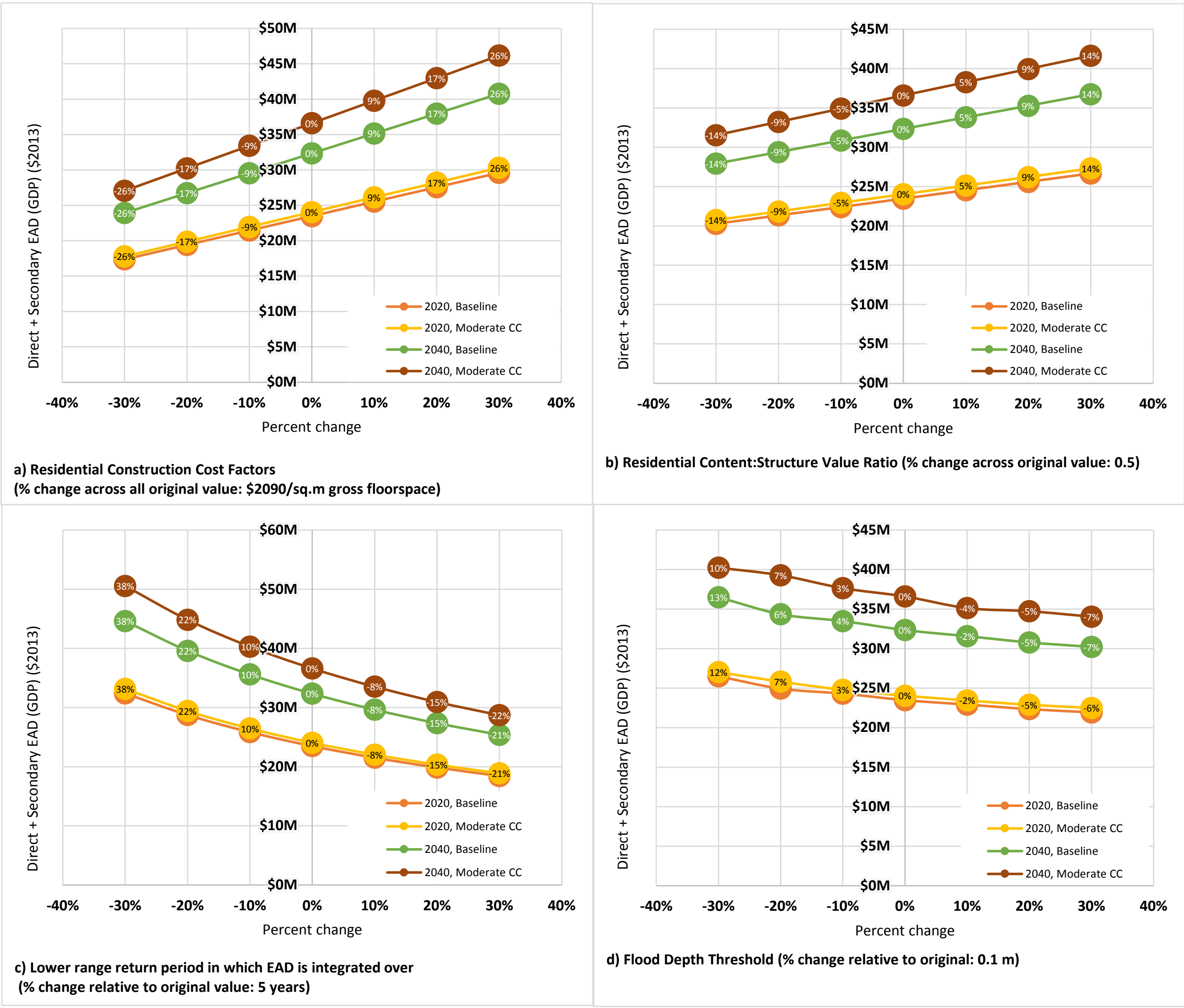
5.6.5 Sensitivity Analysis

Figure 33 demonstrates sensitivity analysis results for four key parameters used in the storm water flood event analysis for Mississauga. Each of these parameters has been plotted in a sensitivity graph demonstrating how the direct and secondary EAD (in terms of GDP) changes as each parameter varies by a given percentage. The results reflect the use of basic I-O Type II multipliers.

Figure 33a) shows how the sum of direct and secondary EAD changes as a function of changing the assumed residential construction cost factor in the moderate climate change scenario.[122] The original construction cost factor was assumed to be $2,090/m^2 gross floor space[123] and it was used to estimate the cost of repairing a detached residential building after a flood event of given flood depth.[124] The relative

[122] All residential buildings considered in this analysis (i.e. prone to flood events in the areas considered) were assumed to be 1-3 story detached residences.
[123] This factor was taken from: Altus Group, (2015). Construction Cost Guide (2015). http://www.altusgroup.com/research/construction-cost-guide/ .
[124] The total reconstruction value of a building was calculated by multiplying the construction cost factor by the gross floor space of the building. The direct structural impact to a building due to a given flood event was then estimated by multiplying this total reconstruction value by the appropriate normalized flood damage curve (i.e. as a function of the given flood depth).

change in EAD as a function of changing this parameter is equal and linear across each scenario and future year. This parameter has a considerable influence on the final result. The direct and secondary EAD changes by about 0.87% for each percent change in the construction cost factor. The high level of sensitivity found with changing this parameter is because around 96% of all buildings considered within the flood zones covered in this analysis are residential detached buildings (645 of 674 buildings).



a) Residential Construction Cost Factors
(% change across all original value: $2090/sq.m gross floorspace)

b) Residential Content:Structure Value Ratio (% change across original value: 0.5)

c) Lower range return period in which EAD is integrated over
(% change relative to original value: 5 years)

d) Flood Depth Threshold (% change relative to original: 0.1 m)

Figure 33: Sensitivity graphs for four parameter sets (see individual captions under each sub-plot)

Figure 33b) depicts how the sum of direct and secondary EAD changes as a function of changing the residential content-to-structure value ratio which was originally assumed to be 0.5:1 (i.e. cost of damage due to content replacement is estimated to be 50% of the cost of re-construction). The relative change in EAD as a function of changing this parameter is equal and linear across each scenario and future year. This parameter is significant to the final result; the direct and secondary EAD changes by about 0.45% for every percent change in the content-to-structure value ratio. Again, the high level of sensitivity found with changing this parameter is due to the vast majority of flooded buildings being residential detached homes.

Figure 33c) depicts the relationship between the sum of direct and secondary EAD and the assumed minimum return period event when calculating the EAD. The original return period range was from 5 to 100 years. As the lower boundary return period varies from 5 years, the EAD changes in a non-linear fashion. The rate of change in EAD with changing this parameter increases as the lower boundary return period decreases; this is due to the shape of the damage versus return probability curve. This parameter is significant to the final EAD result; the EAD changes from 1.27% to 0.72% for each percent change of this parameter from -30% to 30%, respectively.

Lastly, Figure 33d) demonstrates the relationship between the sum of direct and secondary EAD and the assumed flood depth threshold, which was originally assumed to be 0.1 m. The flood depth threshold of 0.1 m was used as a boundary between a flood depth that does and does not create damage to building structure and contents. If a flood depth for a given return period and scenario is above this parameter, then damage to the building is dictated by the given flood depth and the best available flood damage curve. If the flood depth is below the flood depth threshold, then the damage to a building was assumed to be negligible. The change in EAD as a function of changing flood depth threshold is fairly gradual and nearly linear: 0.22% to 0.43% for each percent change in the flood depth threshold.

5.6.6 Limitations

While the direct and secondary impact estimates presented above capture a large portion of anticipated impacts associated with storm water flooding, it is a partial assessment of the impact of storm water flooding due to a number of limitations. While the impact assessment was scoped to focus on damage to assets, due to data limitations, not all impacts could be captured. The following impacts are not captured in the impact assessment for storm water flooding in Mississauga:

- Non-riverine localized flooding resulting from storm water drainage backup, which can be significant
- Damage to roads from erosion and disruption caused by associated road closures.
- Damage to rail lines.
- Power outages caused by flooding, which are expected to be minimal and localized.[125]

Data on whether existing buildings have been constructed to withstand storm water exposure was not available. Impacts will be overestimated to the extent that exposed buildings are resilient to flooding.

The analysis is also limited by the geographic scope of the assessment. Due to data limitations it was only possible to assess a portion of the watersheds that span Mississauga. An additional limitation is that

[125] According to community advisors participating in the community engagement process.

flood depth data could only be generated for a single return period and scenario: a 1 in 100 year event for the historic baseline scenario. The building-specific flood depths of this given return period and scenario were then adjusted by assuming that the relative change in rainfall intensity across the return periods and climate change scenarios was directly proportional to the changes in flood depth across the buildings. Future work is required to determine flood depths for other return periods and climate change scenario. In addition, the existing 1 in 100 year flood data is based on older flood mapping, which is currently in the process of being updated.

Direct impact estimations for storm water flooding assume that all buildings damaged from a flood event will be repaired/rebuilt to their undamaged pre-flood condition. In reality, increases in future rainfall intensity and frequency could create a situation where several parcels of land with existing buildings will be permanently abandoned. Although the scope of this study does not consider adaptation strategies, permanent land abandonment is a possibility in the context of flooding events.

5.7 Freezing Rain Impact Results

In the sub-sections below the results of the impact analysis for freezing rain in Mississauga are presented, beginning with estimates of direct impacts. Secondary impacts are then presented. The direct and secondary impacts presented here represent the opportunity cost of direct, indirect and induced spending – spending that could have been directed elsewhere in the economy were it not for the need to respond to the damages from freezing rain. Estimates for cumulative impacts as well as event-specific impacts are also included below. This is followed by a discussion of key data and analytical limitations and the results of a sensitivity analysis.

5.7.1 Direct Impact

The direct impact estimates presented here are measured as impacts to gross output (which means that they are not directly comparable with the secondary impacts presented below which measure impacts to GDP).[126] Future climate change is likely to significantly increase impacts due to freezing rain events in Mississauga. Taking into consideration damage to trees, electrical restoration costs and lost economic output due to business interruptions (from power outages), by 2020 the EAD as measured by gross output was found to increase by 4% (moderate climate change) to 3% (high climate change) as a result of a changing climate. By 2040, the EAD increases by 33% (moderate climate change) to 32% (high climate change) relative to the baseline scenario. In terms of absolute results (Figure 26), the EAD as measured by gross output attributed to future climate change increased from $230 thousand to $360 thousand in

[126] As per the concept note in the Approach section, direct impacts are first measured as gross output to fully account for intermediate and value added inter-industry linkages in the input-output multiplier analysis. The impacts are then translated to the more commonly reported metric of gross domestic product that highlights the impact on the value of production in the particular year of interest.

2020 to $3.0 million to $3.1 million in 2040 (the range across moderate to high climate change scenarios). Across all return periods and time frames, the moderate climate change scenario had slightly greater intensity than the high climate change scenario, though the difference between the scenarios across all return periods was negligible (0.09% to 0.7%). This implies that the choice of climate change scenario (whether moderate or high) had a relatively small influence on the overall impacts.

The reason for the relatively similar results between the moderate and high climate change scenarios has to do with the expected changes in freezing rain frequency during the colder (December to February) and warmer (November, March, April) freezing rain prone months across this century. By *mid-century*, the change in the frequency of freezing rain events is expected to be about the same in both the moderate and high climate change scenarios for the colder months. However, by *the end of this century* the frequency continues to increase during the colder months for the high climate change scenario while for the moderate climate change scenario, the frequency decreases. In the warmer freezing rain prone months, the frequency of freezing rain decreases significantly more under the high climate change scenario than under the moderate climate change scenario across all time periods during this century. This result suggests that under the high climate change scenario, the climate conditions during the warmer months become too warm for many freezing rain events to occur and thus a decrease in freezing rain during these months is expected where as for the moderate climate change scenario, this warming effect is less pronounced (see Cheng et al. (2007) for greater details).[127] The counteracting phenomenon that results between the warmer and colder months is the main reason why the results are relatively similar between climate change scenarios.

[127] Cheng, C.S., Auld, H., Li, G., Klassen, J., Li, Q. (2007) Possible impacts of climate change on freezing rain in south-central Canada using downscaled future climate scenarios. Natural Hazards and Earth System Sciences 7:71-87.

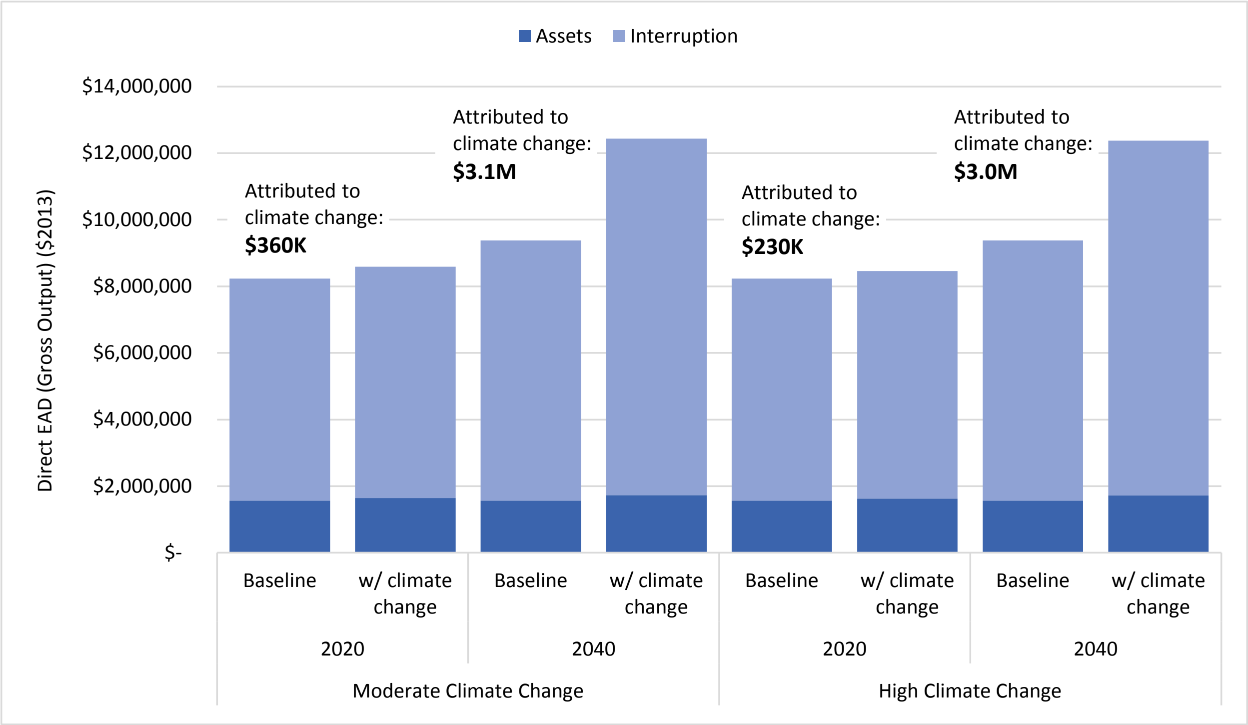


Figure 34: **Expected annual damage (in terms of gross output) from freezing rain events distinguishing between assets and business interruption in Mississauga**

The underlining reason for the increase in direct impacts attributed to climate change *over time* is the significant increase in freezing rain frequency during the colder freezing rain prone months; this is despite the fact that freezing rain frequency is actually likely to *decrease* during the "warmer" freezing rain prone months. Coinciding with the trend in frequency, the trend in intensity of events factors into the impact estimates presented above The increase in intensity between the climate change and baseline scenarios tends to be higher for the longer return periods (i.e. the change in intensity is higher for a 1 in 100 year event relative to a 1 in 25 year event): intensity (measured as ice thickness) ranged from 1% to 13% for return periods ranging from 5 to 500 years, respectively in 2020; and from 3% to 20% for return periods ranging from 5 to 500 years, respectively in 2040.

It is worth noting that impacts due to power outage and subsequent business interruptions and utility repair costs stem from the application of the SPIA index which is a function of both freezing rain intensity and wind speed. Although freezing rain events are projected to become more intense and frequent, average wind speed is expected to not change significantly under the climate change scenarios.

As is noted above, the impacts from freezing rain in this case study include those to trees, electricity restoration and business interruptions (i.e. due to freezing rain induced power outage). Across all scenarios and time periods, the impact from business interruptions represents around 83% (range from 81% to 86%) of the direct EAD impacts (measured as gross output) considered, while impacts to tree-related damages and electricity restoration represent around 17% (range from 14% to 19%) and 0.4% (range from 0.4% to 0.5%), respectively (Figure 35). The community engagement process identified two reasons for the low cost estimates associated with electricity restoration:

1. The tree canopy in Mississauga was identified as "young" compared to the rest of the Greater Toronto Area, which implies that less damage from falling tree limbs would result.

2. Approximately 65% of the power lines in Mississauga are underground and therefore not susceptible to freezing rain damage.[128]

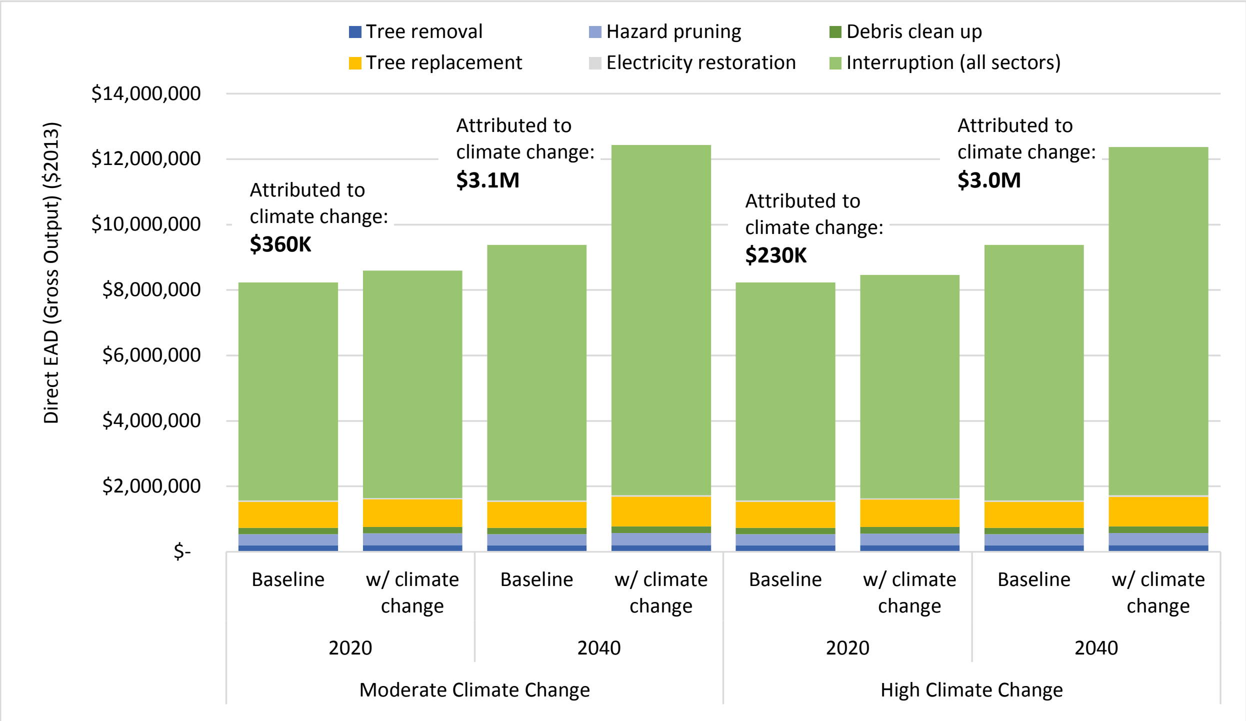


Figure 35: Direct expected annual damage (in terms of gross output) by cost item from the impacts of freezing rain on trees in Mississauga

The most important tree-related impacts in terms of contribution to the direct EAD estimate are: tree replacement costs (which account for 7% to 10%), hazard pruning costs (which account for 3% to 4%), tree removal costs (which account for ~2%) and debris clean-up costs (which account for ~2%).

5.7.2 Secondary Impacts

The secondary impact estimates presented here are measured as impacts to GDP and include damages to trees, electrical restoration costs and lost economic output due to business interruptions from power

[128] Personal communication. Michael Murphy. Director, Internal Audit and Enterprise Risk. Enersource.

outages. They are not directly comparable with the gross output estimates presented above for direct impacts. They were derived using the input-output basic Type II multiplier approach. Additional information on how secondary impacts were calculated is contained in Appendix C. The Type II approach considers both the indirect and induced impacts and was chosen as the approach on which to focus these results as it is considered the most accessible (i.e. because it is based on published provincial Statistic Canada multipliers) of the approaches and the one most likely to be employed by community impact analysis tool users. Figure 36 presents the sum of direct and secondary GDP impact estimates for freezing rain in Mississauga for the baseline and climate change scenarios for 2020 and 2040 for both impacts to assets (trees and electrical infrastructure and business interruptions.[129] Additional graphs for output and employment are located in Appendix D-E.[130]

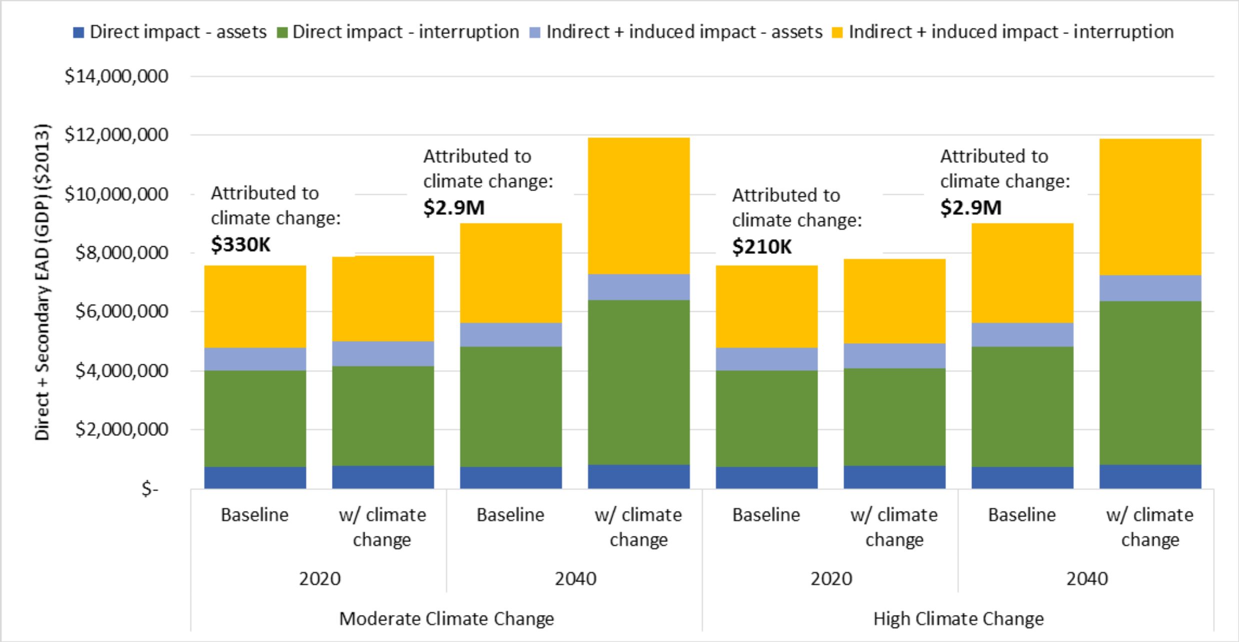


Figure 36: **Direct and secondary expected annual damage (in terms of gross domestic product), as distinguished between assets and business interruption, due to freezing rain in Mississauga**

The sum of direct and secondary impacts to GDP attributed to climate change in 2020 ranged from $210 thousand under the high climate change scenario to $330 thousand under the moderate climate change scenario. The sum of direct and secondary impacts on GDP attributed to climate change increased to $2.9 million in 2040 under both the moderate and high climate change scenarios. The sum of the direct and secondary impacts was approximately 1.9 times higher than the direct impacts alone.

[129] In the case of freezing rain, assets refer to tree-related damage and electric power restoration. Business interruption refers to all sectors impacted through power outage due to freezing rain damage.
[130] Employment impacts are generally quite small using the EAD concept and given the high amount of output per worker that is representative of the Canadian economy.

As is noted in the *Approach* section, several approaches to modelling secondary impacts were employed in this study. Table 13 below highlights the range of the EAD estimates across modelling approaches attributed to climate change for direct and secondary impacts combined measured as GDP. In general, the order of magnitude of the EAD estimates are comparable across the modelling techniques for any given climate change scenario and impact type (i.e. asset versus business interruption). As expected, the CGE model results are for the most part smaller reflecting the offsetting effect of labour mobility across industries not considered in the I-O models. The basic I-O Type II multiplier results (the results focused on above) generally provide a midpoint among the estimates derived from the various techniques. As is noted for the direct impact results, the impact estimates for freezing rain are relatively less sensitive to differences between the moderate and high climate change scenarios and more sensitive to differences over time (i.e. between 2020 and 2040). Indeed, there is a large increase in the impacts across years for business interruption. The basic I-O Type II results show an increase in the EAD attributed to climate change ranging from a low of $0.15 million (business interruption under high climate change) in 2020 to a high of $2.77 million (business interruption under moderate climate change) in 2040.

Table 13. Range of asset (A) and business interruption (BI) expected annual damages in terms of GDP from freezing rain attributed to climate change under moderate (M) and high (H) climate change scenarios ($2013 Millions)

			Basic I-O Type I	Basic I-O Type II	Custom I-O Type I	Custom I-O Type II	CGE
2020	A	M	$0.06	$0.07	$0.06	$0.07	$0.03
		H	$0.05	$0.06	$0.05	$0.06	$0.02
	BI	M	$0.21	$0.26	$0.21	$0.33	$0.16
		H	$0.12	$0.15	$0.12	$0.18	$0.09
2040	A	M	$0.12	$0.15	$0.10	$0.17	$0.07
		H	$0.12	$0.15	$0.10	$0.17	$0.07
	BI	M	$2.21	$2.77	$1.98	$3.14	$0.88
		H	$2.17	$2.71	$1.94	$3.08	$0.86

Along with measures of the EAD, the direct and secondary impacts of climate-related extreme events can be considered in terms of cumulative impacts and event-specific impacts. Results for both of these are presented in below.

5.7.3 Cumulative Impacts

To demonstrate the potential impacts of climate-related extreme events across climate change scenarios, it is useful to consider the cumulative EAD over the timeframe of the analysis (i.e. from the baseline year of 2015 to 2040). Figure 37 demonstrates the cumulative impact measured as the sum of the direct and secondary EAD estimates for freezing rain attributed to climate change, by gross output and GDP. The results reflect the use of basic I-O Type II multipliers. These results depict the overarching trend in EAD as a consequence of climate change; they do not show the scenario-specific direct and secondary EAD.[131]

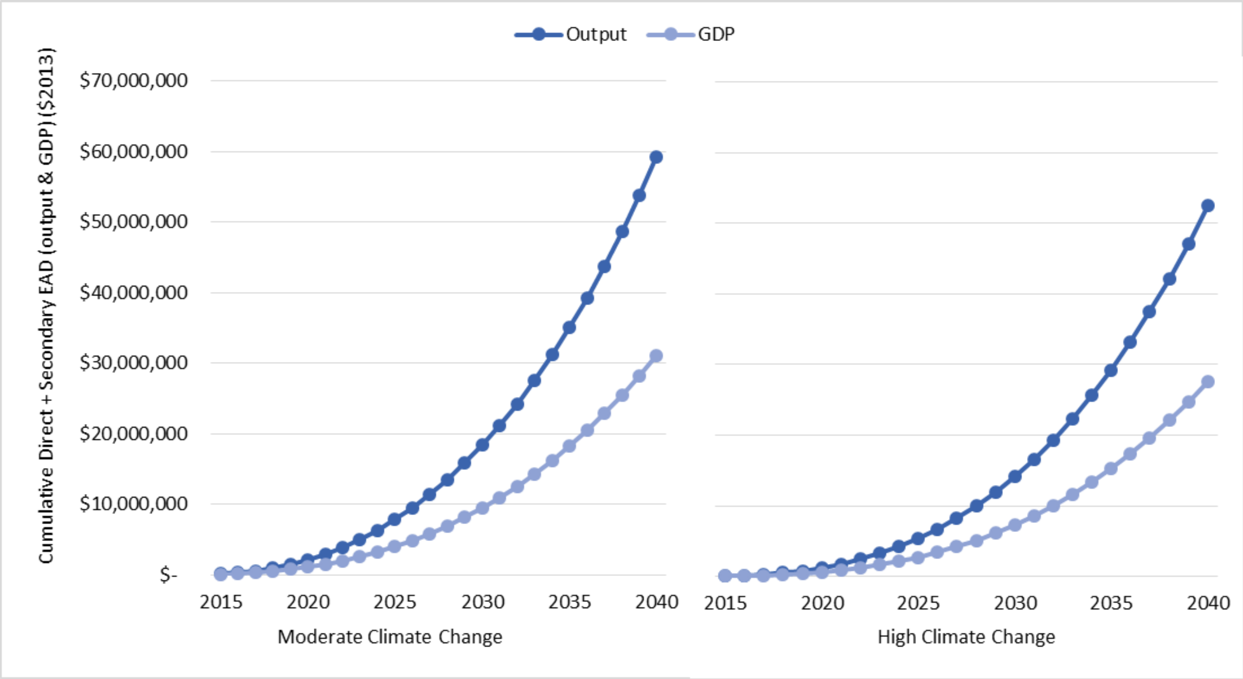


Figure 37: **Cumulative direct and secondary expected annual damage (in terms of gross domestic product) due to freezing rain attributed to climate change in Mississauga**

The cumulative direct and secondary EAD attributed to climate change for freezing rain events in Mississauga was found to steadily increase at exponential rates throughout the entire time horizon (2015-2040) and for both the moderate and high climate change scenarios. The results for the moderate and high climate change scenario are plotted on the same y-axis scale to show the difference between the two climate change scenarios. By 2020, the direct and secondary EAD is expected to be around $1.1 million and $600 thousand for the moderate and high climate change scenarios, respectively. By 2040 this metric is expected to grow considerably, reaching around $31 million and $28 million for the moderate and high climate change scenarios, respectively. According to findings in Cheng et al. (2007)[132] it is likely that the trend in cumulative EAD that is attributed to climate change will continue until the latter half of this century where frequency of freezing rain events is predicted to be significantly higher relative to present times.

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[131] It should be kept in mind that this trend line was built using a best fit 2nd order polynomial equation by fitting the three known points of EAD that is attributed to climate change for the baseline year (2015, which is zero impact by definition) and the future years, 2020 and 2040.

[132] Cheng, C.S., Auld, H., Li, G., Klassen, J., Li, Q. (2007) Possible impacts of climate change on freezing rain in south-central Canada using downscaled future climate scenarios. Natural Hazards and Earth System Sciences 7:71-87.

5.7.4 Event-specific Impacts

The expected impacts of climate-related extreme events can also be measured on an event-specific basis to demonstrate how climate change can influence probabilities and associated damages. Two examples of estimates for impacts (direct and secondary) to GDP resulting from freezing rain are provided below: the expected impacts of a 1 in 25 year freezing rain event and the expected impacts of a 1 in 100 year freezing rain event. The results reflect the use of basic I-O Type II multipliers.

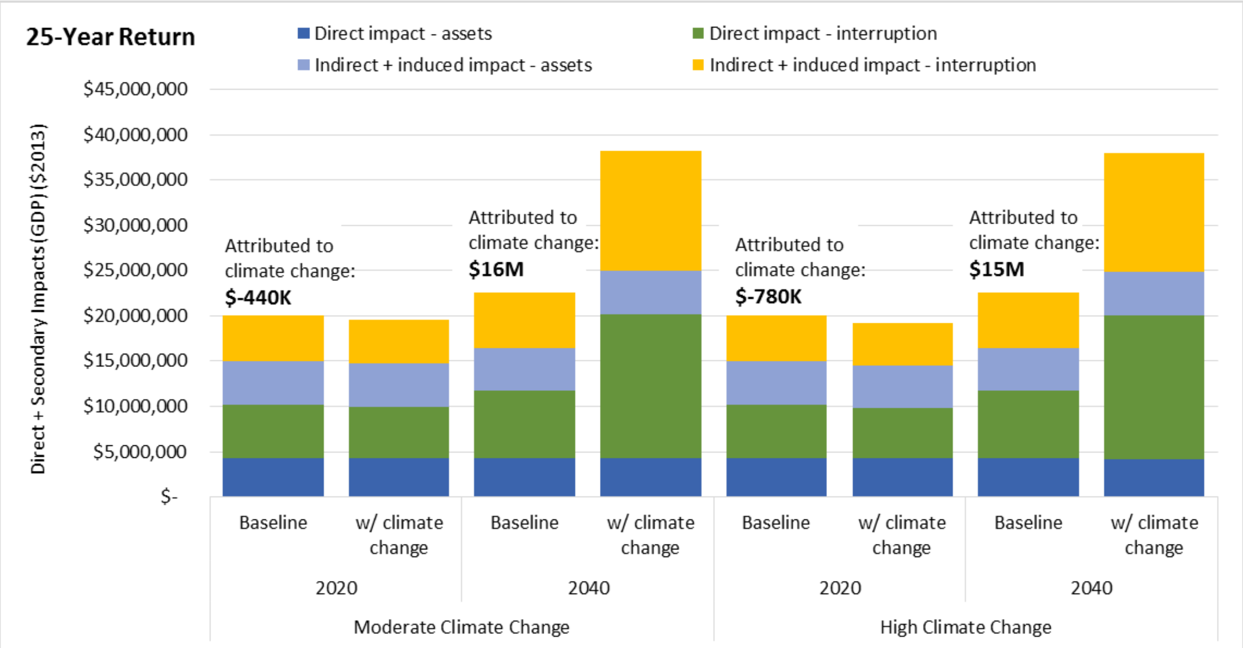


Figure 38: Direct and secondary expected annual damage (in terms of gross domestic product), as distinguished between assets and business interruption, of a 1 in 25 year freezing rain event in Mississauga

Figure 38 demonstrates the event-specific direct and secondary impact on GDP from a 1 in 25 year freezing rain event. Under the moderate climate change scenario, the impact attributed to climate change in 2020 is -$440 thousand. The impact increases to $16 million in 2040. This means that by 2020, if a 1 in 25 year freezing rain event occurs, the impacts attributed to climate change are expected to be slightly lower than the baseline.[133] However, a 1 in 25 year freezing rain event occurring in 2040 would cost an additional $1 million as a result of climate change. Similar results are demonstrated under the high climate change scenario.

[133] The negative economic impact attributed to climate change apparent for the 1 in 25 year event in 2020 is because the difference in freezing rain thickness between this return event under the baseline and future climate change scenarios is very small (though still positive). Therefore, the average wind speed plays a larger role in the final impact (recall that business interruption impacts are a function of freezing rain thickness and average wind speed according to the Sperry-Piltz Index). Since average wind speed distribution was found to decrease under the climate change scenarios, this is the primary reason why the negative values in figure 38 appear in 2020. See Appendix B for greater details the data employed to estimate impacts from freezing rain.

Figure 39 presents impact estimates (direct and secondary) to GDP for a more extreme freezing rain event. In this case, if the 1 in 100 year freezing rain event were to occur in 2020, the anticipated impacts would be $3.6 million to $7.9 million with climate change than without. However, a 1 in 100 year event occurring in 2040 would cost an additional $200 million as a result of climate change.

Across all return periods, freezing rain thickness was found to be larger (i.e. more intense events) under both of the moderate and high climate change scenarios. This results in a significant increase in costs, particularly by 2040 where freezing rain events are anticipated to be more frequent during the winter months.

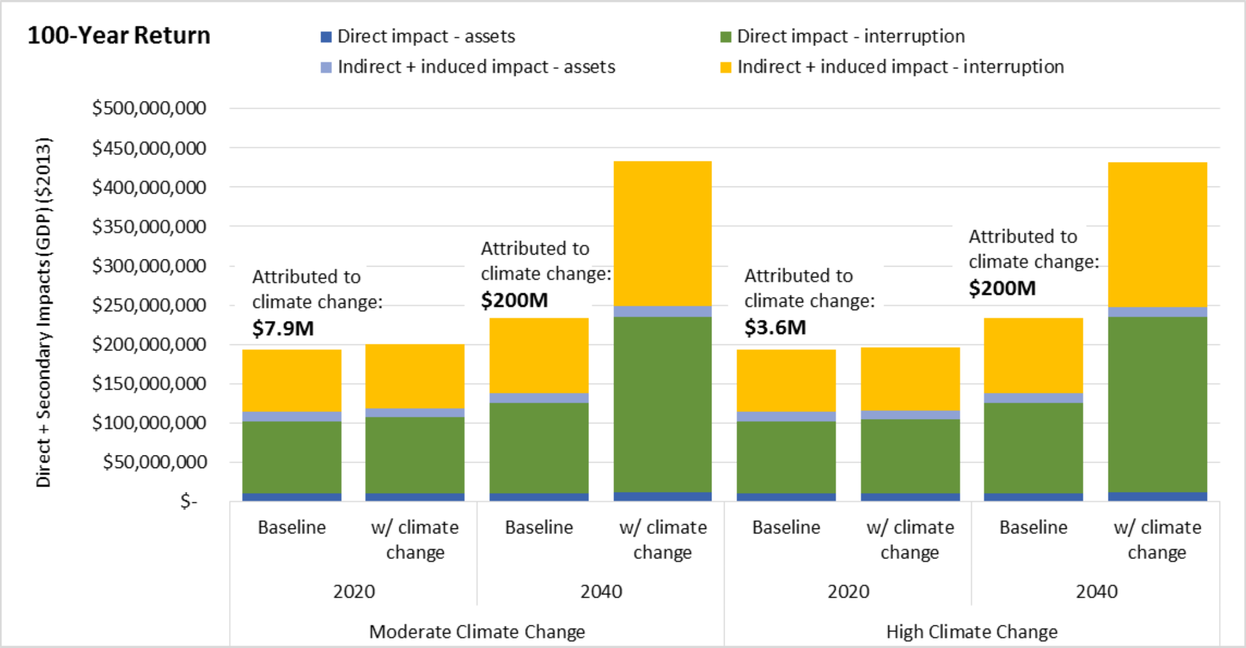


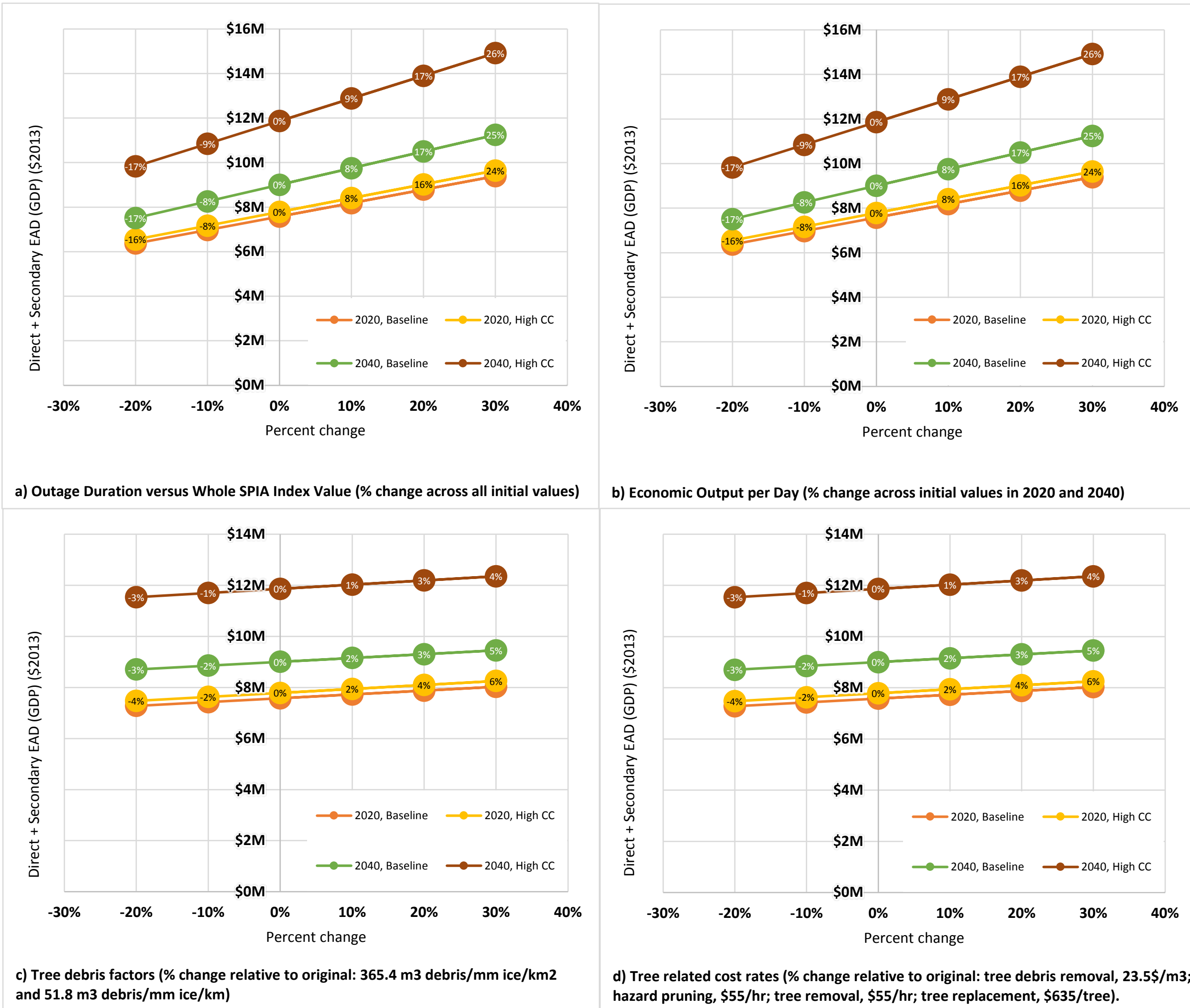
Figure 39: **Direct and secondary expected annual damage (in terms of gross domestic product), as distinguished between assets and business interruption, of a 1 in 100 year freezing rain event in Mississauga**

5.7.5 Sensitivity Analysis

The sensitivity graphs below cover four key parameters used in the freezing rain event analysis for Mississauga. Each of these parameter sets has been plotted in a sensitivity graph demonstrating how the sum of direct and secondary EAD in terms of GDP changes as each parameter varies by a given percentage. The results reflect the use of basic I-O Type II multipliers.

Figure 40a) shows how the direct and secondary EAD changes as a function of changing the assumed power outage duration as a function of the Sperry-Piltz Ice Accumulation Index (which describes the percent change in initial power outage duration values across all whole SPIA index values – see Appendix B for additional details on this index). For example, for an SPIA index of 4 and 5, the estimated total power outage duration was assumed to be 72 and 480 hours, respectively. As the percentage changes, this total power outage duration across each whole SPIA index score changes accordingly. The direct and secondary EAD is quite sensitive to this assumption, changing by an average of 0.82% for each percent change in the total power outage duration as a function of the SPIA index score. The extent of change that this parameter has on the direct and secondary EAD is reasonable considering that the share of direct and secondary EAD that is due to business interruptions was estimated to be 81% to 86%.

Figure 40b) illustrates how the direct and secondary EAD changes as a function of changing the total Mississauga-wide daily economic output across all sectors for 2020 and 2040. Given that this parameter set affects business interruption impacts and that business interruption impacts account for 81% to 86% of the sum of direct and secondary EAD, the change in EAD as a function of changing daily economic output is significant: an ~0.82% change in EAD for each percent change in daily economic output across sectors in Mississauga for 2020 and 2040. Note that this trend is identical to changing the power outage duration versus SPIA index parameter set as explained above since the EAD is equally proportional to the values assumed for both of these parameter sets.



a) Outage Duration versus Whole SPIA Index Value (% change across all initial values)

b) Economic Output per Day (% change across initial values in 2020 and 2040)

c) Tree debris factors (% change relative to original: 365.4 m3 debris/mm ice/km2 and 51.8 m3 debris/mm ice/km)

d) Tree related cost rates (% change relative to original: tree debris removal, 23.5$/m3; hazard pruning, $55/hr; tree removal, $55/hr; tree replacement, $635/tree).

Figure 40: Sensitivity graphs for four parameter sets (see individual captions under each sub-plot)

Figure 40c) indicates the relationship between direct and secondary EAD the assumed tree debris factors. The tree debris factors used in this analysis represent the amount of tree debris generated during a freezing rain event of a specific maximum ice thickness. The average of two factors were used in this analysis, with one being a community area based factor (365.4 m^3 debris per mm ice thickness per square km community area), and the other being a community street distance factor (51.8 m^3 tree debris per mm ice thickness per km community street distance).[134] As these factors change, so will all of the associated tree-related costs. As is shown in Figure 40c), the direct and secondary EAD changes quite gradually as these tree debris factors change: there is a 0.14% to 0.2% change in EAD for each percent

[134] Hauer, R. J., Hauer, A. J., Hartel, D. R., & Johnson, J. R. (2011). Rapid assessment of tree debris following urban forest ice storms. Arboriculture and Urban Forestry 37(5): 236-246.

change in the tree debris factors. This gradual change is expected, since the tree-related impacts equate to only around 14% to 19% of the direct and secondary EAD.

Lastly, Figure 40d) illustrates how the direct and secondary EAD changes as a function of changing all of the tree-related cost factors simultaneously. The tree-related cost factors include the tree debris cleanup cost factor ($23.5/m^3 debris), the hazard pruning cost factor ($55/hr), the tree removal cost factor ($55/hr) and the tree replacement cost factor ($635/tree). The rate of change in direct and secondary EAD as a function of changing these four tree-related cost factors is identical to that which is observed when changing the tree debris factors shown in Figure 40c): there is a 0.14% to 0.2% change in EAD for each percent change in tree-related cost factors.

5.7.6 Limitations

While the results presented in this case study section capture a large portion of the anticipated impacts associated with freezing rain events, a number of limitations of the analysis should be noted. The impact assessment was scoped to focus on damage to assets and associated impacts from affected assets (e.g. power outage from damaged electrical infrastructure). However, due to data limitations, not all impacts in this regard could be captured. More specifically, the following impacts are not captured in the estimates provided above:

- Damage to property from falling tree debris. The data available does not allow damage to property from falling tree debris to be correlated to freezing rain severity. With sufficient data on tree locations relative to buildings, a simulation model could be developed to approximate damages. However, such a modelling exercise was outside the scope of this research.
- Airport and other transportation disruption. Delays have been experienced with freezing rain events, but the necessary data to adequately assess the impact is lacking.
- Business disruptions caused by road conditions or closures. Data was insufficient to properly analyze this impact. However, it was explored with the community advisory group, who reported that within Mississauga, roads are virtually never closed. The main road arteries are kept passable and cleaned of debris. The larger concern relates to tree debris on residential streets of lower priority for clean-up crews. While this could impact some people getting to work, it would have minimal impacts on business activities for the community as a whole.

One limitation in estimating tree damage due to freezing rain events was the challenge of modelling how each urban tree would respond to a given freezing rain event. The only entry point to account for this degree of analysis was to consider the expected volume of tree debris as a function of community size (either km of streets or km^2 community area) and freezing rain accumulated thickness for a given event.[135] Using this tree debris value, estimates could be deduced for the number of actual trees damaged by assuming appropriate debris and solid tree densities and a weighted community-wide average tree diameter at breast height and associated volume.[136] Unfortunately, no empirical data in terms of the percent of citywide trees damaged or percent of damaged trees needing to be completely removed and replaced with a new tree could be attained as a function of freezing rain events, and tree size/type distribution.

5.8 Impact Analysis Summary

The case study analysis for Mississauga focused on the climate-related extreme events of storm water flooding and freezing rain. Table 14 below, provides a summary of the direct and secondary impacts (basic type II GDP) attributed to climate change due to each climate-related event type across each future year and compared between each climate change scenario.

Table 14: Summary of Impacts Attributed to Climate Change in the Mississauga Case Study (M = Million; K = thousand; all values in $2013)

	Freezing Rain				Storm Water Flooding			
	Moderate climate change		High climate change		Moderate climate change		High climate change	
Year	EAD	Cum. EAD	EAD	Cum. EAD	EAD	Cum. EAD	EAD	Cum. EAD
2020	$330K	$1.1M	$210K	$600K	$1.4K	$4.4M	$590K	$1.8M
2040	$2.9M	$31M	$2.9M	$28M	$4.4M	$70M	$1.9M	$30M
1 in 25 yr event	-$440 (2020) $16M (2040)		-$780K (2020) $15M (2040)		$9.1M (2020) $32M (2040)		$5.4M (2020) $12M (2040)	
1 in 100 yr event	$7.9M (2020) $200M (2040)		$3.6M (2020) $200M (2040)		$8.7M (2020) $27M (2040)		$4.3M (2020) $11M (2040)	

[135] Hauer, R. J., Hauer, A. J., Hartel, D. R., & Johnson, J. R. (2011). Rapid assessment of tree debris following urban forest ice storms. Arboriculture and Urban Forestry 37(5): 236-246.
[136] See Appendix B for further details regarding this approach.

6. The Community Impact Analysis Tool

In completing the case study impact analysis for the Halifax Regional Municipality (HRM) and Mississauga, the project team developed elaborate spreadsheets within which the calculations and data are stored to estimate direct and secondary expected annual damages (EAD) for each of the climate-related extreme events of relevance to this project. The outcome is the community impact analysis tool (CIAT), a spreadsheet-based tool that provides a replicable framework for estimating the impact of climate-related extreme events in case study communities. This section of the report provides an overview of the CIAT.

6.1 Purpose

The CIAT contains the calculations required to estimate the direct and secondary impacts of three climate-related extreme events: flooding (CIAT-Flood), extreme wind (CIAT-Wind) and freezing rain (CIAT-Freezing Rain). The CIAT is designed to assist users and communities in understanding and quantifying the potential economic impacts associated with climate-related extreme events. While the existing spreadsheets are only calibrated for flooding, wind and freezing rain, the overall process and framework employed in the CIAT are directly translatable to other climate-related extreme events. The tools themselves can also be modified for other climate-related extreme events but would require a number of event-specific adjustments (e.g. the incorporation of event-specific damage curves).

The Figure below provides an example screen shot of the opening page of CIAT-Flood.

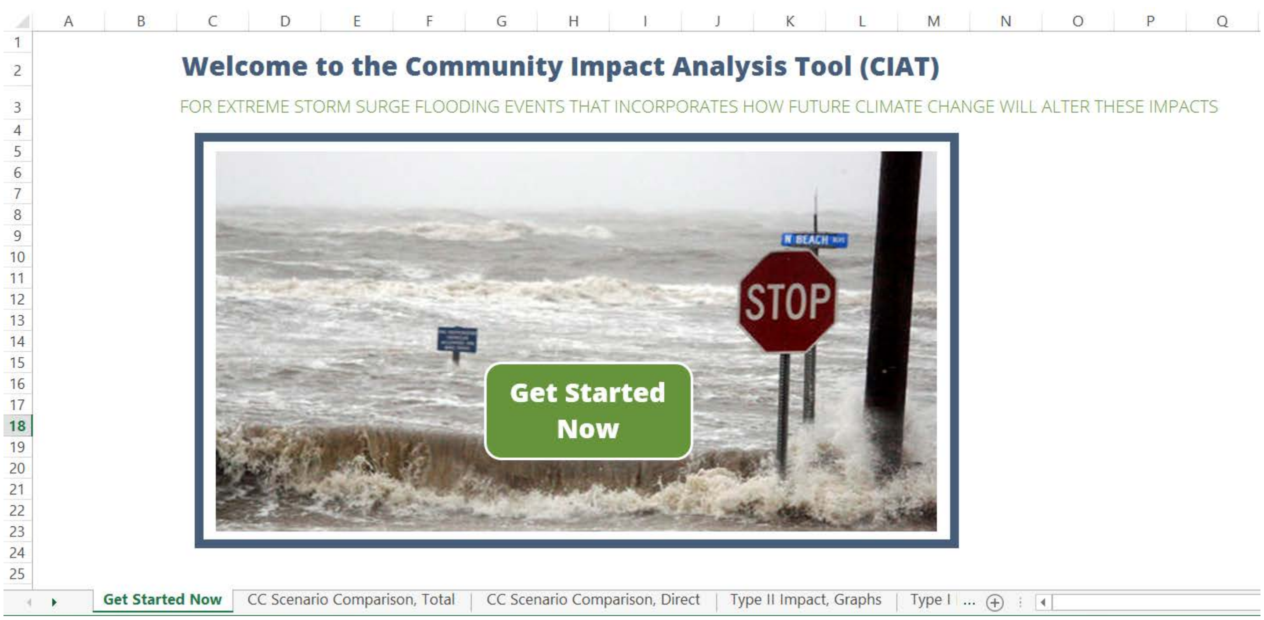


Figure 41: Example first page of CIAT-Flood.

6.2 Target Audience

The CIAT is primarily designed to be used by municipal staff across a range of departments including, but not limited to planning, economic development, environment, parks, forestry, finance, risk management, and transportation and public works departments. Water and sewer services departments and local electrical distribution utility providers may also find the tool useful or be engaged through data sharing.

6.3 Value to Communities

The CIAT is one way to get municipalities actively engaged in estimating the impacts of climate change in their community. Estimating the potential increases in damage costs from climate-related extreme event damage can assist in municipal budgeting exercises and provide a framework for ongoing data collection around key inputs to the CIAT (e.g. tree debris removal costs, building structure and content damage estimates, power outage duration, etc.).

Much of the automation of the CIAT is designed to provide a common platform that can be consistently applied across a range of case study communities of varying size and with varying capacities to undertake this type of analysis. For example, the secondary impact analysis contained in the CIAT makes use of Statistics Canada multipliers that are publicly available and hence easily accessible to users.

6.4 Overview

Each impact tool is built as a standalone Excel Workbook where the user is taken through the impact calculations in a step-by-step fashion. The Figure below provides an example screen shot of the introduction and project log page. The data input required by the user is highlighted and broken down into around ten easy to locate steps (which correspond to spreadsheet tabs) where specific purpose and instructions for each data input are provided. A glossary of key definitions and a list of important references are also provided to quicken the learning and data retrieval process for the user. For each instance of applying the tool, a single workbook is capable of handling one baseline (e.g. 2013) and two future years (e.g. 2020 and 2040) along with a single future climate change scenario. The user can opt to only consider a single future year or just the baseline climate scenario if they chose to do so.

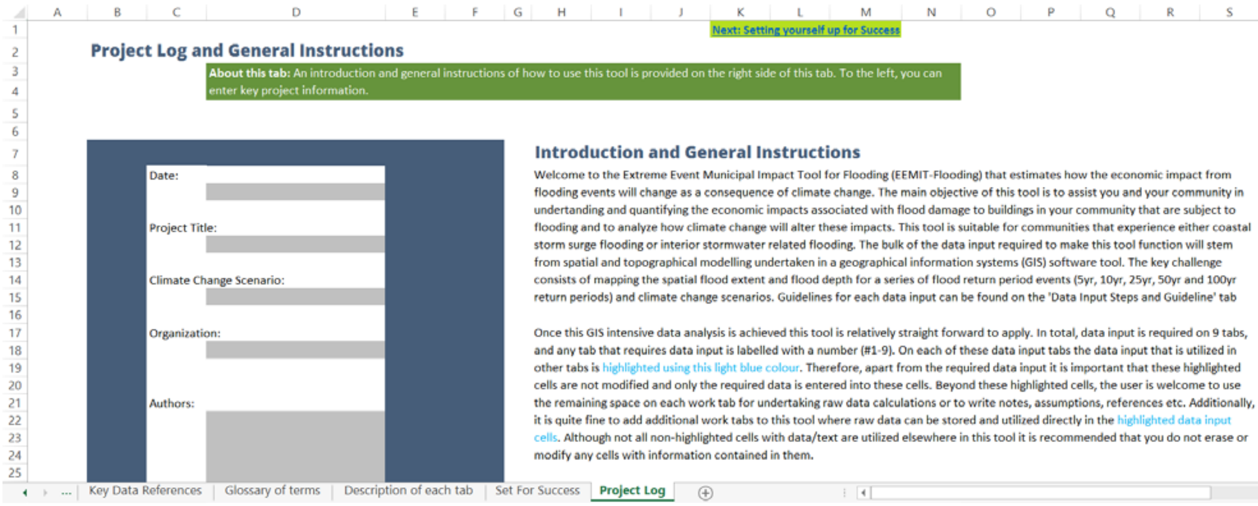


Figure 42: Example introduction and project log page.

Sensitivity analysis can easily be performed across a number of parameters where user friendly ‘sensitivity sliders’ can be used to instantly see how impacts change as a function of a percentage change in a given parameter or set of parameters. In addition, there is an easy to use sensitivity log where the user can save several sensitivity runs across a number of parameters that are found to be significant to the final results. Both direct and secondary impacts are calculated in the tool. Users can choose to employ basic or custom input-output multipliers. Publicly available province-specific Statistics Canada multipliers can be dropped into the tool and the secondary impacts are calculated automatically. Final result graphs are also generated automatically. Both EAD (also cumulative EAD) and event-specific impacts are calculated. All impact estimates can be compared at various levels of disaggregation. The Figure below provides a screen shot of the sensitivity analysis page.

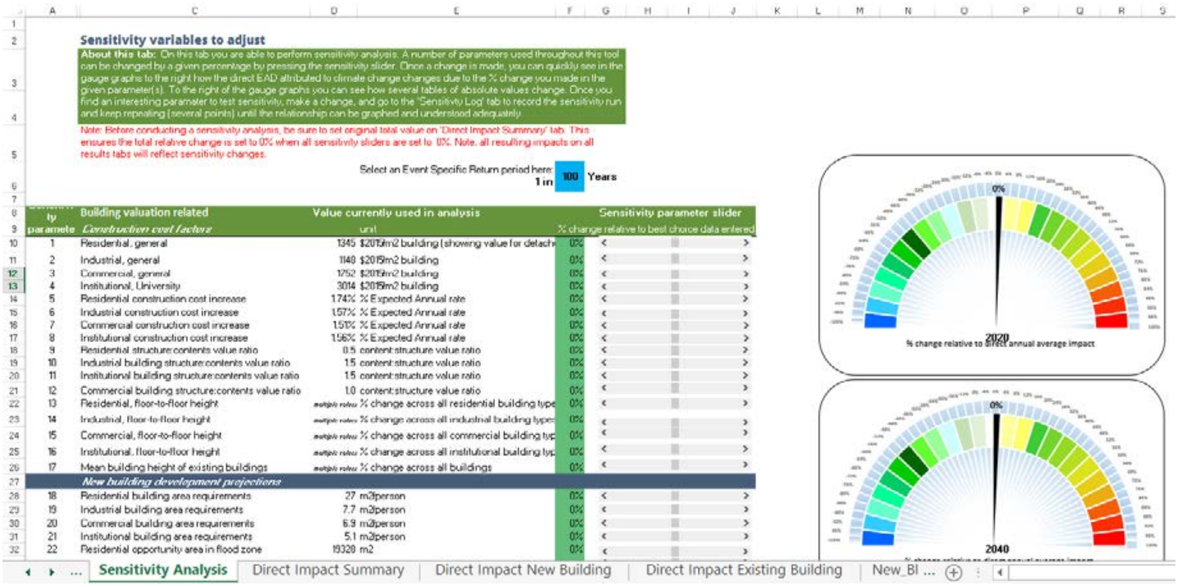


Figure 43: **Example screen shot of the CIAT sensitivity analysis page.**

6.5 Outputs

Depending on the event type, the CIAT provides a number of analytical outputs in tabular and graphic form including, but not limited to, direct monetary expected annual damages to assets and power outage-related business interruptions, secondary impacts (i.e. the indirect and induced economic impacts associated with direct damage), cumulative expected annual damage, and the ability to examine event-specific impacts related to a variety of return probabilities (e.g. a 1 in 100 year climate-related extreme event).

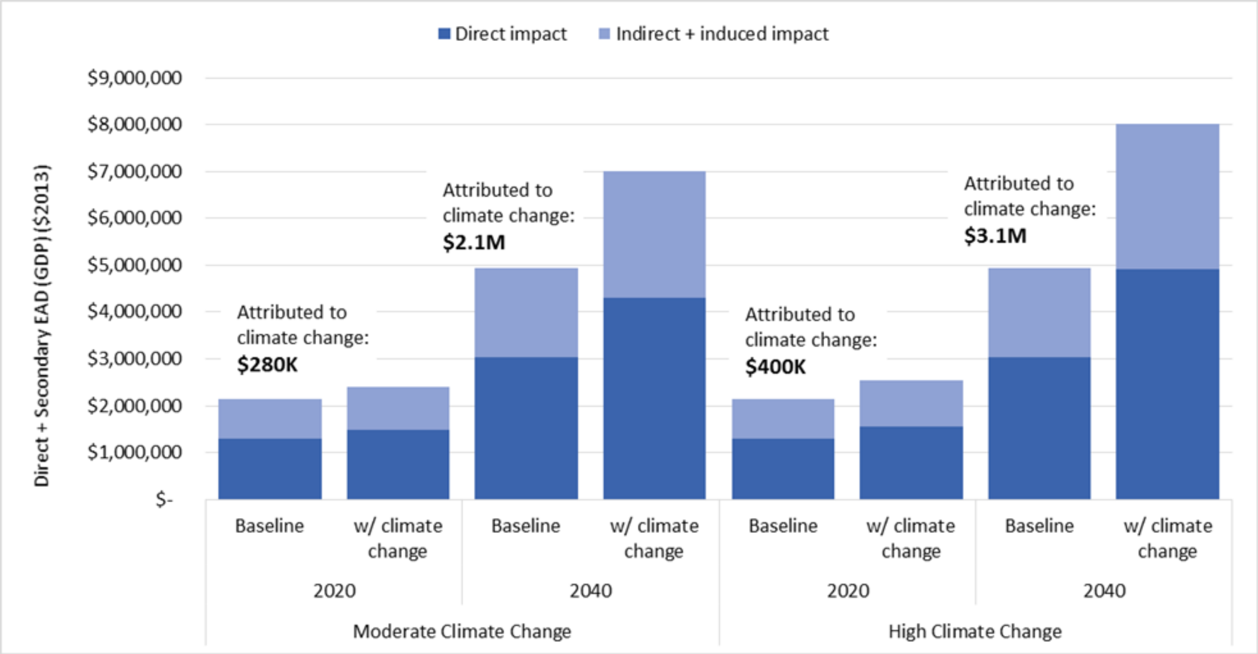


Figure 44: Example graph output of direct and secondary gross domestic product impacts from the CIAT.

The use of the CIAT in other communities will help build community awareness and capacity related to climate change impacts and options for adaption. The data available to communities will range vastly in quality and detail, which will ultimately influence the accuracy of the results. The CIAT is designed to provide significant guidance to users seeking to employ the tool in other case study communities, including guidance on how and where to collect data from. Working through the data collection process and applying the CIAT could have a profound impact on a community's capacity to understand and assess adaptive actions.

7. Conclusion and Lessons Learned

The lessons presented below, organized by theme, were derived through the completion of the case study analysis as well as the community engagement process and the development of the community impact analysis tool (CIAT). They are followed by a brief conclusion.

7.1 Data Requirements

A number of lessons were revealed related to data requirements, including:

- During the community engagement process, the case study communities revealed that data collection related to extreme events tends to be reactionary; in other words, there is no well-structured systematic approach to collecting data on impacts from extreme events. The development of a proactive data collection system/framework at a municipal level could be a valuable future endeavour to help communities and researchers better understand climate-related impacts.
- The data that is available pertaining to climate-related extreme events varies by event type and between regions making the application of uniform analytical approaches across regions difficult.
- The data required to conduct an impact analysis of climate-related extreme events is dispersed across numerous municipal departments and organizations, which means that the completion of an analysis such as this necessarily requires a minimum degree of engagement from many departments (such as parks, forestry, water, power, planning, economic development and geographic information systems) and organizations (conservation authorities and power utilities).
- Because of variations in data collection and availability across regions, the analytical approaches employed to conduct impact analyses may need to be tailored to match the data available in a given region.

7.2 Estimating Direct Impacts

The study revealed the following lessons related to estimating the direct impacts of climate-related extreme events:

- It became evident early in the project that the completion of this type of analysis is relatively cutting edge in Canada, especially at the community level. This is both a benefit of the project, in terms of responding to a need within communities to conduct this type of analysis, and a challenge, as it made for relatively more difficult data collection.
- It was acknowledged during the community engagement process that the analysis would fill a gap in the case study communities and the CIAT would fill a gap for communities across the country.

- The calculation of expected annual damages was confirmed as the appropriate measurement for comparing impacts across climate change scenarios. However, it was also recognized that interpreting expected annual damages can be a challenge.
- Given the difficulty with interpreting expected annual damage estimates, the use of such measures should be complemented with alternatives such as those included in the current study, namely, cumulative impacts over time and event-specific estimates. As such, cumulative and event-specific impacts were incorporated into the study and the Community Impact Analysis Tool.
- The choice of timeframes over which to conduct climate change impact analysis can be difficult. The timeframe of this analysis employed in this study is relatively short in the context of climate change and the time horizons frequently considered in climate change-related analysis. In some cases, the influence of climate change on extreme events may not be significantly different than current conditions within 5 or 25 year planning horizons. However, forecasting economic conditions beyond 25 years into the future can be problematic. As a result, it is challenging to balance integrating climate change forecasting with long time frames and economic forecasting with short time frames.

7.3 Modelling Secondary Impacts

Several lessons were identified in relation to the alternative modelling approaches available and employed to model the secondary impacts resulting from climate-related extreme events, including:

- Modelling approaches need to be accessible to municipalities to be useful; overly complicated and/or costly approaches will not be employed by communities.
- Related to the point above, the use of a computable general equilibrium was deemed inappropriate for this type of study given the scale and application of the analysis. It was also identified as overly sophisticated and hence not sufficiently accessible to communities.
- The use of basic input-output multipliers, that are readily available from Statistics Canada, were identified as the most appropriate method for measuring secondary impacts at the scale and application of relevance to this type of study. This conclusion was reinforced by the results of the case study analysis in which the modelling outcomes from the basic input-output multipliers were more or less mid-point numbers in the range of outputs across the modelling approaches considered.

7.4 Applying the Community Impact Analysis Tool in Canada

The final category of lessons revealed through this study relate to the application of the CIAT in other communities in Canada. They are as follows:

- The community engagement process demonstrated an increasing recognition of the need for, and the value of, this type of tool for communities in Canada.

- The CIAT can play a role both in helping communities prepare for the impacts of climate-related extreme events and also in making the case for investments in adaptation to reduce the impacts from climate-related extreme events.
- The case studies assessed in this report assume no adaptive actions are taken. In other words, the results describe the cost of doing nothing with regards to climate change. This sets a benchmark from which adaptation actions can be measured against. In this way the results can be used to support cost benefit analysis by determining the extent to which adaptation actions reduce expected costs.
- The geography of a particular community can play a significant role in the type and extent of impacts that result from a given climate-related extreme event; this reinforces the need to conduct analysis of such events on a community basis. The CIAT allows analysts to undertake analysis of the expected impacts of climate-related extreme events for case study communities (beyond those considered in this study).

As is evident from the bullets presented above, the lessons revealed through the completion of this project are numerous. They reinforce the need for community-level analysis of the impacts of climate-related extreme events and the important role in engaging municipal staff in such studies. The time to undertake such studies is now. Global temperatures are on the rise. The climate is changing. Canada, like every other country in the world, is vulnerable to the impacts of climate-related extreme events. Such events are, for the most part, projected to increase in magnitude and frequency into the future. To reduce the vulnerability of communities to losses resulting from the impacts of climate-related extreme events requires an understanding of the potential magnitude of the impacts and the associated expected costs at a community specific level. Despite this, assessments of the economic impacts of climate change have largely focused on national and international scales. The current study responds to the lack of community-specific information on the economic impacts of climate-related extreme events through the completion of a case study impact analysis, a community engagement process and the development of the CIAT.

Going forward, analysts can employ the CIAT, along with a community engagement process, to estimate the direct and secondary impacts of climate-related extreme events in their community. By doing so, they will be able to help make the case for investments in adaptation to reduce the impacts from climate-related extreme events.

Glossary of Concepts and Terms

Term	Definition
Adaptation	In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate.
Attributed to climate change	The difference in impact estimates between the baseline scenario and the moderate and high climate change scenarios over time, taking into considerations change in socio-economic conditions (population and economic growth).
Building density	There are a number of building density definitions in circulation. In the context of this tool building density is referred to the building footprint of all buildings on a given parcel of land divided by the area of that parcel of land (m^2 building footprint/m^2 land parcel).
Building footprint	The area of a parcel that a building occupies.
Building zone, Bylaw ID	The Zoning By-law provides specific standards and regulations for all development in a community. A community Zoning By-law regulates the use of land, buildings and other structures where the Zoning By-law ID is a way of defining a specific land zone. The Zoning By-Law ID as specified in this tool is analogous to the prefix of the zoning classification and it indicates the district where a given land parcel is located.
Business interruption	Economic activity measured as gross output or gross domestic product lost due to power outage. Other types of business interruption were considered in this project (e.g. transportation delays and road closures), but not specifically addressed. This was due in part to high quality data for power outages, but not other types of disruption, and also to avoid double counting. For example, a road closure and power outage may occur simultaneously and have the same interruption effect on a business.

CGVD28 The current official datum in Canada is CGVD28 (The Canadian Geodetic Vertical Datum of 1928). CGVD28 was defined in 1928 at 3 tide gauges on the East Coast (Halifax, Yarmouth and Father Point), 2 tide gauges on the West Coast (Vancouver, Prince Rupert). Rouses Point on the border of Quebec and New York was used for testing purpose only. An average of some 18.6 years of water level fluctuation was used to define mean sea level at these locations. The mean water levels at the 5 gauges were assigned the height zero. The official CVGD28 heights are normal orthometric heights. It should be kept in mind that the Canadian Geodetic Vertical Datum has been updated to CGVD2013.

Climate change A change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forces, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.

Climate-related extreme event The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable.

Computable general equilibrium (CGE) model A class of economic models that use actual economic data to estimate how an economy might react to changes in policy, technology or other external factors. A CGE model is one of the most rigorous, cutting-edge quantitative methods to evaluate the impact of economic and policy shocks -particularly policy reforms- in the economy as a whole. Because of its nature, this tool is significantly useful for policy design. CGE modelling reproduces -in the most possible realistic manner- the structure of the whole economy and therefore the nature of all existing economic transactions among diverse economic agents (productive sectors, households, and the government, among others). Moreover, CGE analysis, in comparison to other available techniques, captures a wider set of economic impacts derived from a shock or the implementation of a specific policy reform. In that sense, the CGE approach is especially useful when the expected effects of policy implementation are complex and materialize through different transmission channels.

Construction cost factor or unit construction cost	This cost factor is an estimate of the construction costs of a specific building type on a unit gross floor space basis and typically measured in square feet or square meters. Note this tool requires construction cost factors in units $/m^2 gross floor space.
Cumulative expected annual damage	The year over year accumulation of expected annual damage estimates (the damages per year expected from a given weather peril that accounts for magnitude and probability of the peril) across a given period of time.
Damage, cost and impact	The economic cost of damage to a community or society that occurs from a disaster event.
Damage cost	The physical damage to an asset multiplied by the unit value, in monetary terms, for the asset.
Development area	An area within a community that is earmarked for future development and hence designated an assumed percent of new building demand over time.
Direct impact	The change in economic activity directly due to an external change in conditions or policy. For example, in the case of an extreme weather event, a direct impact could be the economic activity lost due to the closure of a restaurant resulting from a storm-related power outage. In this study, the direct impacts are expressed both in terms of gross output (i.e. in the direct impact sections of the case studies) and in terms of gross domestic product (i.e. in the secondary impact section for comparative purposes).
Disaster	Severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery.
Dissemination area	A small, relatively stable geographic unit composed of one or more adjacent dissemination blocks. It is the smallest standard geographic area for which all census data are disseminated. Dissemination areas cover all the territory of

	Canada.
Employment	The number of full-time equivalent jobs based on the overall average full-time hours worked in either the business or government sectors.
Expected annual damage (EAD)	The damages per year expected from a given weather peril that accounts for magnitude and probability of the peril. "Expected annual" does not mean these damages will occur every year.
Exposure	The presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected.
Flood zone	The flood zone in the context of this tool is analogous to FEMA's definition of Special Flood Hazard Area (SFHA). SFHA are defined as the area that will be inundated by the flood event having a 1-percent chance of being equaled or exceeded in any given year. The 1-percent annual chance flood is also referred to as the base flood or 100-year flood event.
Flow	A variable measured over a period of time that represents the quantity of that variable over the defined period of time.
Floor-to-floor height	It is the height of a single floor in a building measured from the surface of one floor to the surface of the next floor.
Future year	In the context of this tool, it is a year that is beyond the present year in which this tool is applied. It represents a year in which you wish to better understand how climate change will alter the impacts due to a climate-related event.
General equilibrium (GE) models	Refers to a class of economic models focused on identifying economy-wide impacts by describing the way various industries, institutions, and households interact. Input-output models and computable general equilibrium models are two specific types of GE models used in economic impact analysis.
GIS (Geographical Information Systems)	In a general sense, the term describes any information system that integrates, stores, edits, analyzes, shares, and displays geographic information. GIS applications are tools that allow users to create interactive queries (user-

created searches), analyze spatial information, edit data in maps, and present the results of all these operations. Geographic information science is the science underlying geographic concepts, applications, and systems.

Gross domestic product (GDP) The value added component of gross output representing the value of production in a defined time period. In other words, GDP is the value of gross output less the intermediate goods in the production process. GDP is also known as 'net output'. One typical measure of GDP is the sum of payments to primary factors of production (land, labour, and capital) plus taxes net of subsidies.

Gross floor space or gross square meters This measure estimates the surface floor space on every floor of a building. More precisely, and as according to the Canadian Institute of Quantity Surveyors' definition, the gross floor space measurement includes the following: 1. Measure each floor to the outer face of the external walls; 2. No deductions for openings at stairs, elevators or vertical ducts are made; 3. A deduction is made for a non-service vertical protrusion, e.g., atrium space; 4. Mezzanine floors are generally included; 5. Balconies are excluded; enclosed solariums in residential condominiums are included; 6. Sloping and stepped floors (auditoriums/movie theatres) are measured flat; and, 7. Exclude all external covered walkways.

Gross output The value of sales including value added and all intermediate goods used in the production process.

Gumbel distribution A particular case of the generalized extreme value distribution. It is used to model the distribution of the maximum (or the minimum) of a number of samples of various distributions. Such a distribution might be used to represent the distribution of the maximum level of a river in a particular year if there was a list of maximum values for the past ten years. It is useful in predicting the chance that an extreme earthquake, flood or other natural disaster will occur.

Highest high water large tide The average of the highest high waters, one from each of 19 years of predictions. The highest high water is the higher of the two high waters of any tidal day. The single high water occurring daily during periods when the tide is diurnal is considered to be higher high water.

Indirect impact The changes in output or employment within the region in backward-linked industries supplying goods and services to the industry that was directly impacted.

Induced impact The increased output or employment within the region from household spending of the income earned through the directly and indirectly impacted industries. Employees in the directly impacted industry and supporting industries spend the income they earn on housing, utilities, groceries, and other consumer goods and services. This generates induced output and employment throughout the region's economy.

Input-output (I-O) A quantitative economic technique that represents the interdependencies between different branches of a defined regional economy. I-O tables are maintained at a provincial and national level on an annual basis and are used to derive I-O multipliers that are used to derive the secondary impacts associated with a direct impact in terms of additional spending in an economy.

I-O multipliers Provide a measure of the interdependence between an industry and the rest of the economy. Multipliers measure the changes due to inter-industry purchases as they respond to the new demands of the directly affected industries. This includes all the chain reaction of output up the production stream since each of the products purchased will require, in turn, the production of various inputs. Depending on the type of multiplier, they may also account for Induced effects by including the changes in the production of goods and services in response to consumer expenditures induced by households' incomes (i.e. wages) generated by the production of the direct and indirect requirements. The multipliers used in this study consider only the 'within province' impacts.

Labour (Jobs) See Employment.

Net output See Gross domestic product.

Opportunity areas These are land parcel areas in a community that have potential for new building development. This includes areas that are planned for development that are either new sites (i.e. no pre-existing constraints, greenfield) or sites that once had functional buildings but no longer do (i.e. a brownfield). In the context of this tool, opportunity areas (measured in square meters) should be defined in terms of which building zone/bylaw ID they are foreseen to be developed as.

Opportunity cost (and the broken window fallacy)

The value of a foregone alternative. In this analysis the boost in the economic activity required to repair and replace assets due to weather-related damage may be perceived as a benefit to some sectors such as construction. However, in actuality society as a whole is less well-off and the value to restore the damaged assets to whole (i.e. the state of the assets prior to the damage) represents the opportunity cost of new development that could've occurred in the absence of the damage. There is general agreement in the impact literature that damage to assets should only be included in an impact analysis if it is interpreted as the opportunity cost. The following link is a short video presentation explaining the broken window fallacy and how destruction does not necessarily create a net benefit to society: http://youtu.be/erJEaFpS9ls.

Parcel, land

In real estate, a lot or plot is a tract or parcel of land owned or meant to be owned by some owner(s). A lot is essentially considered a parcel of real or immovable property. In this tool it is measured in the units of square meter.

Return period

Represents an estimate of the probability that a given weather peril event will occur. Sometimes referred to as a recurrence interval. For example, a 1 in 100 year probability of a storm of a given magnitude occurring.

Risk

Risk is a function of probability of an event and its consequences or impacts.

Saturated building density

This term refers to the target building density of a given parcel of land at which point no new building development is permitted. In the context of this tool it refers to the expected building density of newly development land parcels once they are fully developed. The unit of measure in this tool is m^2 building footprint per m^2 land parcel.

Sea level

Sea level is generally used to refer to mean sea level (MSL), an average level for the surface of one or more of Earth's oceans from which heights such as elevations may be measured. MSL is a type of vertical datum – a standardised geodetic reference point – that is used, for example, as a chart datum in cartography and marine navigation, or in the context of this tool, measure flood depth. See the definition for CGVD28 which describes the common Geodetic Vertical Data for Canada in which sea level is measured relative to.

Sea level change

There are a number of factors that contribute to long and short-term variations in sea level. Short-term variations generally occur on a daily basis and include waves, tides, or specific flood events, such as those associated with a winter snow melt, or hurricane or other coastal storm. Long-term variations in sea level occur over various time scales, from monthly to several years, and may be repeatable cycles, gradual trends, or intermittent anomalies. Seasonal weather patterns, variations in the Earth's declination, changes in coastal and ocean circulation, anthropogenic influences (such as dredging), vertical land motion, and the El Niño Southern Oscillation are just a few of the many factors influencing changes in sea level over time. When estimating sea level trends, a minimum of 30 years of data are used in order to account for long-term sea level variations and reduce errors in computing sea level trends based on monthly mean sea level. Accounting for repeatable, predictable cycles, such as tidal, seasonal, and inter-annual variations allows computation of a more accurate long-term sea level trend.

Secondary impact

The change in economic activity from secondary and subsequent rounds of spending related to the direct impact. There are two kinds of secondary impacts (see indirect impacts and induced impacts). The secondary impacts in this study are expressed in terms of gross domestic product.

Shock

The expression used to describe how a change in a variable affects other variables contained in a model. In this study, the direct impact estimates were used to *shock* the models used to measure secondary impacts.

Stock

The measurement of a variable at one particular point in time that represents the quantity of the variable at that time.

Storm surge flooding

Flooding that occurs from an abnormal rise in coastal water as a result of low-pressure weather systems (i.e. cyclones or hurricanes) with spiraling winds that draw water upwards.

Storm water flooding

Flooding that is dependent on water volume and timing, occurring when runoff from a precipitation event collects in an area faster than it drains out or is absorbed.

Summary level aggregation This term is used in the context of the Input-Output Multipliers where the multiplier data set used in this tool is based on summarized level of 35 industries. Note that it is possible to attain I-O Multipliers at a more detailed level (up to 234 industries).

Surge residual The meteorologically induced component, sometimes called the non-tidal residual. A large (positive) surge caused by an extreme meteorological event is called a 'storm surge'. The surge above high-water (i.e. surge residual) can then be independently combined with the height of the tide on the day of the event to find the absolute water level reached.

Total impact The sum of the direct and secondary gross domestic product impacts. The total impact does not refer to the comprehensive impacts associated with an individual weather event, but rather is a technical economic definition that only refers to the sum of the sum of the direct and secondary impacts in the analysis of a specific impact from a weather event.

Vulnerability Vulnerability in the context of climate change is a function of exposure to extreme events and the adaptive capacity of communities.

Appendix A. Key Data and Assumptions – Direct Impact Estimates in the Halifax Regional Municipality

This appendix presents key data and assumptions related to the calculation of direct impact estimates for the Halifax Regional Municipality (HRM).

Data Sources

Data used in the HRM case study included:

- Climate and weather data.
    - Weather event return periods.
- Geospatial and physical asset data.
    - City building layers.
- Socio-economic data.
    - Statistics Canada labour force and income data for the HRM (confirm) and the province of Nova Scotia.
    - Statistics Canada Input-output multipliers for the province of Nova Scotia (2008, 2009, 2010[137]).
    - Statistics Canada Input-output tables for the province of Nova Scotia (2010).
    - Statistics Canada Census of Population.
    - The HRM property tax assessment values by building type.
    - Construction cost values by building type.
    - Nova Scotia Power restoration costs.

Climate and Weather Data and Scenarios

This section provides details on the data used to define the frequency and magnitude of the climate-related extreme events of relevance to this study by return period for the baseline, moderate and high climate change scenarios in the HRM.

Storm Surge Flooding

Recently updated storm surge return period data for Halifax Harbour was extracted directly from Daigle (2014).[138] The return period data that was used in this analysis is presented in Table 15 below.

[137] The 2010 Input-output multipliers were the most recent available at the time of the analysis.
[138] Daigle, R.J., 2014. Sea-level rise and coastal flooding estimates for Chignecto Isthmus and Halifax Harbour. Based on IPCC 5th Assessment Report.

Table 15: Total sea level (mean metres above CGVD28) return periods for recent past (2010) and future years under a moderate and high climate scenario (2020 and 2040) [139]

Return period (years)	Surge Residual (m)[1]	2010	2020 – Moderate CC	2020 – High CC	2040 – Moderate CC	2040 – High CC
5	0.64	2.00	2.04	2.06	2.15	2.20
10	0.71	2.07	2.11	2.13	2.22	2.27
25	0.81	2.17	2.21	2.23	2.32	2.37
50	0.88	2.24	2.28	2.30	2.39	2.44
100	0.95	2.31	2.35	2.37	2.46	2.51

1) Surge residual depth versus return period was assumed to be the same across all climate change scenarios. This assumption stemmed directly from the data source.

The total sea level values presented in Table 15 above represent the sum of the Higher High Water Large Tide (HHWLT) baseline value, the regional sea-level rise component relative to the baseline year (by years 2020 and 2040), and the storm-surge return level residual value (for each of 1, 2, 5, 10, 25, 50 and 100-year return periods).

The HHWLT value is calculated as the average of the maximum annual predicted astronomical tide over an 18.6 year cycle, thus representing a baseline level that is not necessarily reached every single year, but can also be exceeded during several years of the 18.6 year cycle.[140] The HHWLT value is referenced to the Canada geodetic vertical datum 1928 (CGVD28). The HHWLT value for Halifax Harbour that was utilized in Daigle (2014) was obtained from Forbes et al. (2009)[141] The relative sea-level rise for the moderate and high climate change scenario are based on the RCP4.5 and RCP8.5 scenarios from the Intergovernmental Panel on Climate Change's fifth assessment report[142] where the localized relative sea level rise values stem from an analysis undertaken by James et al. (2014)[143]. The sea-levels versus return periods depicted above were then utilized to spatially map the flood extent and the associated flood depths across the development area (the urban centre) considered in Halifax using Esri's ArcGIS software.

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[139] Daigle, R.J., 2014. Sea-level rise and coastal flooding estimates for Chignecto Isthmus and Halifax Harbour. Based on IPCC 5th Assessment Report.
[140] Daigle, R.J., 2014. Sea-level rise and coastal flooding estimates for Chignecto Isthmus and Halifax Harbour. Based on IPCC 5th Assessment Report.
[141] Forbes, D.L., et al., 2009. Halifax Harbour Extreme Water Levels in the Context of Climate Change: Scenarios for a 100-Year Planning Horizon, Geological Survey of Canada Open File 6346, 2009
[142] IPCC, 2014. Scenario Process for AR5, Representative Concentration Pathways (RCPs). [Accessed 02.02.2015] http://sedac.ipcc-data.org/ddc/ar5_scenario_process/RCPs.html.
[143] James, T.S., Henton, J.A., Leonard, L.J., Darlington, A., Forbes, D.L., Craymer, M. 2014. Relative Sea-level Projections in Canada and the Adjacent Mainland United States. Natural Resources Canada, Geological Survey of Canada, Open File 737, [Accessed 10.10.2014] http://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/fulle.web&search1=R=295574.

Extreme Wind

Return periods for extreme wind in the HRM were calculated for speed of maximum annual gust (km/hr) using the method developed by the National Institute of Standards and Technology which models extreme wind data using a Gumbel distribution.[144] The baseline peak gust speed results for return periods of 2, 5, 10, 20, 50, 100, 150, and 200 that were used in this analysis are shown in Table 16 below (the 1984 to 2013 time period was utilized).

Table 16: Return periods for maximum wind speed calculated using the methodology outlined by the National Institute of Standards and Technology[145] from speed of maximum gust (km/h) data obtained from the Halifax Stanfield International Airport and the Halifax International Airport across two time periods[146]

Return period (years)	Maximum annual gust (km/hr) 1961-2013	Maximum annual gust (km/hr) 1984-2013
200	154	153
150	151	150
100	147	146
50	140	138
20	131	129
10	124	121
5	117	113
2	106	102

Datasets for future wind gusts under future climate change scenarios were obtained via email from Dr. Chad Cheng at Environment Canada. Dr. Cheng provided the raw wind speed projections from a 2014 study[147] downscaled to hourly resolution for the Halifax weather station across two future climate scenarios (SRES A2 and B1)[148] run in eight different general circulation models (GCMs) and two time periods. With these data sets, the return periods were calculated via a Gumbel distribution for each climate change scenario and GCM across each time period and the average return periods across each climate change scenario (i.e. the average of 8 models) for each future time period was applied in this analysis.[149] With peak gust speed return periods for a recent historic time period (1984-2013) and two

[144] NIST (National Institute of Standards and Technology), 2011. Extreme Wind Speeds Software: Excel. [Accessed 10.10.2014] http://www.itl.nist.gov/div898/winds/excel.htm.
[145] NIST (National Institute of Standards and Technology), 2011. Extreme Wind Speeds Software: Excel. [Accessed 10.10.2014] http://www.itl.nist.gov/div898/winds/excel.htm.
[146] Environment Canada, 2014. Climate database. [Accessed 10.10.2014] http://climate.weather.gc.ca/index_e.html#access.
[147] Cheng, C. S.; Lopes, E.; Fu, C.; Huang, Z., 2014. Possible Impacts of Climate Change on Wind Gusts under Downscaled Future Climate Conditions: Updated for Canada. Journal of Climate 27(3):1255-1270.
[148] The IPCC Special Report Emissions Scenarios A2 was used for the high CC scenario and B1 was used for the moderate CC scenario.
[149] In probability theory and statistics, the Gumbel distribution is used to model the distribution of the maximum (or the minimum) of a number of samples of various distributions. Such a distribution in this case was used to represent the distribution of the maximum peak gust wind speed in a particular year where a list of the maximum annual peak gust wind speed values for the given time periods were applied. A larger sample size (i.e. longer time period) would allow for a more accurate Gumbel distribution. Nevertheless it is not unheard of to even rely on only a 10 year time period to generate a dataset of weather intensity versus return

future time periods (2046-2065 and 2081-2100) from Dr. Cheng, regression analysis was used to determine the best fit peak gust speeds versus return periods assuming an equivalent twenty year duration where the years 2020 and 2040 were set as midpoints. Table 17 below presents the peak gust speed return periods that were applied in this analysis (i.e. midpoint years 1999, 2020 and 2040). The peak gust wind speeds for the future years are based on SRES scenario B1, and the columns denoting the two future years (i.e. 2020 and 2040) were the peak gust wind speeds used for the moderate climate change scenario.

Table 17: Return periods for maximum wind speed calculated using the methodology outlined by the National Institute of Standards and Technology from speed of maximum gust (km/h). Future wind data obtained from Dr. Cheng and representing the moderate climate change scenario (based on SRES scenario B1)

	Time Period (Midpoint year)				
Return period (years)	1984-2013 (1999)	2016-2025 (2020)	2036-2045 (2040)	2046-2065 (2056)	2081-2100 (2091)
200	153	158	161	161	154
150	150	155	157	157	151
100	146	149	151	151	145
50	138	142	142	140	136
20	129	139	129	128	124
10	121	120	119	118	115
5	113	112	109	108	105
2	102	97	94	92	90

Similarly, Table 18 below shows both the historic and future wind speeds where the future wind speeds were based on the SRES A2 scenario which was assumed appropriate for the high climate change scenario.

periods. Therefore, a 20 year time period of peak gust data was deemed appropriate and also necessary to differentiate the climate conditions between the future years under consideration.

Table 18: Return periods for maximum wind speed calculated using the methodology outlined by the National Institute of Standards and Technology[150] from speed of maximum gust (km/h). Future wind data obtained from Dr. Cheng[151] and representing the high climate change scenario (based on SRES scenario A2)

	Time Period (Midpoint year)				
Return period (years)	1984-2013 (1999)	2016-2025 (2020)	2036-2045 (2040)	2046-2065 (2056)	2081-2100 (2091)
200	153	159	162	162	156
150	150	155	158	158	152
100	146	150	152	152	146
50	138	142	143	142	137
20	129	130	130	129	125
10	121	121	120	119	115
5	113	112	110	109	105
2	102	98	95	93	90

Again, the peak gust return periods for the time period 1984-2013 were used to estimate the baseline impact while the return periods for 2016-2025 and 2036-2045 were used to set the impact potential due to climate change for the target years, 2020 and 2040.

From Climate Data to Direct Impact Estimates

This section describes how the climate data (as described above) was combined with other data and assumptions to calculate the direct impact estimates. Specifically, for each climate-related event and city combination, in this section of the appendix details are provided related to:

- GIS data processing
- Building structure and content value
- Future building development assumptions
- Applying damage curves by sector
- Business interruptions due to power outage from tree/power line damage caused by extreme winds

Storm Surge Flooding Direct Impact

GIS Data Processing

Sea levels for the given return periods were input to ArcGIS and the GIS data was processed to develop the following attributes for each of the existing buildings within the flood zone:

[150] NIST (National Institute of Standards and Technology), 2011. Extreme Wind Speeds Software: Excel. [Accessed 10.10.2014] http://www.itl.nist.gov/div898/winds/excel.htm.
[151] Cheng, C. S.; Lopes, E.; Fu, C.; Huang, Z., 2014. Possible Impacts of Climate Change on Wind Gusts under Downscaled Future Climate Conditions: Updated for Canada. Journal of Climate 27(3):1255-1270.

- Unique ID for each existing building:
  - Area (footprint) of the unique building
  - Area of corresponding property parcel
  - Assessment value of the property parcel (if available)
  - Number of building structures on the property parcel
  - Total area of all buildings on the property parcel
  - Building symbol: Any existing building identification (i.e. buildings that correspond with point locations of police stations, fire stations, churches, community centres, etc.).
  - Municipal zoning classification: For buildings without specific use identification, municipal zoning was used to define more general use categories.
  - Minimum, maximum, and mean ground elevation of each building
  - Minimum, maximum, and mean of each building height:
    - Normalized height - established based on the difference between distribution management system (DSM) and digital elevation model (DEM) data.
  - Number of floors for residential buildings:
    - 2.7 metres was the assumed height of a typical story for residential buildings. Using this assumption, the number of floors for residential buildings was determined by dividing the building height by 2.7 metres rounded to the nearest integer. Each building type has a specific assumed floor-to-floor height.[152]
  - Flood depth at each building for all flood return periods:
    - This was determined by taking the difference between the total flood depth (metres above CGVD28) and the estimated ground elevation at each building. This was calculated using both the mean and minimum building ground elevation estimates. Because areas of Halifax are quite steep, using the minimum as opposed to mean ground elevation results in much larger damage estimates. Both depth levels were assessed, but mean ground elevation was taken as a conservative assessment of damages and the mean values were used to develop the current results in this analysis.

Building Structure and Content Values

Property assessment values were available for most but not all existing buildings and no divide between building value and land value is readily available for the HRM. Therefore, building/city specific

[152] Building floor-to-floor heights were based on default building characteristics from the energy simulation software CanQuest Beta (http://www.napeg.nt.ca/news-item/1997458-beta-release-of-new-can-quest-building)

construction costs per unit area[153] were used to estimate the costs of rebuilding/refurbishing a damaged building. Building content values were estimated using the HAZUS building structure to building content value ratios[154] for the general categories of residential, industrial, commercial and institutional buildings. For example, the building structure to contents value ratio for residential buildings was assumed to be 2:1.

Building structure values were also adjusted to account for changes over time. By projecting the historical city and sector specific construction cost index growth rates for residential, commercial, industrial, and institutional buildings,[155] building adjusted construction cost values were further adjusted by a 2020 and 2040 value adjustment factor. These values were used when assessing the direct impacts in 2020 and 2040 under both the recent historical climate and future climate return period scenarios. Existing buildings were assumed to remain in existence from present to 2040. An existing building could be rebuilt/refurbished in this time period but it was assumed that the building area of all existing buildings remains constant on the given parcel of land they are currently located on.

Modelling Future Building Development on Available Opportunity Land

New building development was population driven where population was assumed to grow linearly in accordance with recent population projections.[156] Present day citywide and sector specific building footprints (from GIS output) divided by the current population were used to estimate sector specific building requirements per person and were used to estimate the amount of building growth required as population grows. Zone specific opportunity sites for new buildings across the entire city and only within the flood extent were available from the city via the GIS dataset. These areas were further aggregated to represent development opportunities for residential, industrial, commercial and institutional buildings.

New building development within the flood zone was assumed to have a saturated building density (i.e. a maximum m^2 footprint/m^2 parcel) that is 50% greater than present day building density (own assumption). Fifty percent of all new building demand in the HRM was directed to the opportunity areas that were assumed to be available in the regional or urban centre. Within the regional centre, new building development was assumed to occur at equal rates across all opportunity areas that fell within this region of the HRM. If the population driven new building development demand reached the assumed new

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[153] AltusGroup, 2014. Construction Cost Guide, [Accessed October 20, 2014], http://www.altusgroup.com/research/construction-cost-guide/ .
[154] HAZUS, 2010. Multi-hazard Loss Estimation Methodology, Flood Model. Technical Manual, Federal Emergency Management Agency, Jessup, Maryland.
[155] CANSIM, 2014. Table 327-0044: Price indexes of apartment and non-residential building construction, by type of building and major sub-trade group, quarterly (index, 2002=100) and Table 327-0046: New housing price indexes, monthly (index, 2007=100). [Accessed 15.10.2014] http://www.statcan.gc.ca/.
[156] Halifax Regional Municipality, October 2014. Halifax Regional Municipal Planning Strategy. [Accessed 15.11.2014] http://www.halifax.ca/planning/documents/Halifax_MPS.pdf.

building saturated density for the given parcel of opportunity land, then new building development was halted on the given land parcel.

Allocating Damage Curves

Using the building attributes (described above) each building was allocated a damage curve type. Structure and content damage curve pairs were matched to the existing buildings using two approaches. As a primary choice, specific building uses determined via the building symbol attribute were used to select the most suitable damage curve pair. However, only twelve of the flooded buildings were identified in this manner. When the first choice was not possible, zoning information was used to determine the type of use expected. In the case of residential areas, the zoning specified which buildings are single-family homes, or multi-unit buildings.

Using the estimated number of floors, residential buildings were categorized into one and two or more floor buildings to correspond with available damage curves. Commercially zoned buildings were allocated "typical" or "average" commercial damage curves. Industrial zoned buildings were allocated "typical" or "average" industrial damage curves. In a few cases, buildings were zoned for multi-use purposes, and in these cases the zoning specifications were reviewed to assess the "typical" building types that would be allowed in those zones and an associated "composite" damage curve was developed and applied. The most common of these included a general residential and commercial mix for downtown Halifax which was dominantly a commercial and institutional mix.

A total of 44 damage curves were used to assess the damages based on the calculated flood depths at each building: 22 related to structural damages and 22 related to content / inventory / equipment.

Extreme Wind Direct Impact

GIS Data Processing

The GIS data provided by the city was processed to develop the following attributes at dissemination area[157] (DA) resolution:

- Unique ID for each DA
- Building area footprint within each DA
- Parcel area footprint of each DA
- Assessment value of the property parcel (if available)
- Number of building structures on the property parcel

[157] A dissemination area (DA) is a small, relatively stable geographic unit composed of one or more adjacent dissemination blocks. It is the smallest standard geographic area for which all census data are disseminated. DAs cover all the territory of Canada.

- Buildings within each DA were categorized to coincide with the wind damage curves (see below) which were customized to the following building types:
    - 1-3 story residential buildings
    - 1-3 story commercial/industrial buildings
    - 1-3 story institutional buildings
    - 4-10 story mid-rise buildings

Building Structure Value

Direct monetary damage was assessed only in terms of damage to building structure (i.e. damage to contents/equipment are not included). Property assessment values are available for most but not all existing buildings and no divide between building value and land value was made available to us. Therefore, building/city specific construction costs per unit area[158] were used to estimate the costs of rebuilding/repairing a damaged building. Building structure values were also adjusted to account for changes over time. By projecting the historical city and sector specific construction cost index growth rates for residential, commercial, industrial, and institutional buildings,[159] building adjusted construction cost values were further adjusted by a 2020 and 2040 value adjustment factor. These values were used when assessing the damages in 2020 and 2040 under both the historical climate and future climate extreme weather return period scenarios.

Existing buildings were assumed to remain in existence from present to 2040. An existing building could be rebuilt in this time period but it was assumed that the building area of all existing buildings remains constant on the given parcel of land that they are situated on.

Modelling Future Building Development on Available Opportunity Land

New building development is population driven where population was assumed to grow linearly in accordance with recent population projections.[160] Present day citywide and sector specific building footprints (from GIS output) divided by the current population were used to estimate sector specific building requirements per person and were used to estimate the amount of building growth required as population grows. Zone specific opportunity sites for new buildings across the entire were available from the city via the GIS dataset, and these areas were further aggregated to represent development

[158] AltusGroup, 2014. Construction Cost Guide, [Accessed October 20, 2014], http://www.altusgroup.com/research/construction-cost-guide/ .
[159] CANSIM, 2014. Table 327-0044: Price indexes of apartment and non-residential building construction, by type of building and major sub-trade group, quarterly (index, 2002=100) and Table 327-0046: New housing price indexes, monthly (index, 2007=100). [Accessed 15.10.2014] http://www.statcan.gc.ca/.
[160] Halifax Regional Municipality, October 2014. Halifax Regional Municipal Planning Strategy. [Accessed 15.11.2014] http://www.halifax.ca/planning/documents/Halifax_MPS.pdf.

opportunities for low-rise residential, industrial, commercial, mixed (commercial + industrial), institutional and midrise buildings.

New building development in the regional centre was assumed to have a saturated building density (i.e. m^2 footprint/m^2 parcel) that is 50% greater than present day building density whereas for new development outside of the regional centre the assumption was 25% greater (own assumption). Fifty percent of all new building demand in the HRM was directed to the opportunity areas that were assumed to be available in the regional centre while the remaining 50% of new building demand was directed to the HRM lying beyond the regional centre.[161] Within each of these development area (i.e. regional centre and suburban/rural area) new building development was assumed to occur at equal rates across all opportunity areas that fell within each of these two development areas within the HRM. If the population driven new building development demand reached the assumed new building saturated density for the given parcel of opportunity land, then new building development was halted on the given land parcel.

Allocating Damage Curves

As mentioned above, existing buildings within each dissemination area were divided based on the following categories which coincide with the damage curves being utilized:[162] 1-3 story residential buildings; 1-3 story commercial/industrial buildings; 1-3 story institutional buildings; and 4-10 story mid-rise buildings.

There is an upper and a lower damage band for each damage curve covering these four building types—upper meaning a highest damage estimate and lower meaning a lowest damage estimate for a given one minute sustained wind speed. The impact results presented in this analysis are based on the mean between the upper and the lower damage band. It should also be noted that the peak gust speeds needed to be converted into corresponding one minute sustained wind speeds in order to match the wind speed metric used with the building structure wind damage curves. To make this conversion a peak gust to one minute sustained wind speed factor of 0.807[163] was applied across all peak gust speeds versus return periods.

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[161] These development assumptions were based on the high density scenario found in: HRM 2013. Quantifying the costs and growth benefits of alternative growth scenarios. Prepared by Stantec, April 2013, [Accessed 02.02.2015] http://www.halifax.ca/regionalplanning/documents/HRMGrowthScenariosFinalReportJuly82013.pdf.
[162] Unanwa, C.O., McDonald, J.R., Mehta, K.C., Smith, D.A., 2000. The development of wind damage bands for buildings. *Journal of Wind Engineering and Industrial Aerodynamics* 84:119-149.
[163] WMO (World Meteorological Organization), 2009. Guidelines for converting between various wind averaging periods in tropical cyclone conditions. Sixth Tropical Cyclone RSM Cs/TCWCs Technical Coordinating Meeting, Item 2.3, 2-5th November 2009, [Accessed 03.03.2015] https://www.wmo.int/pages/prog/www/tcp/Meetings/HC31/documents/Doc.3.part2.pdf.

Impacts from Electricity Restoration and Business Interruption due to wind-induced power outages

Besides extreme wind impacts to building structure, impacts due to electricity restoration and business interruption were also considered. Electricity restoration damages are an opportunity cost due to the need to repair electricity grid assets while business interruption relates to sector specific productivity losses. In order to estimate these impacts, data sets from past extreme wind events in Nova Scotia and Halifax were relied upon. Data from past events utilized in this study included the following storms (with month/year of occurrence): Juan (Sept/2003), Beryl (Jul/2006), Kyle (Sept/2008), Earl (Sept/2010), Winter Storm (Dec/2010), Nor'Easter (Oct/2011), Andrea (Jun/2013) and Arthur (Jun/2014). Across each of these past events, where available, the following data items were attained: peak gust wind speed in the HRM, total customers in the HRM during the event, total number of customer interruption hours, the peak number of customers interrupted and the total electricity restoration cost of the event. With these data sets the following relationships were created: a) an average restoration cost per peak customer, b) a peak fraction of customers affected versus peak wind gust best fit equation (power law), c) a customer hour interruption per customer versus peak wind gust best fit equation (power law) and d) a HRM community electricity customers versus year best fit equation (linear).

Event specific restoration costs were then estimated across each return period and climate change scenario by multiplying the above three relationships, a), b) and d) together, where b) is a function of peak gust speed and d) is a function of the future year considered.

In terms of interruption impacts due to power outage during extreme wind events, relationship c) above, was used to estimate the number of hours an average customer loses power as a function of the peak gust wind speed of a given event. The resulting number of hours that an average customer is without power as a function of return period and climate change scenario was then used to estimate the sector specific loss of economic output using the following steps:

- Average hourly economic output was assumed to be equal to the annual city-wide economic output divided by 365 days/year and 24 hours/day (output was calculated from GDP—see Table 31 in Appendix C).
- Average hourly economic output was then multiplied by a sector specific hours of operation probability factor to capture the likelihood that the sector is a) actually operational during the power outage and b) sensitive to a power outage (i.e. likelihood to have on-site generator). Due to a lack of survey data best judgement was used to estimate each sector's probability factor.
- Average sector specific economic loss was calculated by multiplying the number of customer hours without power with the results of B (above) across each return period and climate change scenario combination.

Appendix B. Key Data and Assumptions – Direct Impact Estimates in Mississauga

This appendix presents key data and assumptions related to the calculation of direct impact estimates in Mississauga.

Data Sources

Data used in the Mississauga case study included:

- Climate and weather data.
    - Weather event return periods.
- Geospatial and physical asset data.
    - City building layers.
- Socioeconomic data.
    - Statistics Canada labour force and income data for the city of Mississauga (confirm) and the province of Ontario.
    - Statistics Canada Input-output multipliers for the province of Ontario (2008, 2009, 2010[164]).
    - Statistics Canada Input-output tables for the province of Ontario (2010).
    - Statistics Canada Census of Population.
    - Mississauga building permit values by building type.
    - Construction cost values by building type.
    - Tree debris removal, pruning, and planting costs.
    - Enersource Power restoration costs.

Climate and Weather Data and Scenarios

This section provides details on the data used to define the frequency and intensity of the extreme weather events of relevance to this study by return period for the baseline, moderate and high climate change scenarios.

Storm Water Flooding

Intensity, duration, and frequency (IDF) data for extreme rain was attained from the IDF_CC Tool[165] which was developed by researchers at the University of Western Ontario. This tool provides a user-friendly web-based interface to obtain updated IDFs using historical observed precipitation data from

[164] The 2010 Input-output multipliers were the most recent available at the time of the analysis.
[165] Computerized tool for the Development of Intensity-Duration-Frequency-Curves under a Changing Climate. http:///www.idf-cc-uwo.ca

Environment Canada or user provided data. Projections are based on general circulation models (GCMs) developed for IPCC Assessment Report (AR) 5, and provide future climate scenarios for RCP2.6, RCP4.5, and RCP8.5. The RCP2.6 represents the lower bound, followed by RCP4.5 as an intermediate level and RCP 8.5 represents the higher bound. In this analysis IDF results from RCP4.5 and RCP8.5 are used to represent the moderate and high climate change scenarios, respectively. The tool provides users with two options including when deciding on what GCM to use: (i) select a GCM based on skill score or (ii) select any model from the list of GCMs provided in the tool.

Mississauga IDF curves under a changing climate[166]

The IDF_CC Tool used data from the Toronto Lester B. Pearson Int'l Airport station (Table 19) to generate updated IDF curves for Mississauga. Historical Gumbel distribution IDF curves for both total precipitation (mm) and intensity (mm/h) are shown in Table 19 below.

Table 19: Station information

Station Information	
Station Name	Toronto Lester B. Pearson Int'l A
ID	6158733
Latitude/Longitude	43.68/-79.63
Starting year	1950
Ending year	2007
Number of years (with data)	54

[166] Computerized tool for the Development of Intensity-Duration-Frequency-Curves under a Changing Climate. http://www.idf-cc-uwo.ca

Table 20: **Historical Gumbel distribution IDF with duration (in minutes) and return period (years) for Toronto Lester B. Pearson Int'l A. Table shows both Total Precipitation (mm) and Intensity (mm/h).**

Gumbel Distribution IDF results													
Total PPT (mm)							Intensity rates (mm/h)						
T (yrs)>	2	5	10	25	50	100	T (yrs)>	2	5	10	25	50	100
5 min	8.31	11.16	13.05	15.44	17.2	18.96	5 min	99.78	133.98	156.62	185.23	206.45	227.52
10 min	12.09	16.33	19.15	22.7	25.33	27.95	10 min	72.52	98	114.87	136.19	152.01	167.7
15 min	14.88	20.33	23.94	28.49	31.88	35.23	15 min	59.51	81.31	95.74	113.98	127.5	140.93
30 min	19.68	26.92	31.72	37.78	42.27	46.73	30 min	39.35	53.84	63.43	75.55	84.54	93.47
1 h	22.48	30.5	35.81	42.52	47.5	52.44	1 h	22.48	30.5	35.81	42.52	47.5	52.44
2 h	26.42	35.88	42.14	50.05	55.92	61.75	2 h	13.21	17.94	21.07	25.03	27.96	30.87
6 h	35.36	47.95	56.29	66.82	74.64	82.39	6 h	5.89	7.99	9.38	11.14	12.44	13.73
12 h	41.13	55.39	64.84	76.77	85.62	94.41	12 h	3.43	4.62	5.4	6.4	7.14	7.87
24 h	46.85	62.38	72.66	85.65	95.28	104.85	24 h	1.95	2.6	3.03	3.57	3.97	4.37

Updated IDFs were generated using the CanEMS2 model (Canadian Earth System Model, generation 2), and RCP2.6, RCP4.5, and RCP8.5 emission scenarios for the time period of 2035, and 2050 are presented below in Tables 21 and 22, respectively. The CanESM2 model was selected for two reasons: 1) It was the default model used in the earlier version of the tool, and 2) it ranked as having a high 'skill' level for some of the stations in the Toronto area.

Table 21: Updated IDF under climate change – CanEMS2 model, RCP2.6, RCP4.5, RCP8.5 for time period 2035 for Toronto Lester B. Pearson Int'l A. Table shows both Total Precipitation (mm) and Intensity (mm/h).

CanEMS2 from CCCma 2035													
RCP 2.6													
Total PPT (mm)							Intensity rates (mm/h)						
T (yrs)	2	5	10	25	50	100	T (yrs)	2	5	10	25	50	100
5 min	8.59	11.62	13.63	16.17	18.05	19.92	5 min	103.11	139.49	163.58	194.02	216.59	239
10 min	12.58	17.05	20.02	23.76	26.54	29.3	10 min	75.45	102.31	120.09	142.56	159.23	175.78
15 min	15.52	21.08	24.76	29.41	32.86	36.28	15 min	62.07	84.3	99.02	117.62	131.42	145.12
30 min	20.56	27.98	32.88	39.09	43.69	48.25	30 min	41.13	55.95	65.77	78.17	87.37	96.5
1 h	23.46	31.48	36.79	43.49	48.47	53.4	1 h	23.46	31.48	36.79	43.49	48.47	53.4
2 h	27.41	37.14	43.58	51.72	57.76	63.75	2 h	13.7	18.57	21.79	25.86	28.88	31.87
6 h	36.37	49.92	58.89	70.22	78.62	86.97	6 h	6.06	8.32	9.81	11.7	13.1	14.49
12 h	42.07	57.63	67.93	80.95	90.6	100.19	12 h	3.51	4.8	5.66	6.75	7.55	8.35
24 h	48.29	65.38	76.69	90.98	101.58	112.11	24 h	2.01	2.72	3.2	3.79	4.23	4.67
RCP 4.5													
Total PPT (mm)							Intensity rates (mm/h)						
T (yrs)	2	5	10	25	50	100	T (yrs)	2	5	10	25	50	100
5 min	8.84	12.33	14.64	17.55	19.72	21.87	5 min	106.07	147.92	175.63	210.65	236.62	262.4
10 min	12.94	18.08	21.49	25.79	28.98	32.15	10 min	77.63	108.49	128.91	154.73	173.88	192.88
15 min	15.98	22.4	26.65	32.01	36	39.95	15 min	63.92	89.59	106.58	128.05	143.98	159.8
30 min	21.18	29.73	35.4	42.56	47.87	53.14	30 min	42.35	59.47	70.8	85.11	95.73	106.27
1 h	24.15	33.44	39.6	47.38	53.15	58.88	1 h	24.15	33.44	39.6	47.38	53.15	58.88
2 h	28.24	39.54	47.02	56.48	63.49	70.45	2 h	14.12	19.77	23.51	28.24	31.74	35.22
6 h	37.54	53.26	63.67	76.82	86.57	96.26	6 h	6.26	8.88	10.61	12.8	14.43	16.04
12 h	43.46	61.61	73.63	88.81	100.08	111.26	12 h	3.62	5.13	6.14	7.4	8.34	9.27
24 h	49.88	69.96	83.26	100.06	112.53	124.9	24 h	2.08	2.92	3.47	4.17	4.69	5.2
RCP 8.5													
Total PPT (mm)							Intensity rates (mm/h)						
T (yrs)	2	5	10	25	50	100	T (yrs)	2	5	10	25	50	100
5 min	8.58	11.77	13.89	16.56	18.54	20.5	5 min	102.98	141.28	166.63	198.67	222.44	246.03
10 min	12.56	17.27	20.39	24.34	27.26	30.17	10 min	75.35	103.64	122.37	146.03	163.59	181.02
15 min	15.49	21.36	25.25	30.16	33.8	37.42	15 min	61.98	85.45	101	120.63	135.2	149.66
30 min	20.53	28.36	33.53	40.08	44.93	49.75	30 min	41.07	56.71	67.07	80.16	89.87	99.5
1 h	23.43	31.91	37.53	44.63	49.9	55.13	1 h	23.43	31.91	37.53	44.63	49.9	55.13
2 h	27.36	37.68	44.5	53.13	59.53	65.88	2 h	13.68	18.84	22.25	26.57	29.77	32.94
6 h	36.31	50.65	60.15	72.14	81.04	89.88	6 h	6.05	8.44	10.02	12.02	13.51	14.98
12 h	42	58.51	69.43	83.24	93.49	103.66	12 h	3.5	4.88	5.79	6.94	7.79	8.64
24 h	48.2	66.4	78.45	93.67	104.96	116.17	24 h	2.01	2.77	3.27	3.9	4.37	4.84

Table 22: Updated IDFs under climate change – CanEMS2 model, RCP2.6, RCP4.5, RCP8.5 for time period 2050 for Toronto Lester B. Pearson Int'l A. Table shows both Total Precipitation (mm) and Intensity (mm/h).

CanEMS2 from CCCma 2050													
RCP 2.6													
Total PPT (mm)							Intensity rates (mm/h)						
T (yrs)	2	5	10	25	50	100	T (yrs)	2	5	10	25	50	100
5 min	8.6	11.6	13.59	16.1	17.96	19.81	5 min	103.2	139.22	163.08	193.21	215.57	237.76
10 min	12.6	17.02	19.95	23.65	26.4	29.12	10 min	75.58	102.13	119.7	141.91	158.38	174.73
15 min	15.5	21.15	24.89	29.61	33.11	36.59	15 min	62.02	84.6	99.55	118.44	132.45	146.36
30 min	20.43	28.08	33.15	39.55	44.3	49.01	30 min	40.87	56.17	66.3	79.1	88.6	98.03
1 h	23.4	31.9	37.53	44.65	49.92	55.16	1 h	23.4	31.9	37.53	44.65	49.92	55.16
2 h	27.5	37.7	44.46	52.99	59.32	65.6	2 h	13.75	18.85	22.23	26.49	29.66	32.8
6 h	37.11	51.03	60.25	71.9	80.54	89.11	6 h	6.19	8.51	10.04	11.98	13.42	14.85
12 h	43.38	59.46	70.1	83.55	93.53	103.44	12 h	3.61	4.95	5.84	6.96	7.79	8.62
24 h	49.51	68.07	80.35	95.87	107.38	118.81	24 h	2.06	2.84	3.35	3.99	4.47	4.95
RCP 4.5													
Total PPT (mm)							Intensity rates (mm/h)						
T (yrs)	2	5	10	25	50	100	T (yrs)	2	5	10	25	50	100
5 min	9.13	13.07	15.67	18.97	21.41	23.84	5 min	109.56	156.81	188.09	227.61	256.93	286.03
10 min	13.38	19.17	23.01	27.85	31.45	35.02	10 min	80.26	115.03	138.04	167.12	188.7	210.11
15 min	16.5	23.9	28.79	34.98	39.57	44.13	15 min	66	95.58	115.17	139.92	158.28	176.51
30 min	21.76	31.73	38.33	46.68	52.87	59.01	30 min	43.51	63.46	76.67	93.35	105.73	118.02
1 h	24.88	35.97	43.31	52.59	59.47	66.3	1 h	24.88	35.97	43.31	52.59	59.47	66.3
2 h	29.31	42.69	51.55	62.74	71.05	79.29	2 h	14.65	21.34	25.77	31.37	35.52	39.64
6 h	39.63	57.99	70.14	85.5	96.89	108.2	6 h	6.61	9.66	11.69	14.25	16.15	18.03
12 h	46.37	67.7	81.83	99.68	112.92	126.06	12 h	3.86	5.64	6.82	8.31	9.41	10.51
24 h	52.95	77.54	93.81	114.37	129.63	144.77	24 h	2.21	3.23	3.91	4.77	5.4	6.03
RCP 8.5													
Total PPT (mm)							Intensity rates (mm/h)						
T (yrs)	2	5	10	25	50	100	T (yrs)	2	5	10	25	50	100
5 min	8.76	11.97	14.09	16.78	18.77	20.75	5 min	105.08	143.61	169.12	201.35	225.27	249
10 min	12.83	17.56	20.69	24.64	27.57	30.49	10 min	76.97	105.33	124.11	147.84	165.45	182.92
15 min	15.8	21.84	25.83	30.88	34.63	38.35	15 min	63.19	87.34	103.33	123.53	138.52	153.4
30 min	20.83	28.99	34.39	41.22	46.28	51.31	30 min	41.65	57.97	68.78	82.43	92.56	102.62
1 h	23.84	32.91	38.91	46.5	52.13	57.71	1 h	23.84	32.91	38.91	46.5	52.13	57.71
2 h	28.04	38.94	46.17	55.29	62.06	68.78	2 h	14.02	19.47	23.08	27.65	31.03	34.39
6 h	37.86	52.76	62.63	75.09	84.34	93.52	6 h	6.31	8.79	10.44	12.52	14.06	15.59
12 h	44.26	61.52	72.95	87.39	98.1	108.73	12 h	3.69	5.13	6.08	7.28	8.17	9.06
24 h	50.53	70.42	83.59	100.23	112.57	124.82	24 h	2.11	2.93	3.48	4.18	4.69	5.2

The data consists of intensity values (mm/hr) for 5 minute, 10 minute, 30 minutes, 1 hour, 2 hour, 6 hour, 12 hour and 24 hour durations for each of the following return periods: 2 year, 5 year, 10 year, 25 year and 100 year.

Spatially explicit GIS flood extent data for the historical 100 year return period was available[167] and was used in this analysis but no additional flood extent data existed for other return periods or climate change scenarios. Therefore, the relative changes in IDP based on data from the IDF_CC Tool was used as a proxy to alter the flood depths across the existing buildings within the historical 100 year return period flood extent. This allowed for an estimate of the flood extent across all above return periods both for the historic time period (baseline climate change scenario) and the future time periods while accounting for climate change (moderate and high climate change scenarios).

Firstly, the return period values of the IDF curves for three time periods were utilized: baseline (1960-1990), and two future periods under a climate change scenario (2015-2045 and 2035-2065). The rainfall intensity was provided for several durations (5 mins, 10 mins, 15 mins, 30 mins, 1 hr, 2 hr, 6 hr, 12 hr and 24 hr) measured in mm/hr, and across each return period (2yrs, 5yrs, 10yrs, 25yrs, 50yrs and 100yrs). The average relative rainfall intensity across all durations was calculated between the baseline period (1960-1990) and the two future time periods (2015-2045 and 2035-2065) under the climate change scenario. These relative results provided a proxy to estimate the relative change in flood depth across return periods between the baseline time period (recent historic climate) and the two future time periods under a changing climate (midpoints: 2035 and 2050). Additionally, the average relative rainfall intensity across the durations was calculated between the baseline 100 year return period values and the other baseline return periods considered in this analysis (2yrs, 5yrs, 10yr, 50yrs). Since data was only available for the 100 year historic flood extent, the flood extent for the other baseline return periods were calculated by multiplying this relative change in rainfall intensity as a simple proxy to estimate the flood depths at each building across all of other return periods considered. Once the baseline flood depths versus return periods were calculated for the baseline historic climate change scenario, then the flood depths versus return periods were calculated for the future time periods assuming the given future climate change scenario using the relative change in rainfall intensity as a proxy.

Freezing Rain

Data for freezing rain is not readily available for Mississauga as it is not specifically measured by Environment Canada.[168] A literature search was conducted to locate historical data on freezing rain events as well as projections of freezing rain events into the future. Historical and future freezing rain data

[167] Attained from City of Mississauga.
[168] Personal communication with Ontario Climate Centre at Environment Canada (email dated Oct 7).

that was obtained and reviewed for the Mississauga area (including the Toronto Lester B. Pearson International Airport) included the following:

- Data from the Toronto Lester B. Pearson International Airport weather station, which revealed that the winter seasonal (November to April) average number of days with freezing rain, over the period of 1953/54 to 2000/01 was 5.2 days/year and the winter seasonal number of hours with freezing rain was 17.1 hrs/year over the same time period.[169] Although a linear trend analysis of this data showed that the seasonal frequency of the total number of observed freezing rain hours and days decreased for Toronto, this trend was found to be insignificant.[170]
- A 2003 study by Klassen et al. (2003)[171] that reported on the relationship between temperature and freezing rain occurrences by month for Toronto. For the month of January, the study did not reveal a clear relationship between monthly mean temperature and freezing rain occurrences for the years from 1953 to 2001.[172] For December, monthly mean total hours and days of freezing rain increased with monthly mean temperature, from -7°C to -2°C, after which point they declined as the temperature continued to rise to 0 °C.[173] Similar to December, February occurrences of freezing rain increased as mean monthly temperature increased from -8°C to -5°C, after which point occurrences decreased as mean monthly temperature increased to -2°C.[174]
- A 2004 study that measured changes in the frequency of freezing rain weather patterns out to 2050 for Toronto and projected the frequency to be -1% for freezing rain weather events ≥1 hr, 7% for events ≥4 hrs, and 9% for events ≥6 hrs (based on CGCM2 A2).[175]
- A Canada-wide study[176] that estimated historical freezing rain return periods in terms of ice thickness at major weather stations including the Toronto Lester B. Pearson International Airport weather station. All parameters required for this model stem from observed meteorological data that are routinely recorded by Environment Canada making the model widely applicable.

Considering the availability of data (described briefly above) and the application of that data to Mississauga but also other regions in Canada (which is relevant for the community impact analysis tool development and application), the current study relied on return periods of freezing rain thickness based

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[169] Klaassen, J.; Cheng, S.; Auld, H.; Li, Q.; Ros, E.; Geast, M.; Li, G.; Lee, R., 2003. Estimation of Severe Ice Storm Risk for South-Central Canada.
[170] Klaassen, J.; Cheng, S.; Auld, H.; Li, Q.; Ros, E.; Geast, M.; Li, G.; Lee, R., 2003. Estimation of Severe Ice Storm Risk for South-Central Canada. – see Figures 5 and 6
[171] Klaassen, J.; Cheng, S.; Auld, H.; Li, Q.; Ros, E.; Geast, M.; Li, G.; Lee, R., 2003. Estimation of Severe Ice Storm Risk for South-Central Canada. – see Figure 11
[172] Klaassen, J.; Cheng, S.; Auld, H.; Li, Q.; Ros, E.; Geast, M.; Li, G.; Lee, R., 2003. Estimation of Severe Ice Storm Risk for South-Central Canada. – see Figure 10
[173] Klaassen, J.; Cheng, S.; Auld, H.; Li, Q.; Ros, E.; Geast, M.; Li, G.; Lee, R., 2003. Estimation of Severe Ice Storm Risk for South-Central Canada. – see Figure 9
[174] Klaassen, J.; Cheng, S.; Auld, H.; Li, Q.; Ros, E.; Geast, M.; Li, G.; Lee, R., 2003. Estimation of Severe Ice Storm Risk for South-Central Canada. – see Figure 11
[175] Auld, H.; Klassen, J.; Geast, M.; Cheng, S.; Ros, E.; Lee, R., 2004. Severe Ice Storm Risks in Ontario – see slide 21
[176] Yip, T.-C., (1995). Estimating icing amounts caused by freezing precipitation in Canada. Atmospheric Research 26:221-232.

on the work of Yip (1995)[177] and the icing model of Chaine and Skeates (1974). This model was most recently run in 2009 at which time a Gumbel distribution was used to determine a range of return periods for freezing rain events of a given ice thickness. These Canada-wide return period results were obtained via personal communication with Philip Jarrett of Environment Canada.[178] The baseline ice thickness return periods employed in this analysis are specific to the Lester B. Pearson weather station and are shown in Table 23 below.

Table 23: Freezing rain ice thickness and its associated return period for the region's recent historic climate[179]

Return period (years)	freezing rain (mm)
2	6.6
5	11
10	15
25	19
50	22
100	25
200	28
500	32

With the baseline return periods for freezing rain established, it was necessary to estimate future freezing rain projections for Mississauga.[180] To do so, we relied on results from Cheng et al. (2007)[181] where they used a statistical method to downscale results from two climate change scenarios using four GCMs for selected weather stations. According to this study, into the 2050s Southern Ontario could experience:

- An increase in freezing rain by 40% (95% Confidence Interval (CI): ±6%) in the cooler freezing rain prone months of December, January, and February as compared to the average occurrence over the past 40 years.
- A decrease in freezing rain by 10% (95% CI: ±3%) in the warmer freezing rain prone months of November, March, and April.

[177] Yip, T-.C., (1995). Estimating icing amounts caused by freezing precipitation in Canada. Atmospheric Research 26:221-232.
[178] Personal communication with Philip Jarrett, head of the Engineering Climate Services Unit of Environmental Canada (email with data received October 27 2014).
[179] Personal communication with Philip Jarrett, head of the Engineering Climate Services Unit of Environmental Canada (email with data received October 27 2014).
[180] Cheng, C.S., Auld, H., Li, G., Klassen, J., Li, Q. (2007) Possible impacts of climate change on freezing rain in south-central Canada using downscaled future climate scenarios. Natural Hazards and Earth System Sciences 7:71-87.
[181] Cheng, C.S., Auld, H., Li, G., Klassen, J., Li, Q. (2007) Possible impacts of climate change on freezing rain in south-central Canada using downscaled future climate scenarios. Natural Hazards and Earth System Sciences 7:71-87.

Into the 2080s, the analysis revealed that Southern Ontario could experience:

- An increase in freezing rain by 45% (95% CI: ±9%) in the cooler months of December, January, and February.
- A decrease in freezing rain by 15% (95% CI: ±5%) in the warmer months of November, March, and April.

The authors state that the magnitude of percentage increases in future freezing rain events for the three colder months is generally greater for a longer duration event than a shorter duration event.

The average percentage change in future freezing rain events of various durations (for Region 3) with a 95% confidence interval is shown in Table 24 below.[182] Region 3 includes: London, Sault Ste. Marie, Toronto, Wiarton, and Windsor. Similar to all of Southern Ontario, projections for Region 3 show increases in the average percent of future freezing rain events for all durations and time periods in the colder months of December, January, and February. Projections for the warmer months of November, March, and April show decreases for all durations (CGCM2-B2 shows an increase of 1% for ≥1hr).

For our analysis, we utilized their results for two future time periods (2040-2059 and 2070-2089) where the SRES scenarios A2 and B2 represented the high and moderate climate change scenarios, respectively. Regression analysis was used to estimate percentage change in freezing rain frequency for 2020 and 2040. Cheng et al. (2007)'s [183] findings in terms of the percentage increase in freezing rain frequency relative to recent historical climate trends for the region covering Mississauga are shown in Table 24 below.

[182] Cheng, C.S., Auld, H., Li, G., Klassen, J., Li, Q. (2007) Possible impacts of climate change on freezing rain in south-central Canada using downscaled future climate scenarios. Natural Hazards and Earth System Sciences 7:71-87, Table 4, page 82
[183] Cheng, C.S., Auld, H., Li, G., Klassen, J., Li, Q. (2007) Possible impacts of climate change on freezing rain in south-central Canada using downscaled future climate scenarios. Natural Hazards and Earth System Sciences 7:71-87.

Table 24: Relative change in freezing rain event frequency due to future climate change projections relative to recent historical climate trends[184]

For cooler freezing rain prone months: December, January, February							
		Time Period: 2040 - 2059			Time Period: 2070 - 2089		
	Duration	CGCM1 CGCM2-A2	CGCM2-B2	GFDL-A2	CGCM1 CGCM2-A2	CGCM2-B2	GFDL-A2
Region 3 (Southern Ontario)	≥ 1 hr	39%	37%	8%	48%	28%	24%
	≥ 4 hr	51%	51%	21%	62%	34%	37%
	≥ 6 hr	57%	57%	23%	71%	38%	39%
For warmer freezing rain prone months: November, March, April							
		Time Period: 2040 - 2059			Time Period: 2070 - 2089		
	Duration	CGCM1 CGCM2-A2	CGCM2-B2	GFDL-A2	CGCM1 CGCM2-A2	CGCM2-B2	GFDL-A2
Region 3 (Southern Ontario)	≥ 1 hr	-12%	1%	-13%	-19%	-2%	-17%
	≥ 4 hr	-11%	-1%	-13%	-18%	-2%	-17%
	≥ 6 hr	-14%	-1%	-5%	-25%	-2%	-12%
Note: Southern Ontario includes results for London, Sault Ste. Marie, Toronto, Wiarton and Windsor							

The freezing rain changes in frequency for SRES climate change scenario A2 (GCMs: CGCM1/CGCM2) was used for the high CC scenario while results from the SRES climate change scenario B2 (GCM: CGCM2) was used for the moderate CC scenario. Recent historical freezing rain event frequency between the cooler and warmer freezing rain prone months was determined to be about 78% and 22%, respectively.[185]

Resulting net percentage increases in freezing rain storm frequencies for the future target years are presented in Table 25 below for both moderate and high CC scenarios.

Table 25: Net percentage increases in freezing rain storm frequencies for the future target years

Event duration	2020, Moderate CC	2040, Moderate CC	2020, High CC	2040, High CC
≥ 1 hr	5.3%	14.9%	4.5%	14.7%
≥ 4 hr	7.4%	20.2%	6.0%	19.7%
≥ 6 hr	8.3%	22.5%	6.6%	21.9%

These values were used to adjust the historical freezing rain return periods used in the future (2020 and 2040) probability distributions with climate change.

[184] Cheng, C.S., Auld, H., Li, G., Klassen, J., Li, Q. (2007) Possible impacts of climate change on freezing rain in south-central Canada using downscaled future climate scenarios. Natural Hazards and Earth System Sciences 7:71-87.
[185] Ice storm events from 1996 to 2014 recorded in USA regions adjacent to Mississauga were utilized to estimate this % split. Data stemmed from the National Climatic Data Center Storm Events Database of the NOAA (National Oceanic and Atmospheric Administration. [Accessed October 14 2014] http://www.ncdc.noaa.gov/stormevents/ .

Table 26: Radial Ice Thickness Return Periods for the Future Years under the Moderate and High Climate Change Scenarios

Return period (years)	2020, Moderate CC	2040, Moderate CC	2020, High CC	2040, High CC
2	7.5	7.9	7.4	7.9
5	11.6	12.0	11.5	12
10	14.7	15.2	14.6	15.1
25	18.8	19.3	18.7	19.2
50	21.9	22.4	21.8	22.4
100	24.9	25.5	24.9	25.5
200	38	28.6	28.0	28.6
500	32.1	32.7	32.1	32.7

The probability of several average wind speed ranges was also required to undertake the freezing rain impact assessment in Mississauga where both a historic and a future climate change data set was created. Hourly historical wind speed data, from the Toronto Lester B. Pearson International Airport for January, February, March, October, November, and December (1955-2013) were downloaded from the Environment Canada Climate Database website.[186] This data was used to estimate the historical average wind speed in Mississauga as is summarized below.

Table 27: Historic number of days with mean hourly wind speed greater or less than indicated for the 1954-2013 time period[187]

Time	Number of days within monthly range with mean daily wind speed				Corresponding probability of the average wind speed ranges			
November to March	<24.1 km/hr	>24.1 & <40.2 km/hr	>40.2 & <56.3 km/hr	>56.3 km/hr	<24.1 km/hr	>24.1 & <40.2 km/hr	>40.2 & <56.3 km/hr	>56.3 km/hr
1954-2013	9,223	1,638	59	0	0.85	0.15	1.1e-4	0

Hourly future wind speed data centered on Mississauga were downloaded from the OCCDP[188] for two future available time periods of interest (2015-2045 and 2035-2065). Probabilities were calculated for the average wind speed ranges throughout November to March using both a single year (i.e. 2020 and 2040) and a ten year timespan where 2020 and 2040 are midpoints (the latter were utilized in this analysis).

[186] Environment Canada, 2014. Climate database. [Accessed 10.10.2014] http://climate.weather.gc.ca/index_e.html#access.
[187] Environment Canada, 2014. Climate database. [Accessed 10.10.2014] http://climate.weather.gc.ca/index_e.html#access.
[188] Wang, X. and Huang, G., 2013. "Ontario Climate Change Data Portal". Website: http://www.ontarioccdp.ca.

Table 28: Projected number of hours with mean daily wind speed greater or less than indicated for 2016-2045 time period (P50). *Grid Cell Coordinates: 43.7906_280.5112*

Time	Number of hours within monthly range with mean daily wind speed				Corresponding probability of the average wind speed ranges			
November to March	<24.1 km/hr	>24.1 & <40.2 km/hr	>40.2 & <56.3 km/hr	>56.3 km/hr	<24.1 km/hr	>24.1 & <40.2 km/hr	>40.2 & <56.3 km/hr	>56.3 km/hr
2016-2025	31,336	4,660	4	0	0.87	0.13	1.1e-4	0
2020	3,057	542	1	0	0.85	0.15	2.8e-4	0
2036-2045	21,868	4,131	1	0	0.88	0.12	0	0
2040	3,327	273	0	0	0.92	0.076	0	0

Table 29: Projected number of hours with mean daily wind speed greater or less than indicated for 2036-2065 time period (P50). *Grid Cell Coordinates: 43.7906_280.5112*

Time	Number of hours within monthly range with mean daily wind speed				Corresponding probability of the average wind speed ranges			
November to March	<24.1 km/hr	>24.1 & <40.2 km/hr	>40.2 & <56.3 km/hr	>56.3 km/hr	<24.1 km/hr	>24.1 & <40.2 km/hr	>40.2 & <56.3 km/hr	>56.3 km/hr
2036-2045	30,345	5,651	4	0	0.84	0.16	1.1e-4	0
2040	3,254	346	0	0	0.90	0.096	0	0

From Climate Data to Direct Monetary Damages

This section describes how the climate data (as described above) was combined with other data and assumptions to calculate the direct impact estimates. Specifically, for each hazard and city combination, in this section of the appendix details are provided related to:

- GIS data processing
- Building structure and content value
- Future building development assumptions
- Applying damage curves by sector
- Business interruptions due to power outage from tree/line damage

Flooding Direct Impact

GIS Data Processing

Sea levels for the given return periods were input to ArcGIS and the GIS data was processed to develop the following attributes for each of the existing buildings within the flood zone:

- Unique ID for each existing building:
    - Area (footprint) of the unique building

- Area of corresponding property parcel
- Assessment value of the property parcel (if available)
- Number of building structures on the property parcel
- Total area of all buildings on the property parcel
- Area adjusted assessment value for each building on the property parcel
- Building symbol: Any existing building identification (i.e. buildings that correspond with point locations of police stations, fire stations, churches, community centres, etc.).
- Municipal zoning classification: For buildings without specific use identification, municipal zoning was used to define more general use categories.
- Minimum, maximum, and mean ground elevation of each building
- Minimum, maximum, and mean of each building height:
  - Normalized height - established based on the difference between distribution management system (DSM) and digital elevation model (DEM) data.
- Number of floors for residential buildings:
  - 2.7 metres was the assumed height of a typical story for residential buildings. Using this assumption, the number of floors for residential buildings was determined by dividing the building height by 2.7 metres rounded to the nearest integer. Each building type has a specific assumed floor-to-floor height.[189]
- Flood depth at each building for all flood return periods:
  - This was determined by taking the difference between the total flood depth (metres above CGVD28) and the estimated ground elevation at each building.

Building Structure and Content Values

Property assessment values are available for most but not all existing buildings and no divide between building value and land value is readily available. Therefore, building/city specific construction costs per unit area[190] were used to estimate the costs of rebuilding/refurbishing a damaged building. Building content values were estimated using the HAZUS building structure to building content value ratios[191] for the general categories of residential, industrial, commercial and institutional buildings. For example, the building structure to contents value ratio for residential buildings was assumed to be 2:1.

Building structure values were also adjusted to account for changes over time. By projecting the historical city and sector specific construction cost index growth rates for residential, commercial, industrial, and

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[189] Building floor-to-floor heights were based on default building characteristics from the energy simulation software CanQuest Beta (http://www.napeg.nt.ca/news-item/1997458-beta-release-of-new-can-quest-building)
[190] AltusGroup, 2014. Construction Cost Guide, [Accessed October 20, 2014], http://www.altusgroup.com/research/construction-cost-guide/ .
[191] HAZUS, 2010. Multi-hazard Loss Estimation Methodology, Flood Model. Technical Manual, Federal Emergency Management Agency, Jessup, Maryland.

institutional buildings,[192] building adjusted construction cost values were further adjusted by a 2020 and 2040 value adjustment factor. These values were used when assessing the direct impacts in 2020 and 2040 under both the recent historical climate and future climate return period scenarios. Existing buildings were assumed to remain in existence from present to 2040. An existing building could be rebuilt/refurbished in this time period but it was assumed that the building area of all existing buildings remains constant on the given parcel of land they are located on.

Modelling Future Building Development on Available Opportunity Land

For Mississauga, the opportunity land available for development within the Credit Valley flood extent is negligible and therefore, future building development within the flood extent was assumed to be zero in this analysis.

Allocating Damage Curves

Using a combination of the above building attributes, each building was allocated a damage curve type. Structure and content damage curve pairs were matched to the existing buildings using two approaches. As a primary choice, specific building uses determined via the building symbol attribute were used to select the most suitable damage curve pair. However, only twelve of the flooded buildings were identified in this manner. When the first choice was not possible, zoning information was used to determine the type of use expected. In the case of residential areas, the zoning specified which buildings are single-family homes, or multi-unit buildings.

Using the estimated number of floors, residential buildings were categorized into one and two or more floor buildings to correspond with available damage curves. Commercially zoned buildings were allocated “typical” or “average” commercial damage curves. Industrial zoned buildings were allocated “typical” or “average” industrial damage curves. In a few cases, buildings were zoned for multi-use purposes, and in these cases the zoning specifications were reviewed to assess the “typical” building types that would be allowed in those zones and an associated “composite” damage curve was developed and applied. A total of 44 damage curves were used to assess the damages based on the calculated flood depths at each building: 22 related to structural damages and 22 related to content / inventory / equipment.

[192] CANSIM, 2014. Table 327-0044: Price indexes of apartment and non-residential building construction, by type of building and major sub-trade group, quarterly (index, 2002=100) and Table 327-0046: New housing price indexes, monthly (index, 2007=100). [Accessed 15.10.2014] http://www.statcan.gc.ca/.

Freezing Rain Direct Impact

Business Interruption Due to Power Outages

The approach that was utilized to quantify the economic impact due to business interruption during power outages that are instigated from freezing rain events (FRE) of varying intensity is centred on a relatively new extreme weather index known as the Sperry-Piltz Utility Ice Accumulation (SPIA) Damage Index.[193]

The SPIA index provides a scale from zero to five with respect to how extreme a FRE can be in terms of power outage duration and spatial extent. A SPIA score for a given FRE is determined by knowing a combination of the accumulated ice thickness and the average wind speed during the event. The SPIA index table is depicted below (Table 30):

Table 30: **Sperry-Piltz Utility Ice Accumulation damage index**

Ice Index	Radial Ice Amount (inches)	Wind (mph)	Damage and Impact Descriptions
1	< 0.25	15-25	Some localized utility interruptions possible, typically lasting only 1 or 2 hours maximum.
	0.25-0.50	< 15	
2	< 0.25	>= 25	Scattered utility interruptions expected, typically lasting less than 8-12 hours maximum.
	0.25-0.50	15-25	
	0.50-1.00	< 15	
3	0.25-0.50	>= 25	Numerous utility interruption, with some damage to main feeder lines expected with outages lasting from 1-3 days.
	0.50-0.75	15-25	
	0.75-1.00	<15	
4	0.50-0.75	>= 25	Prolonged & widespread utility interruptions, with extensive damage to main distribution feeder lines and possibly some high voltage transmission lines. Outages expected to last more than 3 to 5 days.
	0.75-1.00	15-25	
	1.00-1.50	< 15	
5	0.75-1.00	>= 25	Catastrophic damage to entire utility systems. Outages could last from one week to several weeks in some areas.
	1.00-1.50	15-25	
	> 1.50	< 15	

The ice thickness and average wind speed probabilities are combined[194] to determine the probability that the given ice thickness and wind speed range combination occur at the same time. The likelihood of a given SPIA index score can be determined for all combinations of ice thickness and wind speed ranges through the following equation:

[193] McManus, G.D., Piltz, S.F., Sperry, S., McPherson, R.A., Gartside, A.D., McClain, D., Meyer, T., Fetsch, C., Shafer, M.A., 2009. Development and testing of an ice accumulation algorithm. [Accessed 6.6.2014] http://www.crh.noaa.gov/images/eax/IceDamageIndex/IceUtilityIndexPaper.pdf.
[194] Our approach is partially based on the work of Binning, C.D., Meszaros, J.L., 2013. A proposed procedure for conducting an ice storm evaluation in a RAMCAP risk and resilience analysis. AEM Corporation, Chantilly, Virginia.

$$P(T_i\ AND\ W) = P(T_i) * P(W) \quad (1)$$

Where $P(T_i)$ is the probability of an ice thickness within a given range and P(W) is the probability of an average wind speed within a given range. The SPIA index probabilities for the baseline climate scenario and climate change scenarios in 2020 and 2040 that were used in this analysis are shown in Figure 45 below.

→ Wind speed → ↓ Ice thickness ↓	W ≤ 24 km/h	24<W≤40 km/h	40<W≤56 km/h	W > 56 km/h
$T_i \le 0.25$ cm	0	0	0	0
$0.25 < T_i \le 0.64$ cm	0	1	2	3
$0.64 < T_i \le 1.3$ cm	1	2	3	4
$1.3 < T_i \le 1.9$ cm	2	3	4	5
$1.9 < T_i \le 2.5$ cm	3	4	5	5
$2.5 < T_i \le 3.8$ cm	4	5	5	5
$T_i > 3.8$ cm	5	5	5	5

a) Baseline (historic climate)

SPIA index	*P(SPIA)*
0	0.41
1	0.38
2	0.16
3	0.041
4	0.0093
5	0.0036
sum	1.000

b) 2020 with climate change

SPIA index	*P(SPIA)*
0	0.37
1	0.41
2	0.17
3	0.04
4	0.010
5	0.0040
sum	1.000

c) 2040 with climate change

SPIA index	*P(SPIA)*
0	0.31
1	0.43
2	0.19
3	0.052
4	0.012
5	0.0048
sum	1.000

Figure 45: SPIA index scores for each combination of ice thickness and average wind speed range: The annual probability of each SPIA index score using a) historic climate baseline, b) with climate change to 2020 and c) with climate change to 2040

The *P(SPIA)* data points as depicted in Figure 45 were plotted and a best fit equation was used to create a continuous relationship between the probability of a SPIA index score and a power outage duration. The power outage duration is based on the description of each SPIA index score as given in Figure 45 above. Due to lack of better data relating freezing ice thickness with the percent of the city's customers affected by power outage of a given duration and SPIA index score, an assumption was made to relate power outage duration and SPIA index with the fraction of the city that is experiencing the power disruption. This relationship is as follows: $D(SPIA)/D(SPIA)_{max}*0.75$, where *D(SPIA)* is the duration of no power (in hours) for a given SPIA index score and $D(SPIA)_{max}$ is the maximum power outage duration due to a maximum SPIA index score of 5 (assumed in this analysis to be 480 hours without power). Given these relationships, as a freezing rain event becomes more intense, a greater percent of the city will be affected. The most extreme and rare freezing rain event (i.e. SPIA index = 5) results in 75% of the city being without power.

A mathematical relationship between the *P(SPIA)* function, the SPIA index versus power outage duration function, and the SPIA index versus percent of customers affected function was established to determine the annual average hours that the entire city is without power due to freezing rain events.

The resulting average annual hours that the city is without power was then used to estimate the sector specific loss of economic output using the following steps:

- Average hourly output was assumed to be equal to the annual city-wide economic output divided by 365 days/year and 24 hours/day (output was calculated from GDP—see Table 32 in Appendix C).

- Average hourly economic output was then multiplied by a sector specific hours of operation probability factor to capture the likelihood that the sector is a) actually operational during the power outage and b) sensitive to a power outage (i.e. likelihood to have on-site generators). Due to a lack of survey data best judgement was used to estimate each sector's probability factor.
- Average sector specific economic loss was calculated by multiplying the annual average number of hours without citywide power with the results of B. (above).

Electricity restoration costs were estimated using a restoration cost per hour outage cost factor based on the restoration costs in Mississauga during the 2013 December ice storm.[195] At the date of reporting (January 6 2014) electricity restoration had cost Enersource just over $1 million, while the total power outage duration of the event in Mississauga lasted for an estimated 72 hours. Therefore, the simplistic cost factor used in this analysis was $1 million/72 hrs = $13,900/hr. This cost factor was then multiplied by the total estimated power outage duration for each return period event under each climate change scenario.

Tree Damage and Associated Clean-up/Replacement Costs

A recent publication[196] was used to relate citywide tree debris during freezing rain to observed ice thickness. Three tree debris estimates are considered from this study where the first two in the list below are applied in the current analysis:[197]

- A city area factor: 365.4 m^3 tree debris per km^2 city area per cm ice thickness
- A city street distance factor: 51.8 m^3 tree debris per km city street distance per cm ice thickness
- A city street distance equation: Tree debris(m^3) = -99,136 + 311.2*Street distance (km) + 15,031.9*Ice thickness (cm)

The ice thickness probability functions for the historic baseline climate and future climate change scenario to 2020 and 2040 were integrated and multiplied with the tree debris factors resulting in the estimated annual average tree debris expected due to freezing rain events. The following assumptions were used to relate annual average tree debris estimates to costs due to tree debris clean up, tree removal, hazard pruning and tree replacement.

For tree debris cleanup, a straightforward costs factor (in $/$m^3$ tree debris) was applied.[198] A recent study[199] that mapped Mississauga urban tree species composition and size distribution (in terms of

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[195] Baker, J.M. (2014). Ice Storm, December 2013 – Preliminary Report. January 6, 2014. City Manager and Chief Administrative Officer, [Accessed 1.11.2015] http://www7.mississauga.ca/documents/Communications/2014/Ice_Storm_December_2013_Preliminary_Report.pdf
[196] Hauer, R.J., Hauer, A.J., Hartel, D.R., Johnson, J.R., 2011. Rapid assessment of tree debris following urban forest ice storms. Arboricultre & Urban Forestry 37(5):236-246.
[197] Current results assume the city area factor as it is the most conservative of the three tree debris estimates.

diameter at breast height (DBH)) was used to estimate weighted average tree density (490 kg dry basis/m^3) and volume per tree (0.29 m^3/tree). Assuming a tree debris density to average tree density factor, the total average tree equivalents damaged by freezing rain was estimated.

In the current analysis, the percentage of damaged trees assumed to survive and recover changed as a function of freezing rain event return period (80-94% from 2 to 500 year return period) while the remaining 20-6% of damaged trees were assumed not fit for recovery.[200] Only surviving trees were assumed to require hazard pruning while trees not fit for recovery were assumed to require whole tree removal and subsequent tree replacement. A mathematical relationship between tree removal and hazard pruning labour time as a function of tree diameter at breast height (DBH) class[201] and Mississauga's tree DBH distribution[202] was established to estimate the weighted average tree removal and hazard pruning hours required per citywide average tree.

Tree removal and hazard pruning cost factors were then applied to estimate these associated costs.[203] A tree replacement cost factor specific to Mississauga[204] was applied in this study.

[198] SDRC (Storm Damage Resource Center), 2014. Storm Damage Estimates spreadsheet tool. [Accessed 20.10.2014] http://www.umass.edu/urbantree/icestorm/pages/assess1.html.
[199] TRCA (Toronto and Region Conservation Authority), 2011. City of Mississauga Urban Forest Study. [Accessed 6.6.2014] http://www.mississauga.ca/file/COM/2012eacagendapart3_june5.pdf.
[200] Own assumption.
[201] SDRC (Storm Damage Resource Center), 2014. Storm Damage Estimates spreadsheet tool. [Accessed 20.10.2014] http://www.umass.edu/urbantree/icestorm/pages/assess1.html.
[202] TRCA (Toronto and Region Conservation Authority), 2011. City of Mississauga Urban Forest Study. [Accessed 6.6.2014] http://www.mississauga.ca/file/COM/2012eacagendapart3_june5.pdf.
[203] SDRC (Storm Damage Resource Center), 2014. Storm Damage Estimates spreadsheet tool. [Accessed 20.10.2014] http://www.umass.edu/urbantree/icestorm/pages/assess1.html.
[204] City of Mississauga. (2014) Forestry Fees and Charges Effective January 1, 2014-December 31 2014. [Accessed 15.11.2014] http://www7.mississauga.ca/departments/rec/parks/pdf/parks_fees_and_charges.pdf.

Appendix C. Key Data and Assumptions – Secondary Impact Analysis

This section of the document focuses on the key data and assumptions associated with the secondary impact analysis – the derivation of indirect and induced impacts to gross output and gross domestic product (GDP) and labour force using input-output (I-O) and computable general equilibrium (CGE) models.

Economic Calibration

In the sub-sections below key assumptions and results related to GDP and labour force projections (for 2020 and 2040) are presented along with comparisons of these projections with published data.

City-Specific Input-Output Calibration for 2010/2011

Statistics Canada's 2010 Provincial I-O structure was used as the starting point for creating city-specific I-O tables. The provincial structure was scaled to the city based on detailed labour force and income statistics available from Statistics Canada. This approach assumes that the same technology mix that exists at the provincial level applies to the city on average.

City-Specific Input-Output Calibration for 2020 and 2040

The historical provincial GDP trend by sector was used to calibrate future city-specific GDP by sector. The linear forward projection used in the current analysis was based on 2013 constant dollar historical Statcan data by sector for the period of 1997 to 2013 (CANSIM Table 379-0030).

City-specific labour force trends by sector were used to calibrate future labour force levels by sector. Future labour force levels were cross-checked with municipal planning documents and city projections of labour force. In both cities, the labour force projections used were somewhat more conservative than the projections used in the municipal planning documents. The municipal projections for the most recent available census year revealed that the municipal projections were higher than the actual level in that year. The linear forward projections used in the current analysis were based on historical Statcan data by sector for the period of 1987 to 2013 (CANSIM Table 282-0061).

Halifax Gross Domestic Product Projection

The calibration process resulted in the following key projections/assumptions for Halifax (details in Table 31 below):

- The total estimated GDP for Halifax is projected to increase 51% by 2040.
- The only sector-specific downward trend is in the arts, entertainment and recreation sector.

- The highest rate of change (101% by 2040) is in the administrative and support, waste management and remediation sector.
- The retail trade and construction sectors also have high projected growth rates of 76% and 72%, respectively.

Table 31: Halifax gross domestic product projection

Sector	Baseline GDP ($2013M)	2020 GDP ($2013M)	2040 GDP ($2013M)	% Change to 2020	% Change to 2040
Crop and animal production	30.4	34.7	42.1	14%	39%
Forestry and logging	5.7	6.5	7.9	14%	39%
Fishing, hunting and trapping	32.0	36.6	44.4	14%	39%
Support activities for agriculture and forestry	2.2	2.5	3.0	14%	39%
Mining, quarrying, and oil and gas extraction	424.7	476.1	466.4	12%	10%
Utilities	322.8	329.2	345.7	2%	7%
Residential construction	117.0	144.4	201.6	23%	72%
Non-residential building construction	58.5	72.2	100.8	23%	72%
Engineering construction	113.2	139.8	195.1	23%	72%
Repair construction	477.7	589.6	823.2	23%	72%
Other activities of the construction industry	205.4	253.5	353.9	23%	72%
Manufacturing	783.7	817.7	909.0	4%	16%
Wholesale trade	691.4	798.2	1,041.2	15%	51%
Retail trade	966.8	1,211.5	1,702.1	25%	76%
Transportation and warehousing	660.5	694.7	735.0	5%	11%
Information and cultural industries	928.5	1,117.4	1,489.8	20%	60%
Finance, insurance, real estate, rental and leasing and holding companies	3,884.0	4,606.1	6,193.0	19%	59%
Professional, scientific and technical services	1,297.7	1,580.6	2,182.5	22%	68%
Administrative and support, waste management and remediation services	463.4	631.5	932.9	36%	101%
Educational services	1,400.9	1,604.4	2,070.7	15%	48%
Health care and social assistance	2,204.6	2,632.8	3,582.3	19%	62%
Arts, entertainment and recreation	168.8	164.4	145.9	-3%	-14%
Accommodation and food services	357.7	391.8	445.9	10%	25%
Other services (except public administration)	379.9	450.8	575.8	19%	52%
Other federal government services	1,412.3	1,502.5	1,783.7	6%	26%
Other provincial and territorial government services	532.5	566.5	672.5	6%	26%
Other municipal government services	233.7	248.6	295.1	6%	26%
Other aboriginal government services	4.7	5.0	6.0	6%	26%
Total	18,160.5	21,109.8	27,347.4	16%	51%

Mississauga GDP Projection

The calibration process resulted in the following key projections/assumptions for Mississauga (details in Table 32 below):

- The total estimated GDP for Mississauga is projected to increase 57% by 2040.
- Downward trends are projected for the mining, quarrying and oil and gas extraction sector and the manufacturing sector.
- The highest rate of change (91% by 2040) is in the information and cultural industries sector.
- The administrative and support, waste management and remediation services sector and the retail trade sector also have high projected growth rates of 78% each.

Table 32: Mississauga gross domestic product projection

Sector	Baseline GDP ($2013M)	2020 GDP ($2013M)	2040 GDP ($2013M)	% Change to 2020	% Change to 2040
Crop and animal production	73.6	79.4	95.6	8%	30%
Forestry and logging	2.4	2.6	3.1	8%	30%
Fishing, hunting and trapping	1.3	1.4	1.6	8%	30%
Support activities for agriculture and forestry	2.1	2.3	2.8	8%	30%
Mining, quarrying, and oil and gas extraction	141.7	116.6	70.8	-18%	-50%
Utilities	326.8	367.5	464.3	12%	42%
Residential construction	374.7	457.4	637.9	22%	70%
Non-residential building construction	128.7	157.1	219.1	22%	70%
Engineering construction	151.2	184.5	257.3	22%	70%
Repair construction	701.4	856.1	1,194.0	22%	70%
Other activities of the construction industry	331.3	404.3	563.9	22%	70%
Manufacturing	3,713.7	3,427.0	2,349.3	-8%	-37%
Wholesale trade	2,704.7	3,346.1	4,785.6	24%	77%
Retail trade	1,964.3	2,469.9	3,493.4	26%	78%
Transportation and warehousing	1,702.2	1,978.2	2,555.3	16%	50%
Information and cultural industries	1,511.8	1,968.5	2,883.0	30%	91%
Finance, insurance, real estate, rental and leasing and holding companies	8,705.5	10,709.1	14,837.7	23%	70%
Professional, scientific and technical services	3,742.1	4,719.7	6,602.9	26%	76%
Administrative and support, waste management and remediation services	938.9	1,196.0	1,668.2	27%	78%
Educational services	1,634.3	1,946.5	2,653.4	19%	62%
Health care and social assistance	3,052.4	3,643.8	4,946.0	19%	62%
Arts, entertainment and recreation	189.7	220.3	270.4	16%	43%
Accommodation and food services	579.3	635.6	732.5	10%	26%
Other services (except public administration)	660.5	812.7	1,089.3	23%	65%
Other federal government services	241.4	283.5	387.6	17%	61%
Other provincial and territorial government services	277.7	326.2	446.0	17%	61%
Other municipal government services	636.2	747.1	1,021.6	17%	61%
Other aboriginal government services	-	-	-	0%	0%
Total	34,489.9	41,059.4	54,232.5	19%	57%

Halifax Labour Force Projection

The calibration process resulted in the following key projections/assumptions for Halifax (details in Table 33 below):

- The total labour force is expected to increase by approximately 22% by 2040.
- Labour force declines are expected in the utilities, manufacturing and public administration sectors.
- The largest percent increase is projected in the business, building and other support services sector (~58%).

Table 33: Halifax labour force projection by sector

Sector	Baseline	2020	2040	% Change to 2020	% Change to 2040
Agriculture [111-112 1100 1151-1152]	410	411	409	0.3%	-0.2%
Forestry, fishing, mining, quarrying, oil and gas [21 113-114 1153 2100]	1,735	2,746	2,348	58.3%	35.3%
Utilities [22]	1,330	959	1,259	-27.9%	-5.4%
Construction [23]	13,210	14,387	17,455	8.9%	32.1%
Manufacturing [31-33]	10,285	9,769	10,139	-5.0%	-1.4%
Trade [41 44-45]	34,260	35,350	40,192	3.2%	17.3%
Transportation and warehousing [48-49]	9,620	10,308	11,246	7.2%	16.9%
Finance, insurance, real estate and leasing [52-53]	14,500	14,893	16,391	2.7%	13.0%
Professional, scientific and technical services [54]	15,635	20,577	22,888	31.6%	46.4%
Business, building and other support services [55-56]	11,725	18,684	18,477	59.3%	57.6%
Educational services [61]	18,365	20,161	23,855	9.8%	29.9%
Health care and social assistance [62]	26,410	30,177	35,370	14.3%	33.9%
Information, culture and recreation [51 71]	6,450	7,308	8,355	13.3%	29.5%
Accommodation and food services [72]	15,165	17,799	20,254	17.4%	33.6%
Other services [81]	13,700	17,106	18,157	24.9%	32.5%
Public administration [91]	28,390	24,415	22,574	-14.0%	-20.5%
Total	221,190	245,048	269,368	10.8%	21.8%

Mississauga Labour Force Projection

The calibration process resulted in the following key projections/assumptions for Mississauga (details in Table 34 below):

- The total labour force is expected to increase by approximately 45% by 2040.
- Labour force declines are expected in the agriculture, mining, quarrying, oil and gas extraction, utilities and manufacturing sectors.
- The largest percent increase is projected in the business, building and other support services sector (~81%).

Table 34: Mississauga labour force projection by sector

Sector	Baseline	2020	2040	% Change to 2020	% Change to 2040
Agriculture [111-112 1100 1151-1152]	800	807	791	0.9%	-1.1%
Forestry, fishing, mining, quarrying, oil and gas [21 113-114 1153 2100]	875	716	693	-18.2%	-20.8%
Utilities [22]	2,070	1,787	1,593	-13.7%	-23.0%
Construction [23]	20,580	23,059	30,451	12.0%	48.0%
Manufacturing [31-33]	44,595	48,895	44,315	9.6%	-0.6%
Trade [41 44-45]	71,325	85,698	108,310	20.2%	51.9%
Transportation and warehousing [48-49]	26,380	29,573	38,595	12.1%	46.3%
Finance, insurance, real estate and leasing [52-53]	38,410	42,282	54,327	10.1%	41.4%
Professional, scientific and technical services [54]	37,155	44,437	63,055	19.6%	69.7%
Business, building and other support services [55-56]	20,460	26,268	36,933	28.4%	80.5%
Educational services [61]	22,565	26,806	36,085	18.8%	59.9%
Health care and social assistance [62]	29,800	33,193	44,899	11.4%	50.7%
Information, culture and recreation [51 71]	11,340	11,711	15,509	3.3%	36.8%
Accommodation and food services [72]	21,140	25,561	33,493	20.9%	58.4%
Other services [81]	20,625	25,078	31,605	21.6%	53.2%
Public administration [91]	15,040	13,719	15,462	-8.8%	2.8%
Total	**383,160**	**439,588**	**556,117**	14.7%	45.1%

Comparison of Labour Force Projections

In this section the projected labour force numbers used in this analysis are compared with those available in the literature to give a sense of the relative uncertainty (or lack thereof) in the projections.

Halifax

The Halifax Regional Municipal Planning Strategy[205] contains total labour force forecasts for 2011, 2016, 2021, 2026 and 2031. No sector specific details were included. The actual labour force level reported for Halifax in 2011 was below the municipal forecast. The sector-specific projections for 2020 and 2040 used in this analysis provide a somewhat more conservative estimate of total labour force growth.

[205] Halifax Regional Municipal Planning Strategy October 2014. http://www.halifax.ca/regionalplanning/FinalRegPlan.php#RMPS2014

Table 35: Halifax labour force projection comparison

Year	Municipal Forecast	Sector-specific projection
2011	246,085	221,190 (actual)
2016	260,152	
2020		245,048
2021	272,086	
2026	282,286	
2031	291,118	
2040		269,368

Mississauga

The Mississauga planning document[206] contains total employment forecasts for 2011, 2021 and 2031. No sector specific details were included. The actual labour force level reported by Statcan for the year 2011 was 383,160 compared to the municipal forecast of 455,000. Otherwise, the total labour force based on sector-specific trends were reasonably in line with the municipal projection, with the expectation that the Mississauga labour force will exceed 500,000 by the year 2031.

Table 36: Mississauga labour force projection comparison

Year	Municipal Forecast	Sector-specific projection
2011	455,000	383,160 (actual)
2020		439,588
2021	500,000	
2031	510,000	
2040		556,117

From Direct Impacts to Secondary Impacts

Example: Secondary impacts on assets: building structure and content

The following tables (Tables 37 and 38) document an example of translating the direct expected annual damage (EAD) from storm surge flooding on structure and contents to the direct GDP impact using the basic I-O Type II direct GDP multiplier (multiplied by the direct impact on gross output). In this case the sectors that are shocked are residential construction, non-residential construction[207] (for structure impacts), and the retail and wholesale trade sectors for contents (i.e. retail trade for residential contents and wholesale trade for non-residential contents)

[206] Mississauga Official Plan March 14, 2013, Chapter 5 – Direct Growth. http://www.mississauga.ca/portal/residents/mississaugaofficialplan
[207] Non-residential includes commercial, industrial, and institutional.

Table 37: Example of secondary impact derivation for asset damage - Direct Impact

structure or content	sector type	Direct Impact on Gross Output ($2013)	Direct GDP multiplier	Direct GDP Impact ($2013)
structure	Residential	$111,551	0.320	$35,702
structure	Commercial	$414,778	0.352	$146,070
structure	Industrial	$36,748	0.352	$12,941
structure	Institutional	$603	0.352	$212
content	Residential	$69,846	0.653	$45,580
content	Commercial	$896,399	0.654	$586,148
content	Industrial	$96,935	0.654	$63,385
content	Institutional	$13,828	0.654	$9,042

After estimating the direct GDP impacts, the direct + secondary GDP multiplier is applied to the direct impact on gross output to derive the sum of direct and secondary GDP impacts (see Table 38 below). The secondary GDP impacts can then be isolated by subtracting the direct GDP impact identified in Table 37 above from the sum of direct and secondary GDP impacts identified in Table 38 below.

Table 38: Example of secondary impact derivation for asset damage - Secondary Impacts

Structure or content	Sector type	Direct Impact on Gross Output ($2013)	Direct+ Secondary GDP Multiplier	Sum of direct and secondary GDP impacts ($2013)	Secondary GDP Impacts Only ($2013)
structure	Residential	$111,551	0.656	$73,144	$37,442
structure	Commercial	$414,778	0.716	$297,029	$150,959
structure	Industrial	$36,748	0.716	$26,316	$13,374
structure	Institutional	$603	0.716	$432	$219
content	Residential	$69,846	1.038	$72,483	$26,904
content	Commercial	$896,399	0.991	$888,043	$301,895
content	Industrial	$96,935	0.991	$96,032	$32,646
content	Institutional	$13,828	0.991	$13,699	$4,657

Example: Secondary impacts on business interruption

The following tables (Tables 39 and 40) provide an example of the derivation of secondary impacts from the multiplier analysis for business interruption related to power outages caused by extreme wind. Business interruption impacts all sectors of the economy, and therefore, the direct impact is multiplied using the multiplier specific to each corresponding sector. Table 39 below summarizes the direct impact on gross output from business interruption in 2020 under the baseline climate change scenario.

Table 39: Example secondary impact derivation for business interruption - Direct Impact

I-O Sector code	Sector Name	Direct impact (Gross Output)
BS11A	Crop and animal production	$1,911
BS115	Support activities for agriculture and forestry	$34
BS210	Mining, quarrying, and oil and gas extraction	$51,403
BS220	Utilities	$21,845
BS23A	Residential construction	$6,233
BS23B	Non-residential building construction	$2,832
BS23C	Engineering construction	$4,658
BS23D	Repair construction	$20,750
BS23E	Other activities of the construction industry	$8,093
BS3A0	Manufacturing	$106,202
BS410	Wholesale trade	$35,112
BS4A0	Retail trade	$23,509
BS4B0	Transportation and warehousing	$54,046
BS510	Information and cultural industries	$28,539
BS5B0	Finance, insurance, real estate, rental and leasing and holding companies	$85,663
BS540	Professional, scientific and technical services	$36,970
BS560	Administrative and support, waste management and remediation services	$19,926
BS610	Educational services	$32,005
BS620	Health care and social assistance	$52,727
BS710	Arts, entertainment and recreation	$5,784
BS720	Accommodation and food services	$36,853
BS810	Other services (except public administration)	$9,198
GS911	Other federal government services	$23,610
GS912	Other provincial and territorial government services	$14,611
GS913	Other municipal government services	$4,989
GS914	Other aboriginal government services	$81

The direct impacts on output are then multiplied by the sector-specific direct GDP multiplier and the sum of direct + secondary GDP multiplier to derive the direct and summed impact on GDP (see Table 40 below). Finally, the direct GDP impact is subtracted from the summed impact to isolate the secondary GDP impacts.

Table 40: Example secondary impact derivation for business interruption – Secondary Impact

I-O Sector code	Sector Name	Direct GDP multiplier	Sum of direct + secondary GDP multiplier	Sum of direct + secondary GDP impact ($2013)	Direct GDP Impact ($2013)	Secondary GDP Impact ($2013)
BS11A	Crop and animal production	0.397	0.751	$1,436	$759	$677
BS115	Support activities for agriculture and forestry	0.350	0.654	$22	$12	$10
BS210	Mining, quarrying, and oil and gas extraction	0.623	0.863	$44,364	$32,042	$12,322
BS220	Utilities	0.517	0.730	$15,945	$11,301	$4,644
BS23A	Residential construction	0.320	0.656	$4,087	$1,995	$2,092
BS23B	Non-residential building construction	0.352	0.716	$2,028	$997	$1,031
BS23C	Engineering construction	0.415	0.760	$3,541	$1,931	$1,611
BS23D	Repair construction	0.393	0.702	$14,566	$8,145	$6,421
BS23E	Other activities of the construction industry	0.495	0.695	$5,622	$4,010	$1,612
BS3A0	Manufacturing	0.280	0.501	$53,214	$29,746	$23,468
BS410	Wholesale trade	0.654	0.991	$34,785	$22,959	$11,825
BS4A0	Retail trade	0.653	1.038	$24,397	$15,341	$9,055
BS4B0	Transportation and warehousing	0.469	0.765	$41,325	$25,349	$15,976
BS510	Information and cultural industries	0.650	0.870	$24,837	$18,550	$6,286
BS5B0	Finance, insurance, real estate, rental and leasing and holding companies	0.540	0.883	$75,679	$46,250	$29,429
BS540	Professional, scientific and technical services	0.666	1.016	$37,571	$24,613	$12,958
BS560	Administrative and support, waste management and remediation services	0.653	1.031	$20,543	$13,017	$7,526
BS610	Educational services	0.682	1.003	$32,100	$21,839	$10,262
BS620	Health care and social assistance	0.643	0.995	$52,461	$33,909	$18,552
BS710	Arts, entertainment and recreation	0.428	0.862	$4,985	$2,477	$2,508
BS720	Accommodation and food services	0.459	0.834	$30,742	$16,918	$13,823
BS810	Other services (except public administration)	0.639	0.982	$9,028	$5,873	$3,155
GS911	Other federal government services	0.670	1.014	$23,933	$15,824	$8,109
GS912	Other provincial and territorial government services	0.435	1.005	$14,678	$6,362	$8,315
GS913	Other municipal government services	0.568	0.975	$4,865	$2,834	$2,031
GS914	Other aboriginal government services	0.686	1.092	$89	$56	$33

Appendix D. Employment Impact Results

Appendix D presents further results surrounding employment impacts in the units of fulltime equivalents. In the graphs denoted as expected annual damage (EAD), the impacts can be seen as the number of fulltime jobs impacted annually. In the graphs depicting cumulative EAD, the impacts can be seen as the cumulative number of fulltime jobs lasting one year that are lost over a specific time period relative to the baseline year and that is attributed to climate change. In the graphs for specific events (i.e. either a 1 in 25 or 1 in 100 year event) the impacts can be viewed as the total number of fulltime jobs lasting for the duration of a year that are impacted due to a specific event. For each community and climate-related event, there are four graphs: 1. Direct and secondary EAD in terms of type II labour impact; 2. Cumulative direct and secondary EAD attributed to climate change in terms of type II labour impact; 3. 1 in 25 year event direct and secondary impact in terms of type II labour; and, 4. 1 in 100 year event direct and secondary impact in terms of type II labour.

Halifax Flooding

Direct and Secondary EAD, Labour Impact (full-time equivalents)

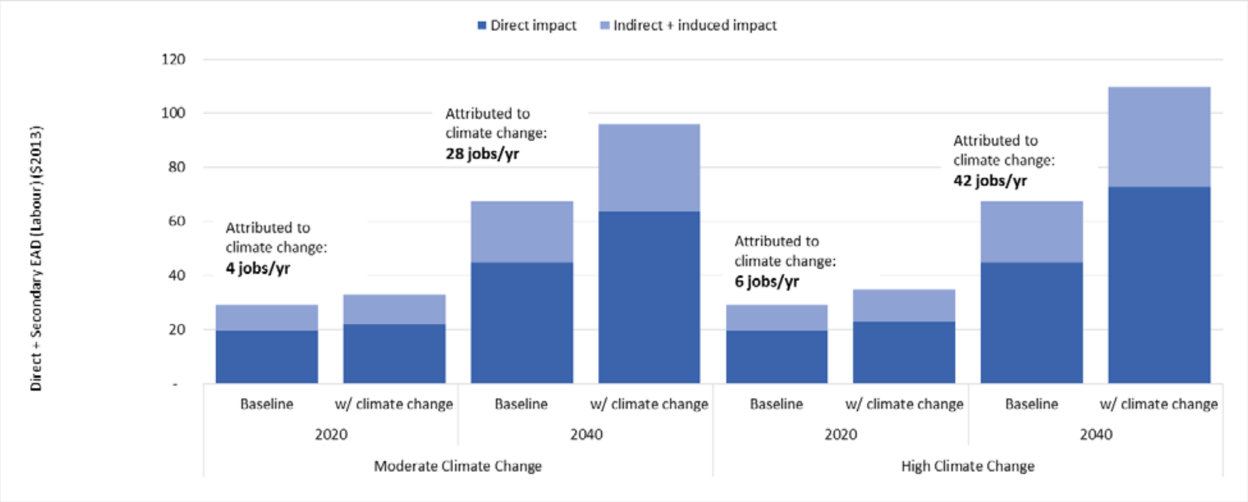

Figure 46: Direct and secondary expected annual damage (in terms of employment, basic type II multipliers) due to storm surge flooding in the Halifax Regional Municipality

Cumulative EAD, Labour Impact (full-time equivalents)

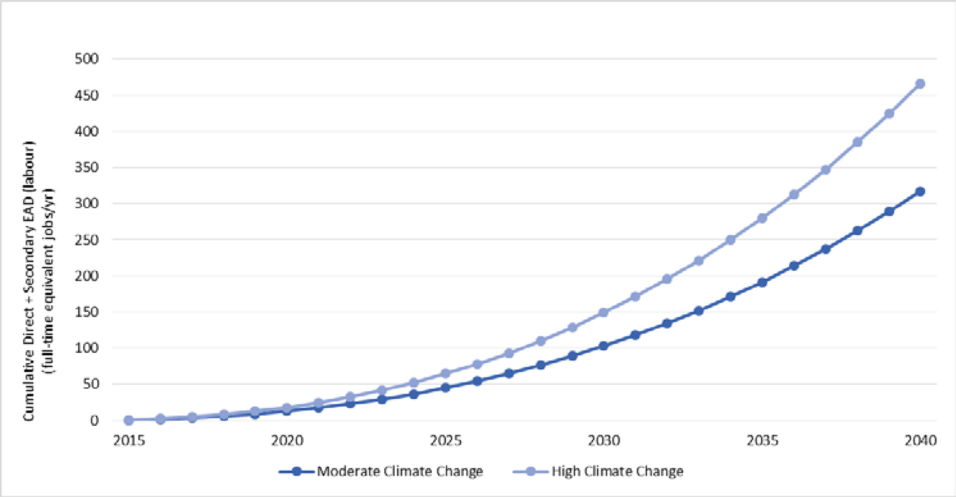

Figure 47: Cumulative direct and secondary expected annual damages due to storm surge flooding (in terms of employment, basic type II multipliers) attributed to climate change in the Halifax Regional Municipality

Labour Impact due to a 1-in-25 Year Return

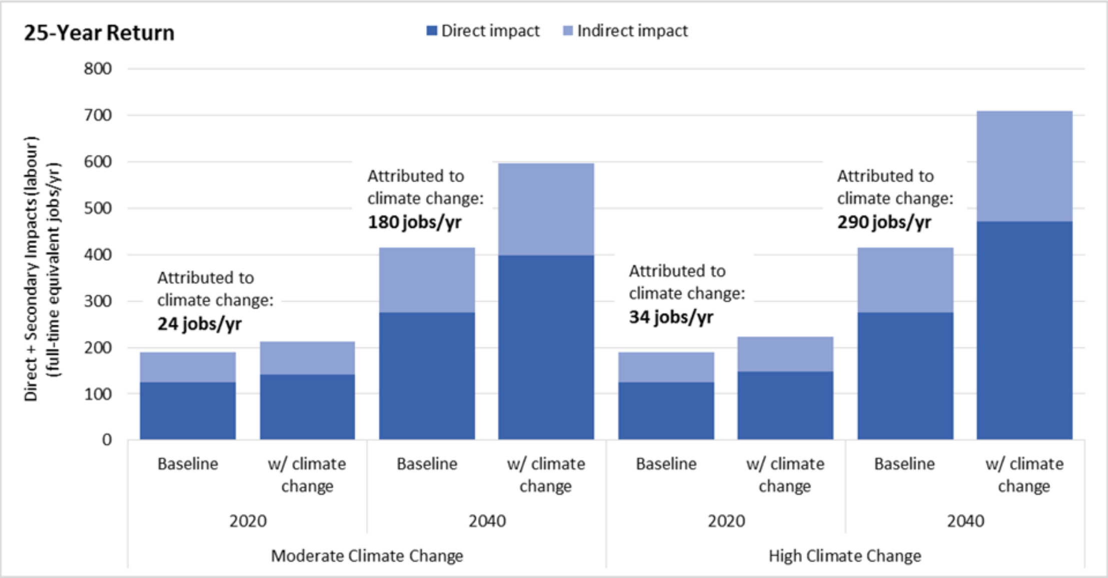

Figure 48: Direct and secondary impacts (in terms of employment, basic type II multipliers) due to a 1 in 25 year storm surge flooding event in the Halifax Regional Municipality

Labour Impact due to a 1-in-100 Year Return

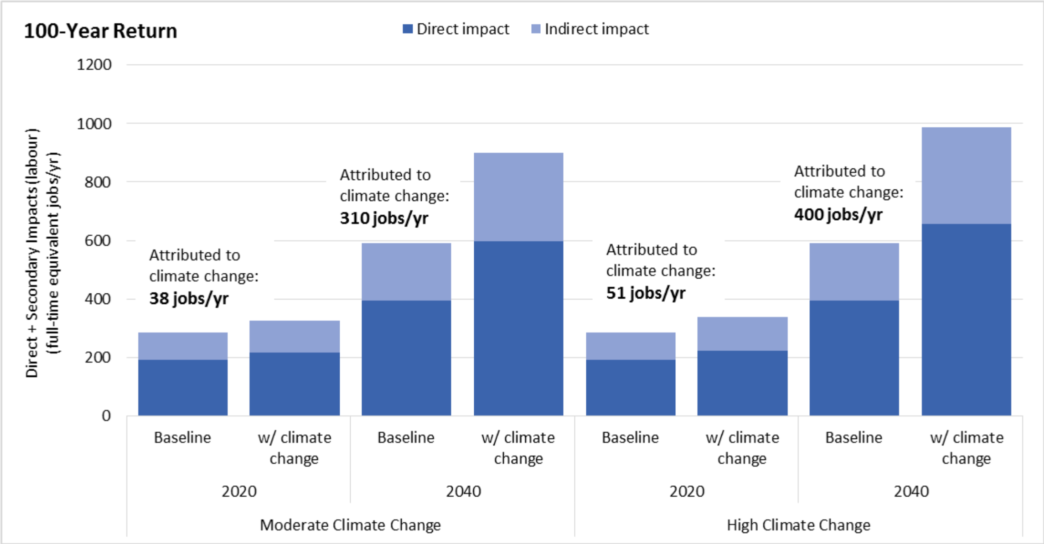

Figure 49: Direct and secondary impacts (in terms of employment, basic type II multipliers) due to a 1 in 100 year storm surge flooding event in the Halifax Regional Municipality

Halifax Extreme Wind

Direct and Secondary EAD, Labour Impact (full-time equivalents)

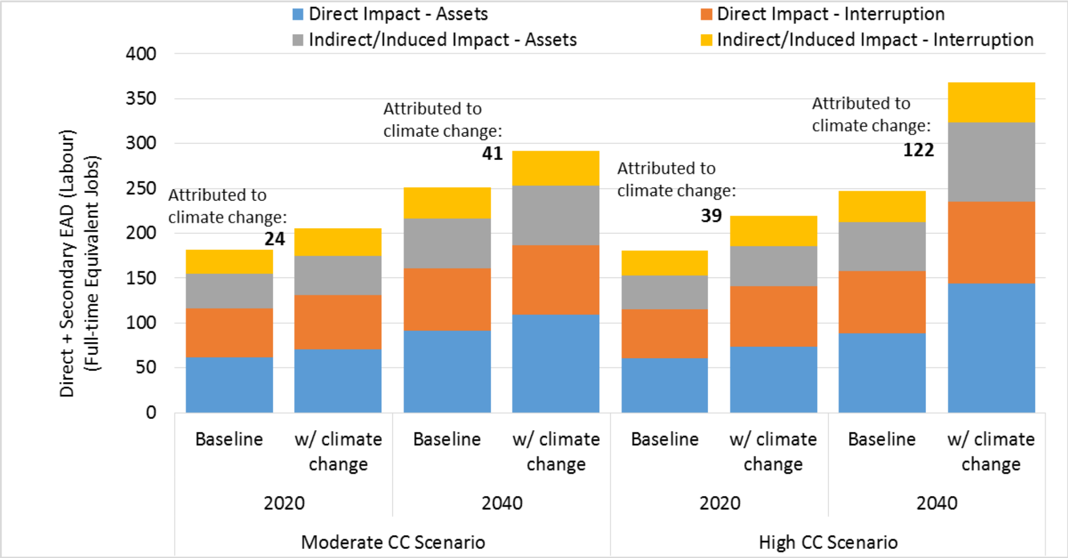

Figure 50: Direct + secondary expected annual damage (in terms of employment, basic type II multipliers) due to extreme wind in the Halifax Regional Municipality

Cumulative EAD, Labour Impact (full-time equivalents)

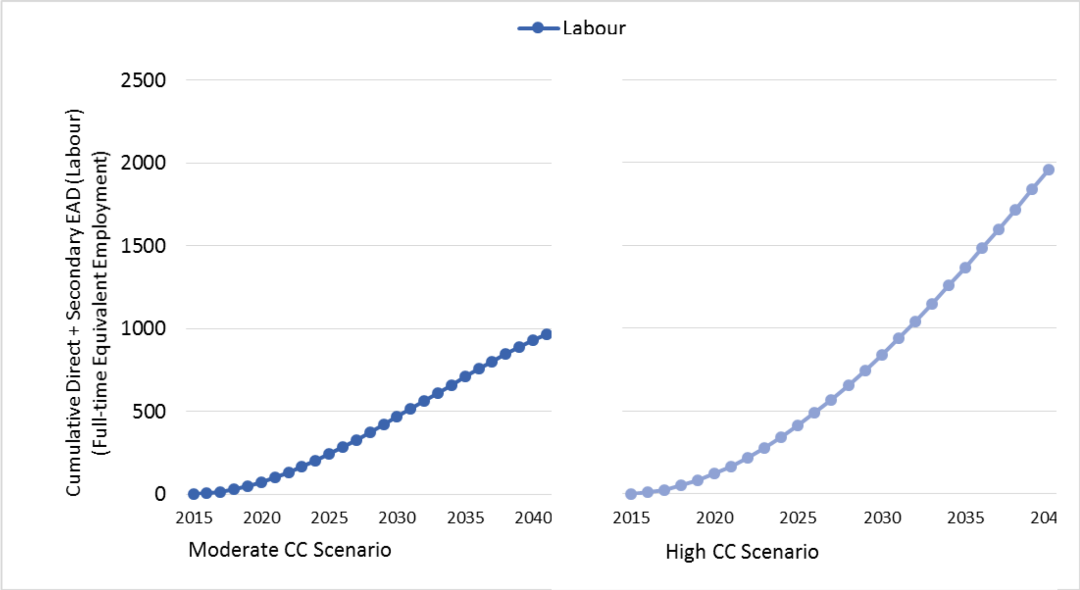

Figure 51: **Cumulative direct and secondary expected annual damages (in terms of employment, basic type II multipliers) due to extreme wind attributed to climate change in the Halifax Regional Municipality**

Labour Impact due to a 1-in-25 Year Return

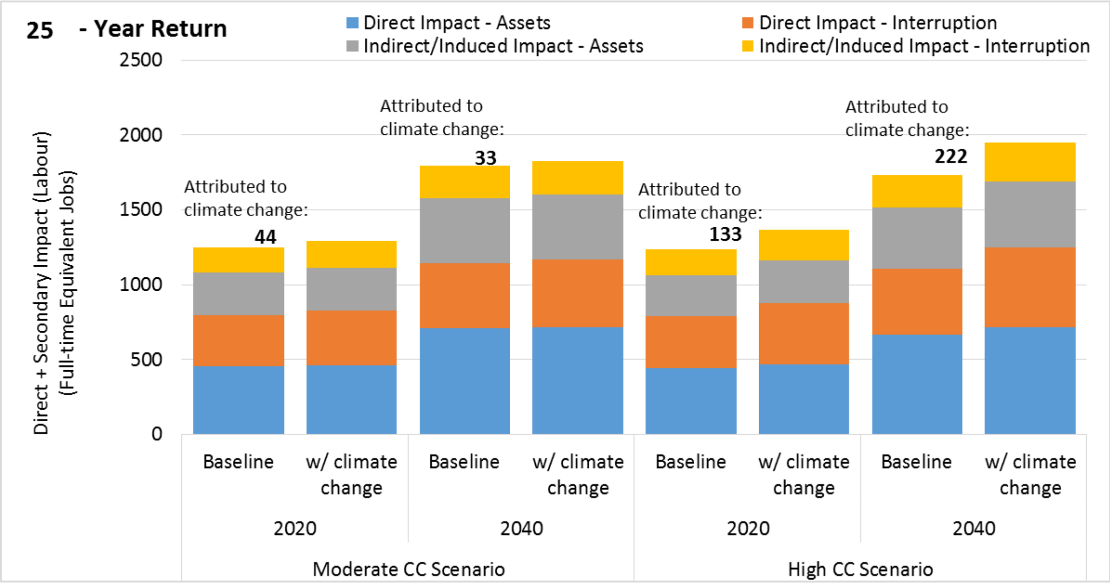

Figure 52: **Direct and secondary, asset and interruption impacts (in terms of employment, basic type II multipliers) due to a 1 in 25 year extreme wind event in the Halifax Regional Municipality**

Labour Impact due to a 1-in-100 Year Return

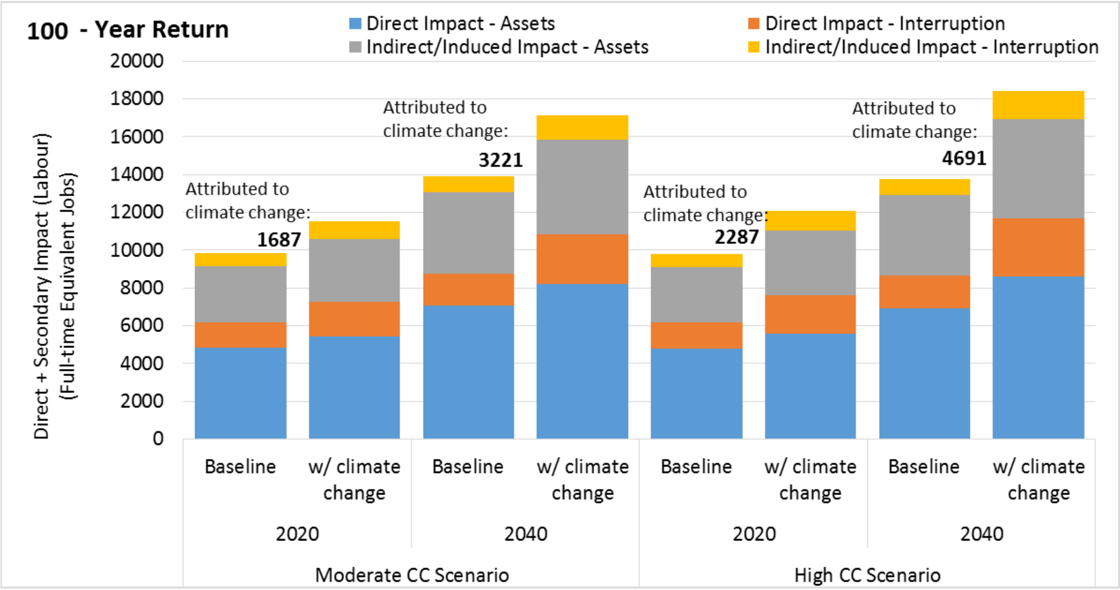

Figure 53: **Direct and secondary, asset and interruption impacts (in terms of employment, basic type II multipliers) due to a 1 in 100 year extreme wind event in the Halifax Regional Municipality**

Mississauga Freezing Rain

Direct and Secondary EAD, Labour Impact (full-time equivalents)

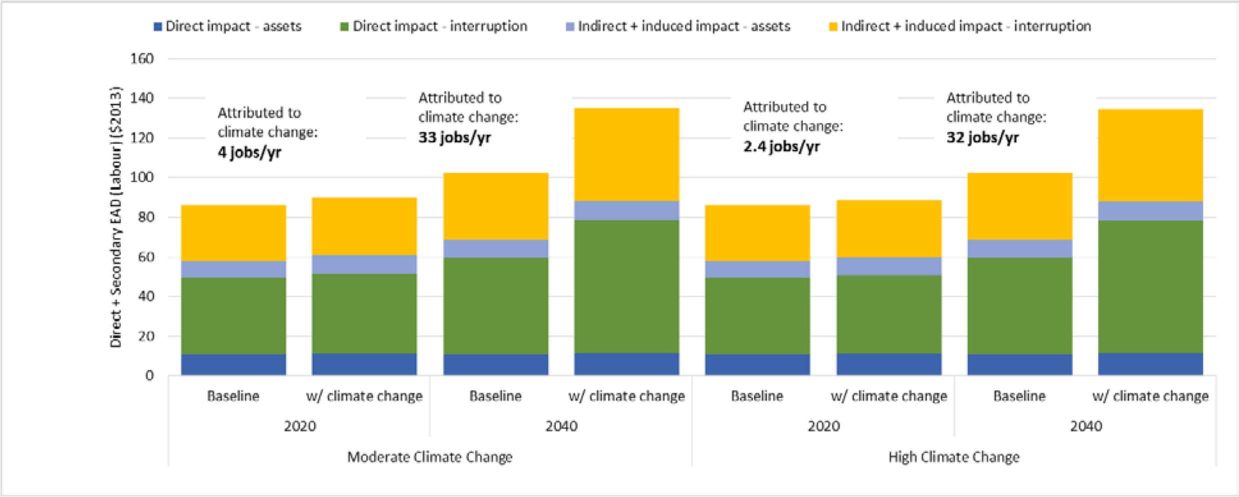

Figure 54: **Direct and secondary expected annual damage (in terms of employment, basic type II multipliers) due to freezing rain in Mississauga**

Cumulative EAD, Labour Impact (full-time equivalents)

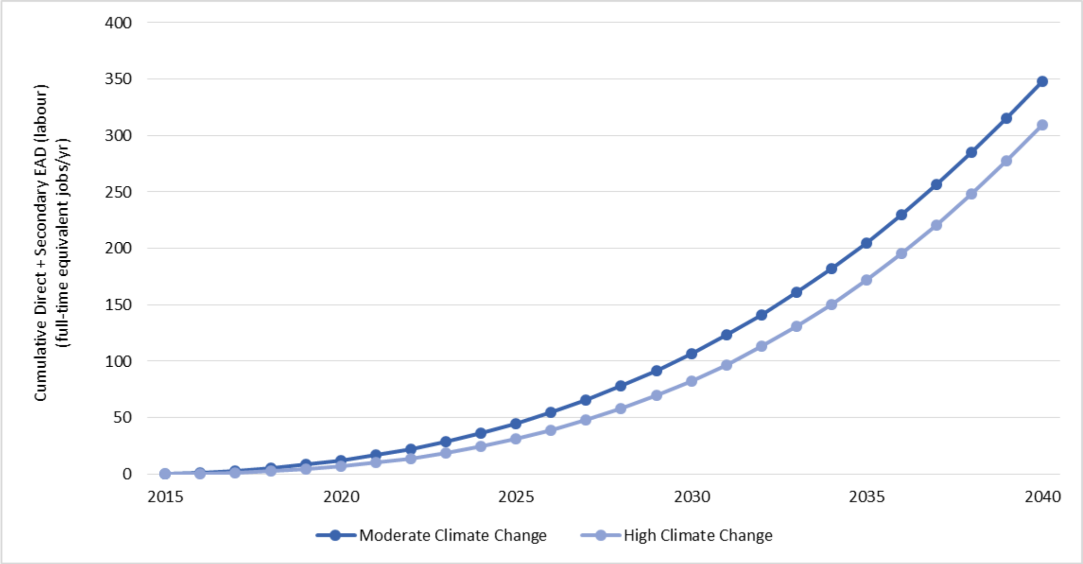

Figure 55: **Cumulative direct and secondary expected annual damages (in terms of employment, basic type II multipliers) due to freezing rain attributed to climate change in Mississauga**

Labour Impact due to a 1-in-25 Year Return

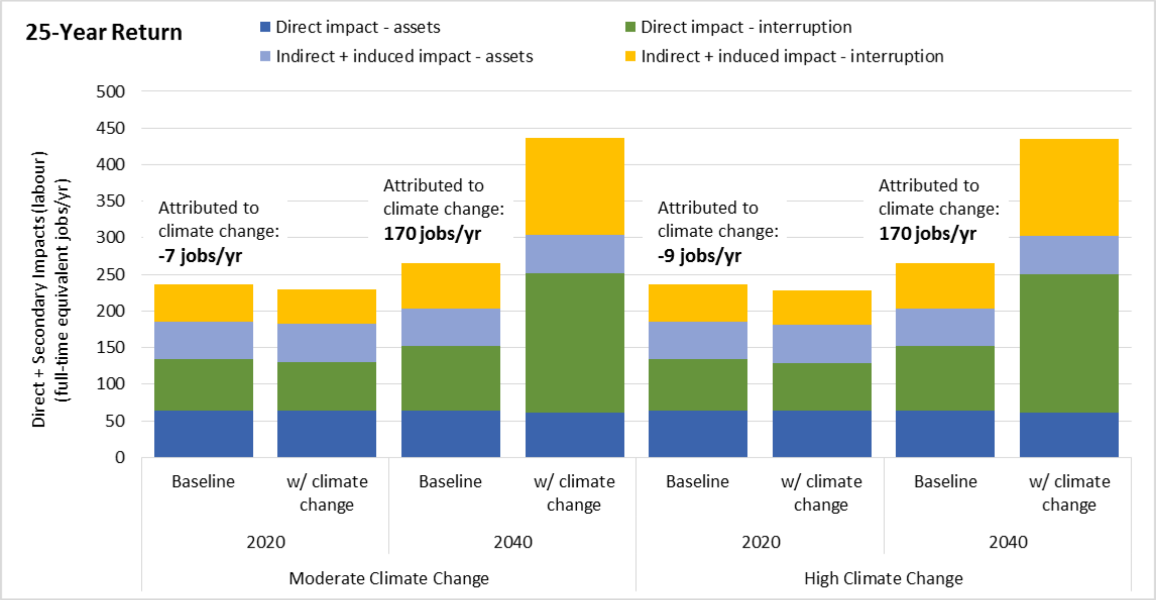

Figure 56: **Direct and secondary, asset and interruption impacts (in terms of employment, basic type II multipliers) due to a 1 in 25 year freezing rain event in Mississauga**

Labour Impact due to a 1-in-100 Year Return

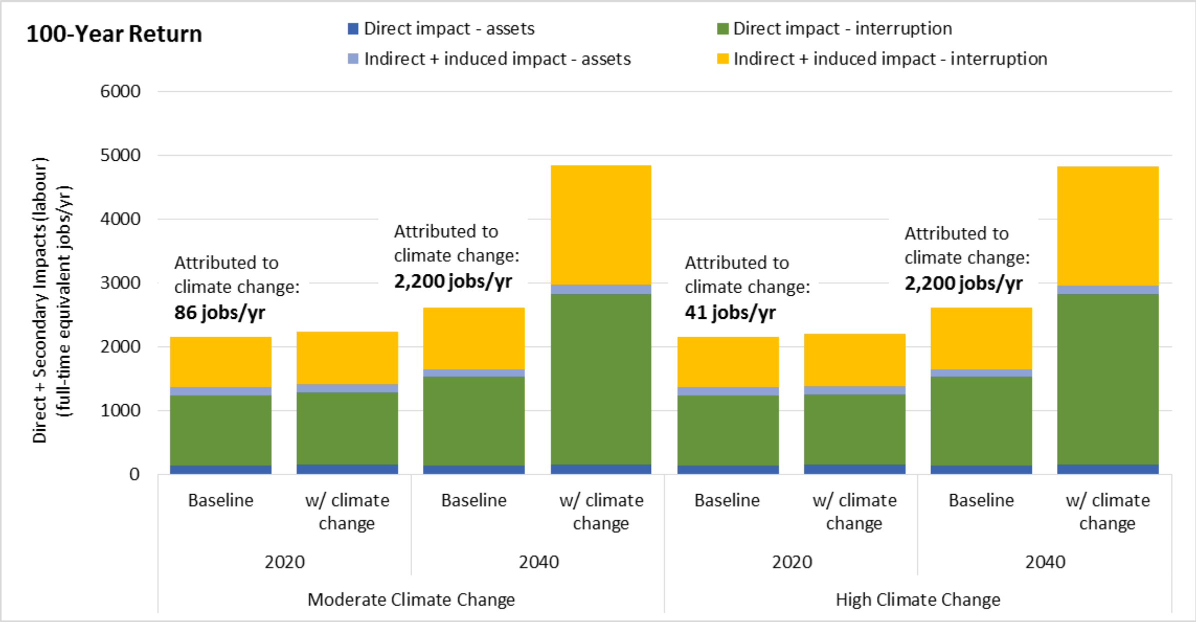

Figure 57: Direct and secondary, asset and interruption impacts (in terms of employment, basic type II multipliers) due to a 1 in 100 year freezing rain event in Mississauga

Mississauga Storm Water Flooding

Direct and Secondary EAD, Labour Impact (full-time equivalents)

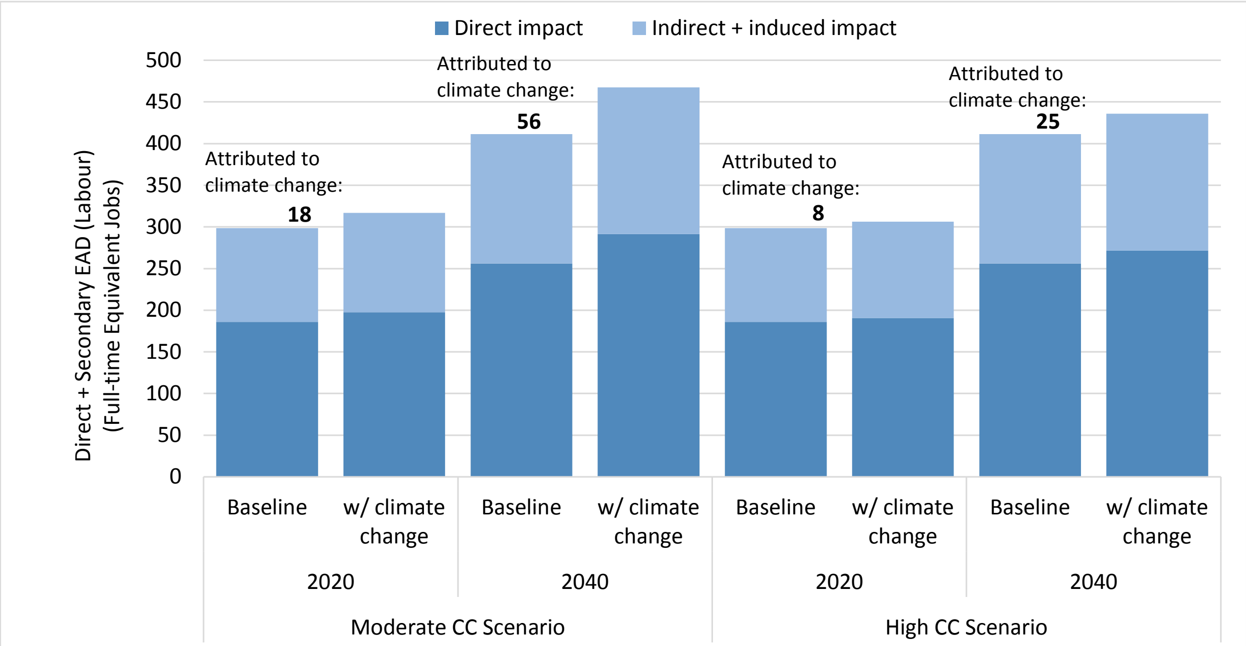

Figure 58: Direct and secondary expected annual damage (in terms of employment, basic type II multipliers) due to storm water flooding in Mississauga

Cumulative EAD, Labour Impact (full-time equivalents)

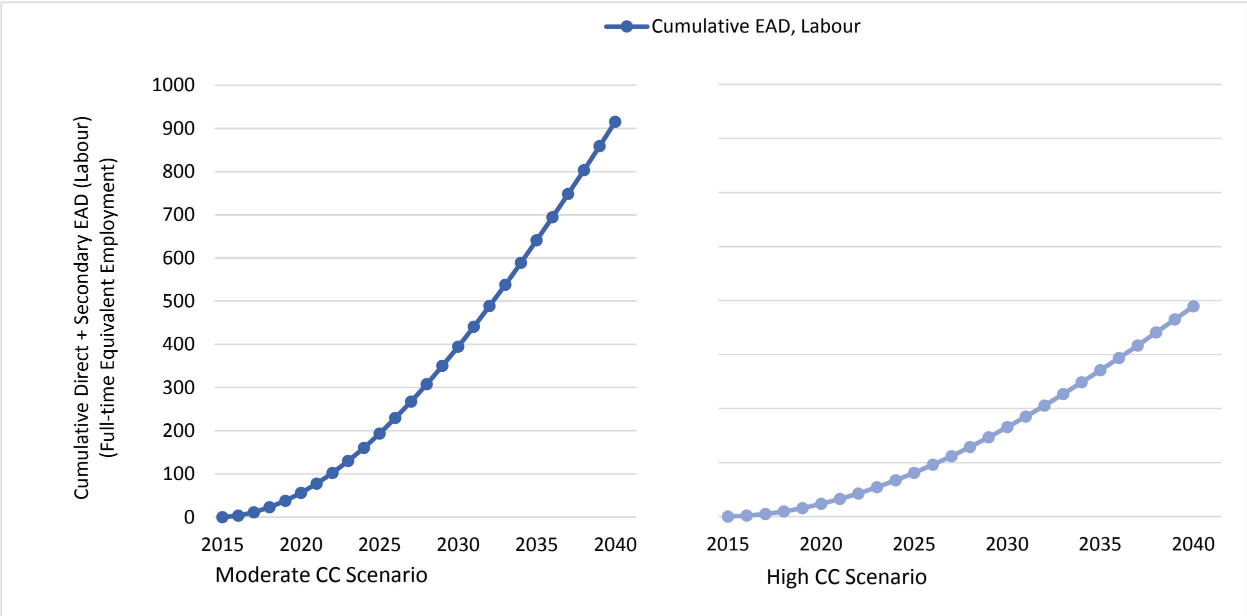

Figure 59: **Cumulative direct and secondary expected annual damage (in terms of employment, basic type II multipliers) due to storm water flooding attributed to climate change in Mississauga**

Labour Impact due to a 1-in-25 Year Return

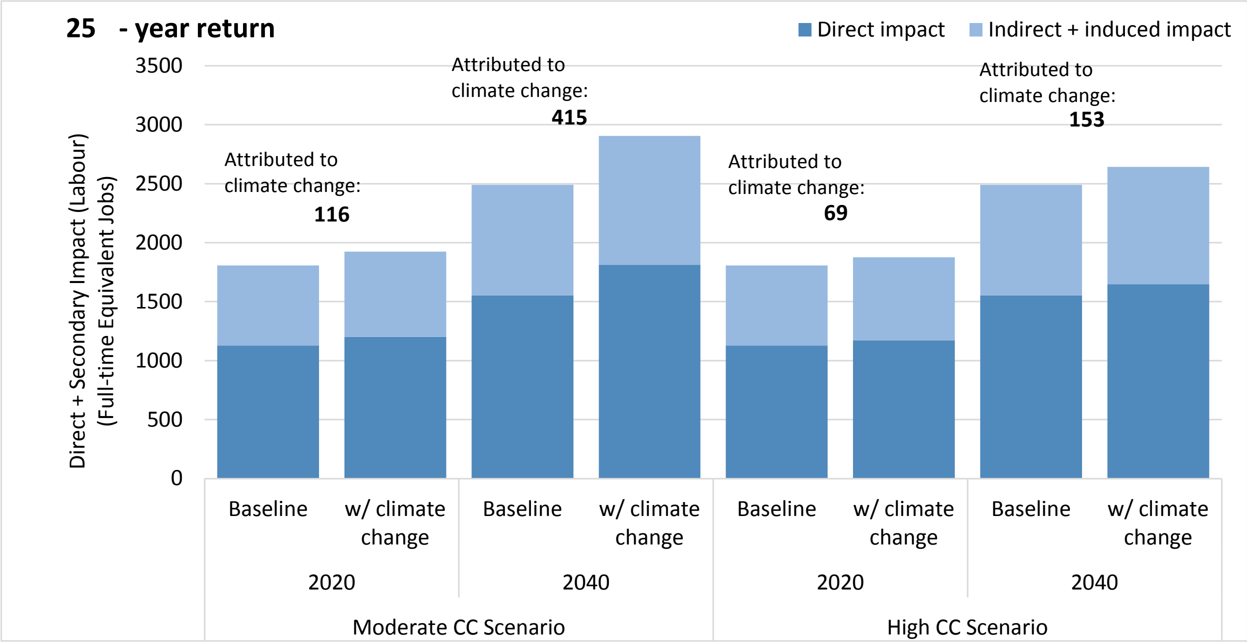

Figure 60: **Direct and secondary, asset and interruption impacts (in terms of employment, basic type II multipliers) due to a 1 in 25 year storm water flood event in Mississauga**

Labour Impact due to a 1-in-100 Year Return

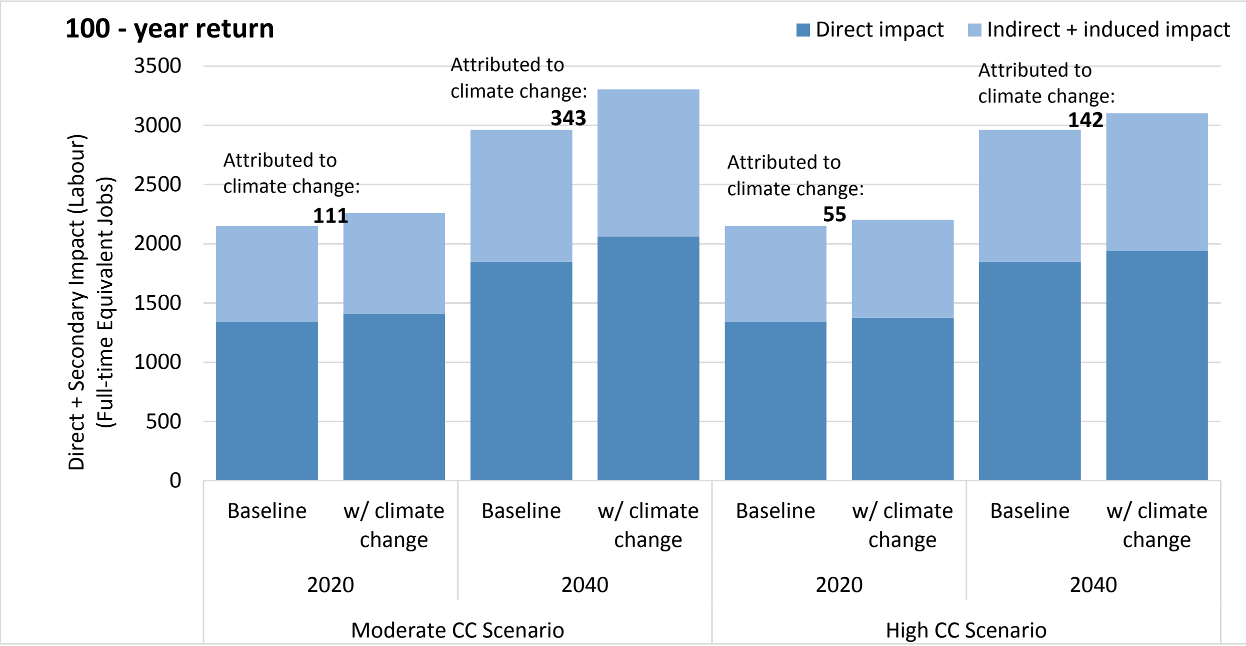

Figure 61: **Direct and secondary, asset and interruption impacts (in terms of employment, basic type II multipliers) due to a 1 in 100 year storm water flood event in Mississauga**

Appendix E. Gross Output Impact Results

Appendix E presents further results figures surrounding gross output impacts. In the graphs denoted as expected annual damage (EAD), the impacts can be seen as the monetary gross output impacted annually. In the graphs depicting cumulative EAD, the impacts can be seen as the cumulative monetary gross output that is impacted over a specific time period relative to the baseline year and that is attributed to climate change. In the graphs for specific events (i.e. either a 1 in 25 or 1 in 100 year event) the impacts can be viewed as the monetary gross output that is impacted due to a specific event. For each community and climate-related event, there are three graphs: 1. Direct and secondary EAD in terms of type II monetary gross output impact; 2. 1 in 25 year event direct and secondary impact in terms of type II monetary gross output; and, 3. 1 in 100 year event direct and secondary impact in terms of type II monetary gross output.

Halifax Flooding

Direct and Secondary EAD, Gross Output

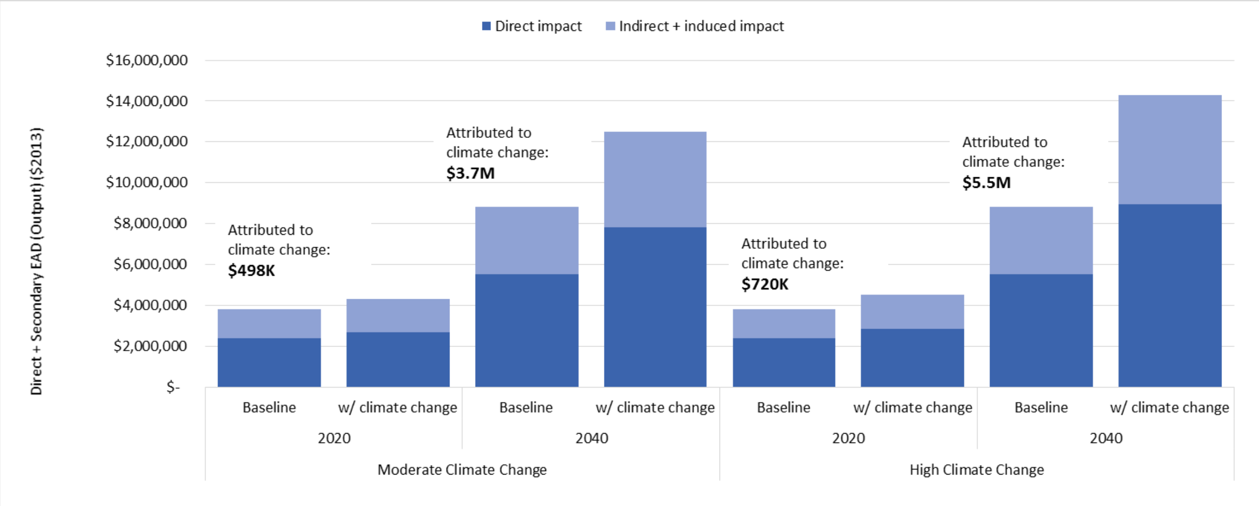

Figure 62: Direct and secondary expected annual damage (in terms of gross output, basic type II multipliers) due to storm surge flooding in the Halifax Regional Municipality

Gross Output Impact due to a 1-in-25 Year Return

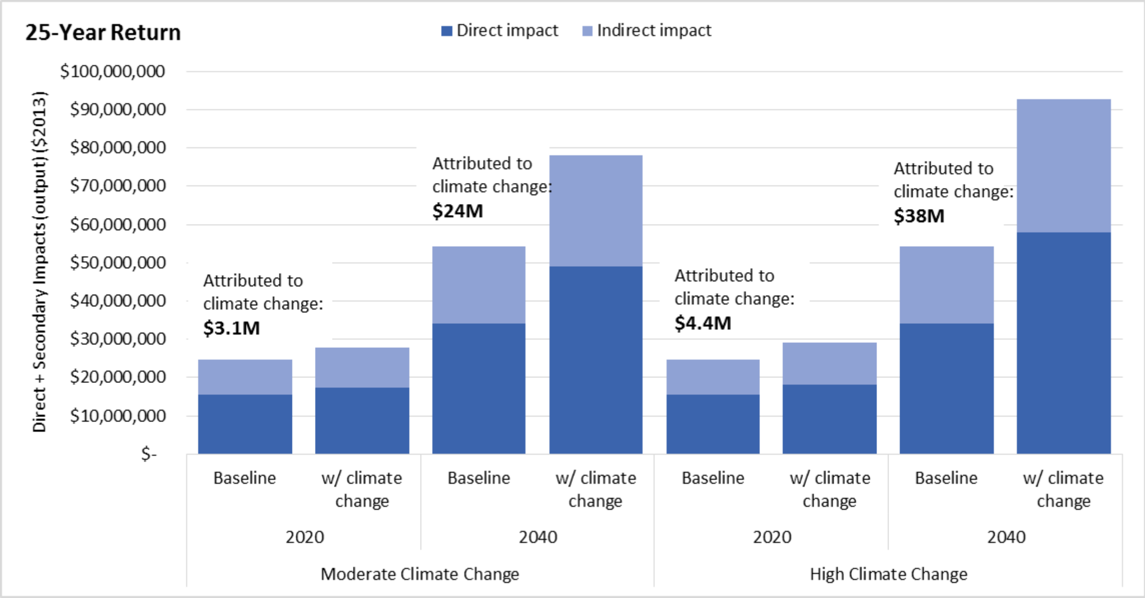

Figure 63: Direct and secondary impacts (in terms of gross output, basic type II multipliers) due to a 1 in 25 year flooding event in the Halifax Regional Municipality

Gross Output Impact due to a 1-in-100 Year Return

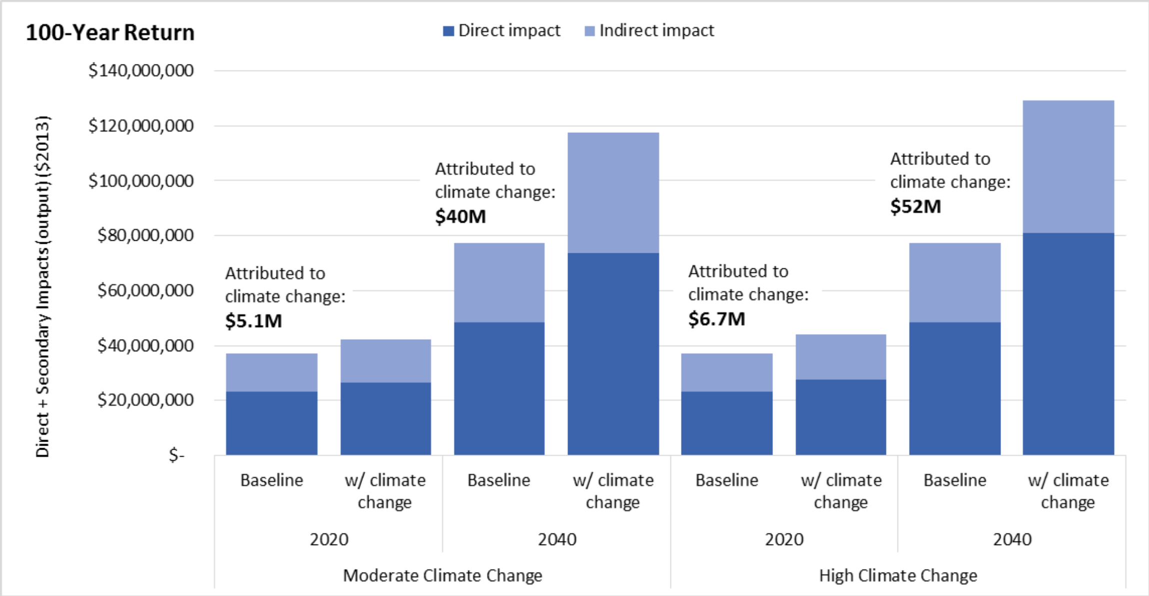

Figure 64: Direct and secondary impacts (in terms of gross output, basic type II multipliers) due to a 1 in 100 year flooding event in the Halifax Regional Municipality

Halifax Extreme Wind

Direct and Secondary EAD, Gross Output

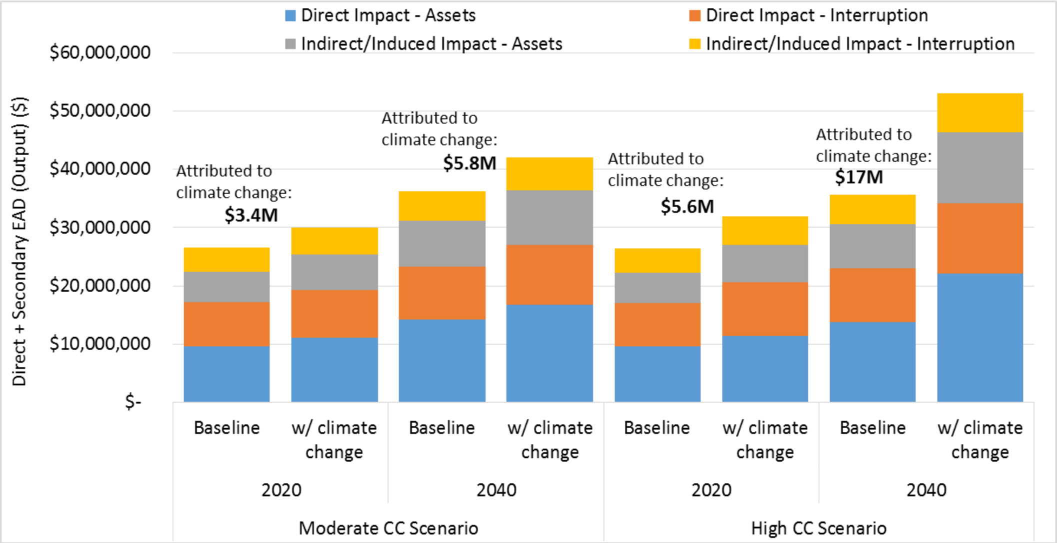

Figure 65: **Direct and secondary expected annual damage (in terms of gross output, basic type II multipliers) due to extreme wind in the Halifax Regional Municipality**

Gross Output Impact due to a 1-in-25 Year Return

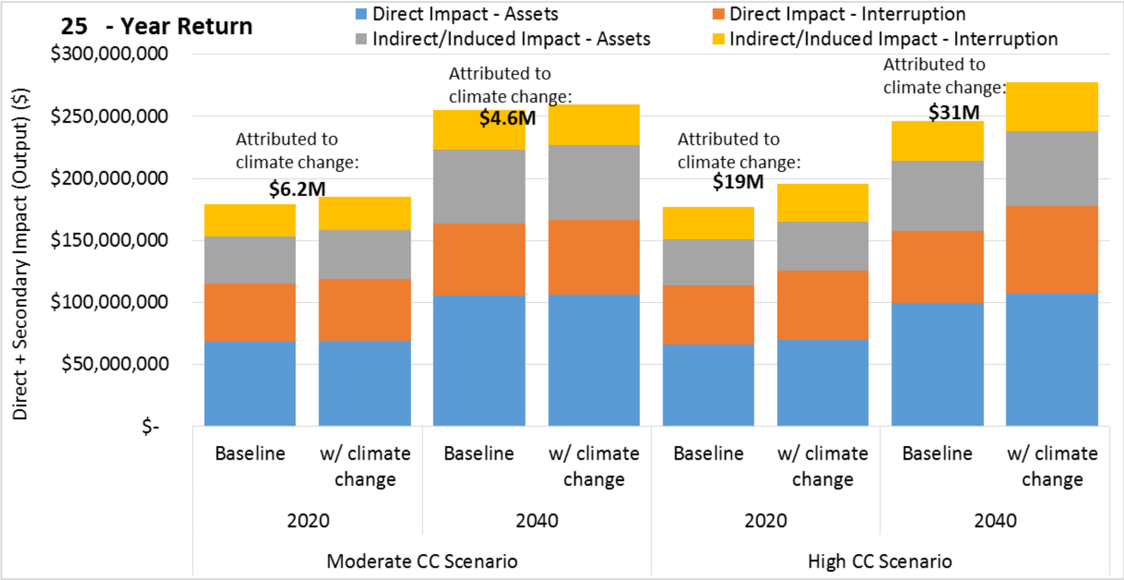

Figure 66: **Direct and secondary, asset and interruption impacts (in terms of gross output, basic type II multipliers) of a 1 in 25 year extreme wind event in the Halifax Regional Municipality**

Gross Output Impact due to a 1-in-100 Year Return

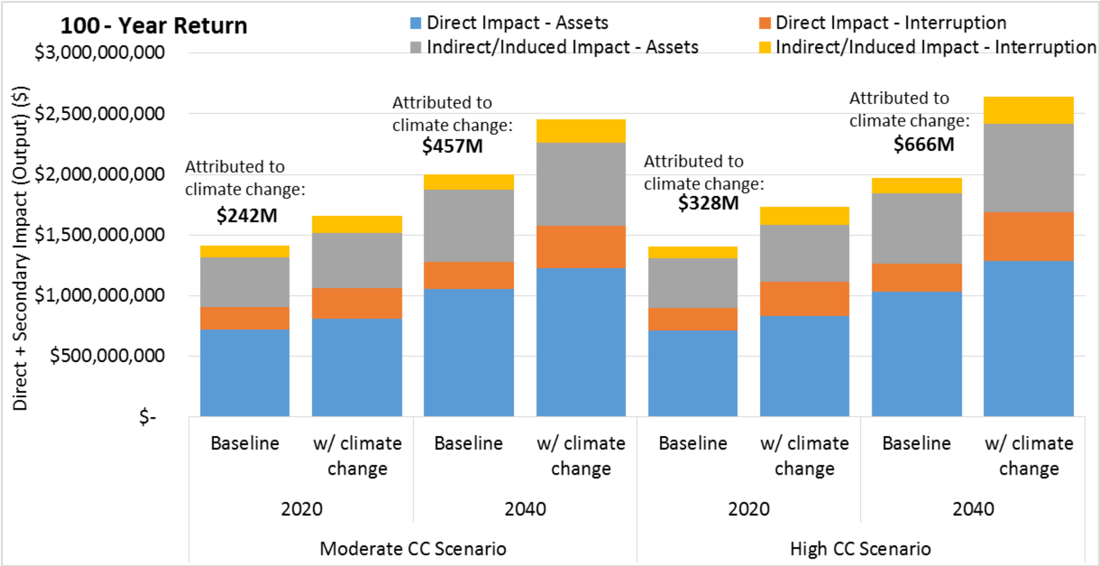

Figure 67: Direct and secondary, asset and interruption impacts (in terms of gross output, basic type II multipliers) due to a 1 in 100 year extreme wind event in the Halifax Regional Municipality

Mississauga Freezing Rain

Direct and Secondary EAD, Gross Output

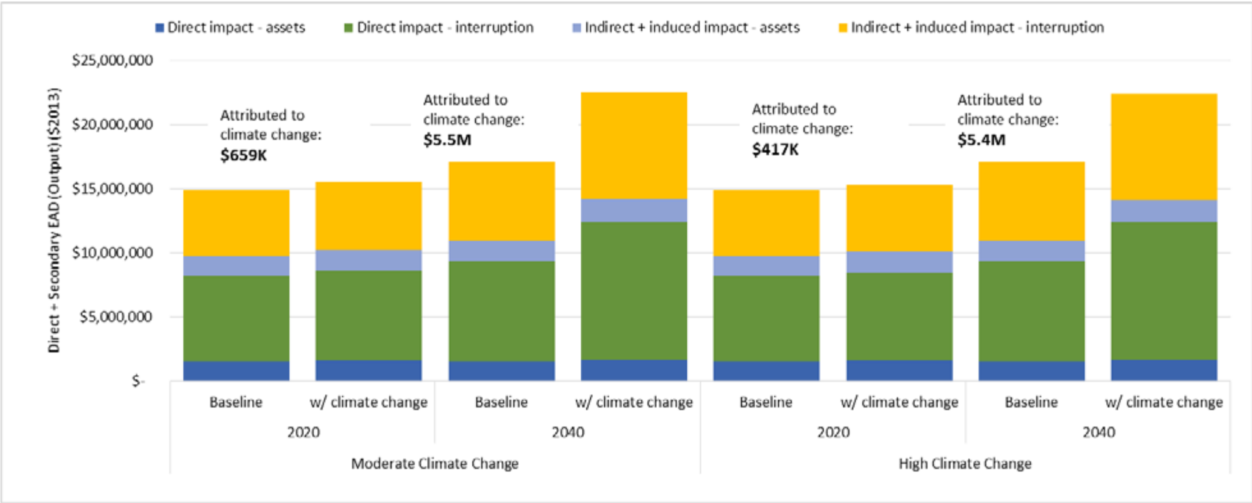

Figure 68: Direct and secondary expected annual damage (in terms of gross output, basic type II multipliers) due to freezing rain in Mississauga

Gross Output Impact due to a 1-in-25 Year Return

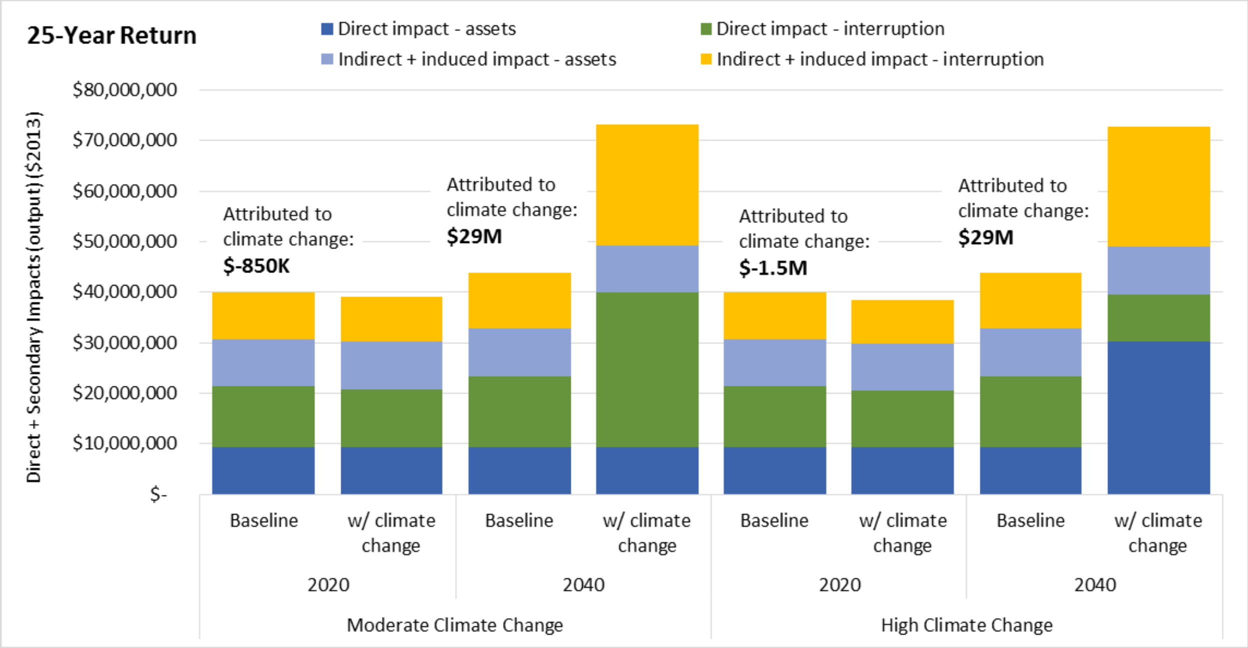

Figure 69: **Direct and secondary, asset and interruption impacts (in terms of gross output, basic type II multipliers) due to a 1 in 25 year freezing rain event in Mississauga**

Gross Output Impact due to a 1-in-100 Year Return

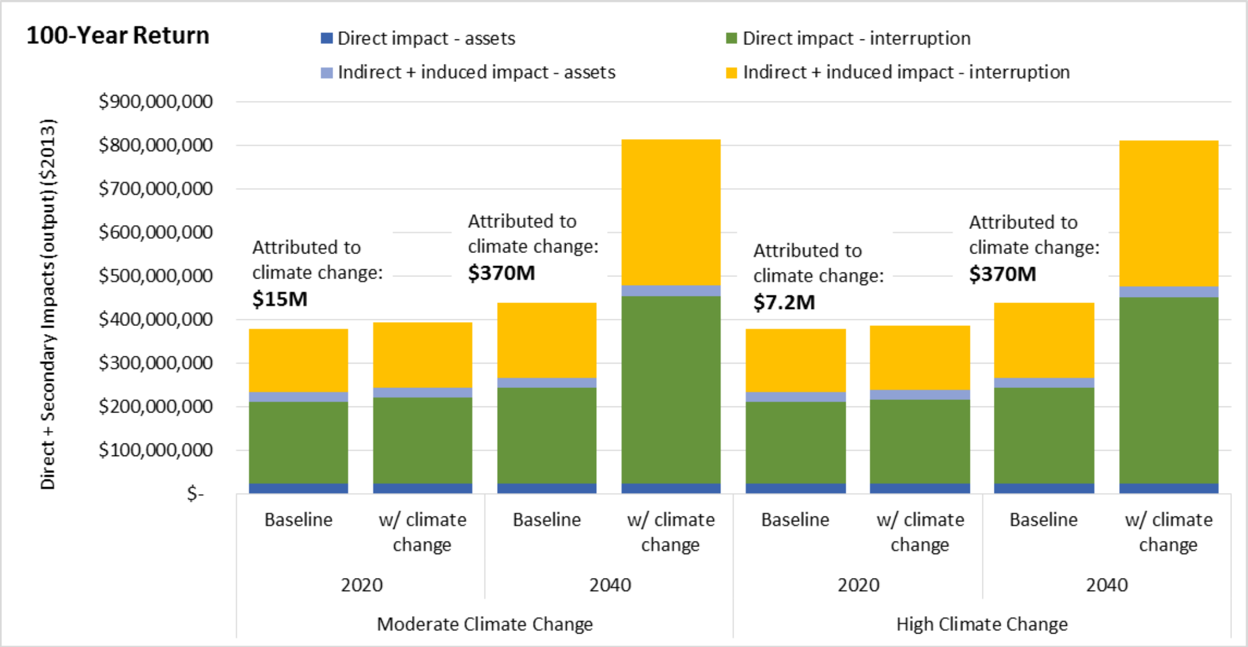

Figure 70: **Direct and secondary, asset and interruption impacts (in terms of gross output, basic type II multipliers) due to a 1 in 100 year freezing rain event in Mississauga**

Mississauga Storm Water Flooding

Direct and Secondary EAD, Gross Output

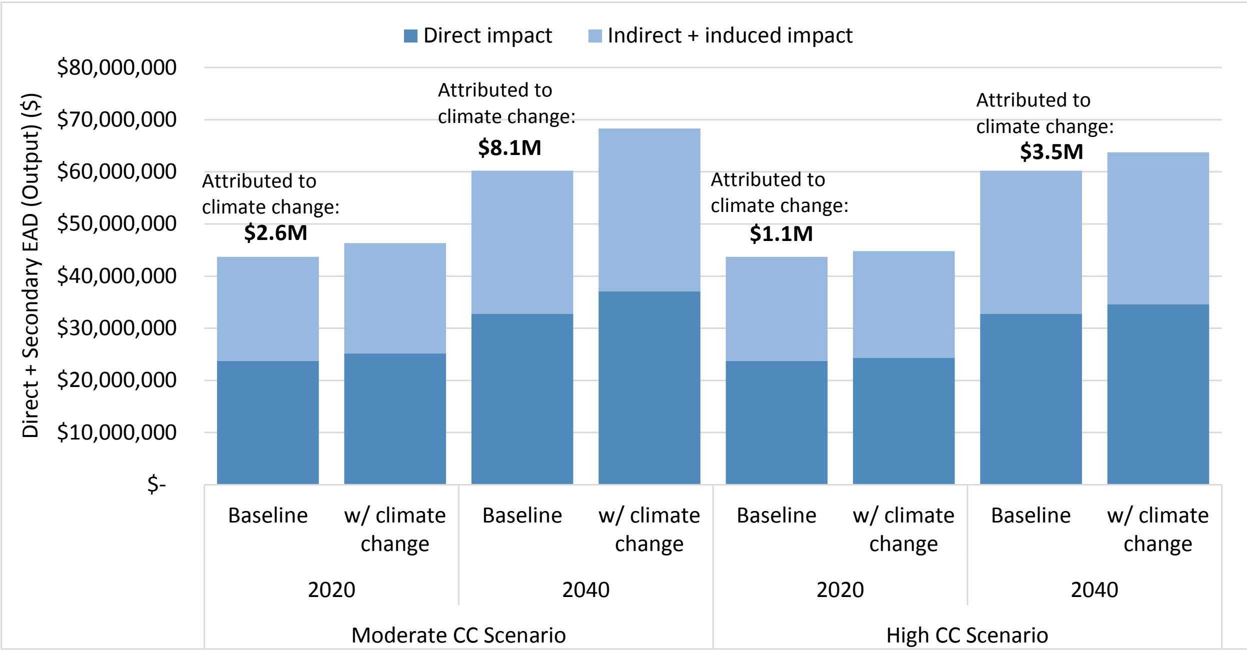

Figure 71: Direct and secondary expected annual damage (in terms of gross output, basic type II multipliers) due to storm water flooding in Mississauga

Gross Output Impact due to a 1-in-25 Year Return

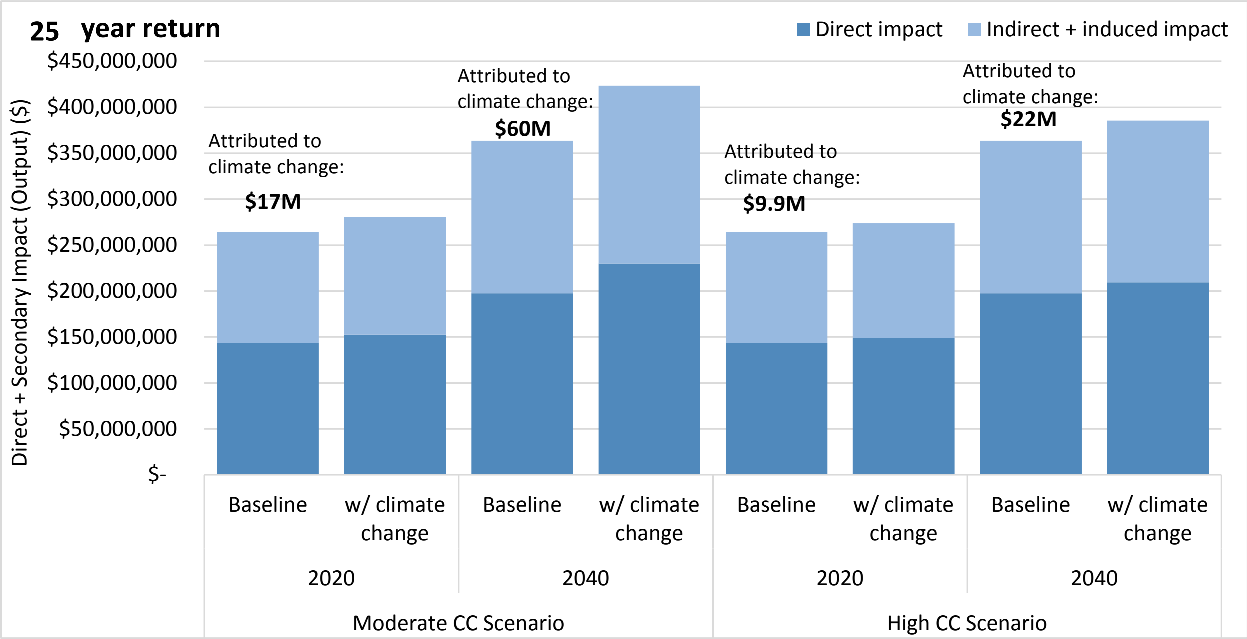

Figure 72: Direct and secondary, asset and interruption impacts (in terms of gross output, basic type II multipliers) due to a 1 in 25 year storm water flood event in Mississauga

Gross Output Impact due to a 1-in-100 Year Return

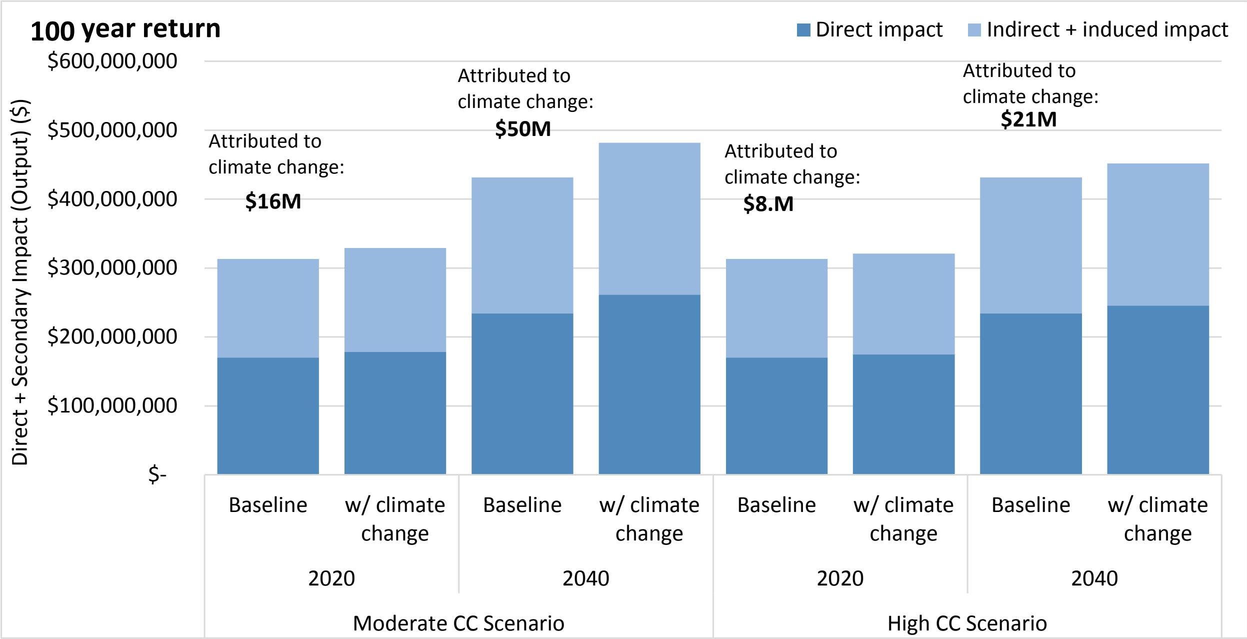

Figure 73: **Direct and secondary, asset and interruption impacts (in terms of gross output, basic type II multipliers) due to a 1 in 100 year storm water flood event in Mississauga**