FLOOD RISK MANAGEMENT IN THE ERA OF CLIMATE CHANGE

A CASE STUDY OF HALIFAX, NOVA SCOTIA

Jason Thistlethwaite, University of Waterloo

Research conducted 2016-2017

Canadian Water Network

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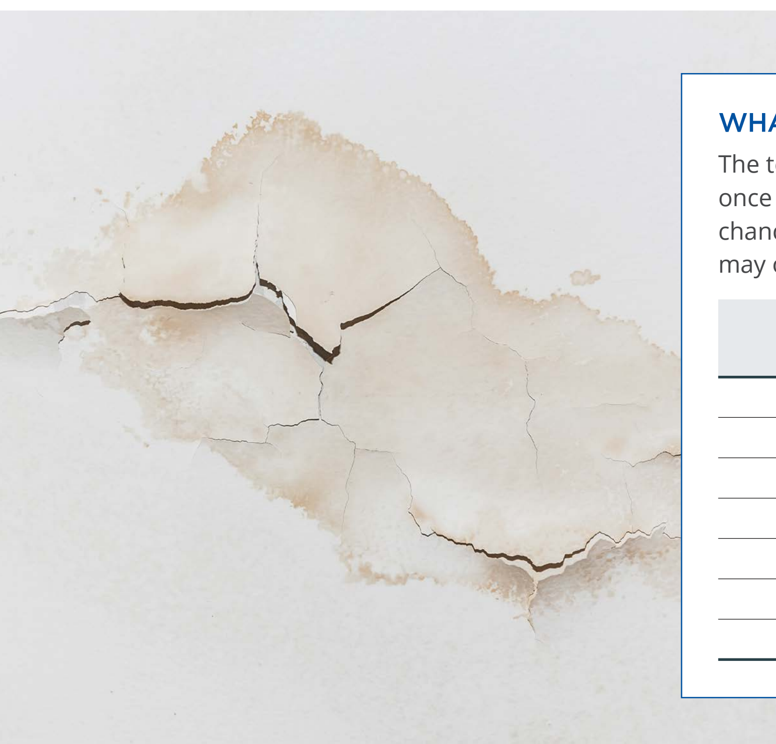
WHY DID WE DO THIS RESEARCH?

Flooding is Canada's most costly and common natural hazard, with damages that exceed $1.2 billion annually. Taxpayer-funded flood recovery costs have more than doubled, from an average of $118 million per year from 1996 to 2011 to $280 million per year from 2012 to 2015. (Sandink et al. 2016a) and was expected to increase to $673 million annually by 2016 (Parliamentary Budget Office 2016). Urban areas are particularly vulnerable to these financial risks due to their population density, property and infrastructure. Climate change may escalate costs further, through extreme weather and storms, and this has not been incorporated into flood risk assessment in Canada. Because damage estimates are based on historical weather patterns, there is uncertainty in the insurance industry on how much climate change could increase damage in certain areas. This has made insurance coverage less affordable for affected property owners (Bouwer 2010).

Historically, governments have employed a hazard-based approach, developing floodplain maps based on a 100-year flood (or other) standard to delineate where development could safely take place. If the floodplain is exceeded and property is damaged, governments compensate victims to support rebuilding. This type of approach does not prioritize risk or account for changing precipitation patterns and is financially unsustainable. As a result, governments at all levels are now encouraging the adoption of Flood Risk Management (Henstra and Thistlethwaite 2017a; PSC 2015; NRCAN and PSC 2017).

Many municipalities lack up-to-date risk information and rely on outdated floodplain maps. An important first step in flood risk reduction is to identify where damage is most likely to occur and where additional protection measures and insurance are justified. Risk assessment must consider both exposure and vulnerability. For example, flood risk maps include information on assets (i.e., people or property) that could be affected by flooding (FEMA 2015). Risk assessment can help decision-makers to prioritize mitigation responses and inform municipal decisions on land-use, building codes and by-laws to encourage property-level flood protection.

A recent survey conducted by the University of Waterloo indicated that 94% of Canadians living in communities that have been designated flood risk areas under the Flood Damage Reduction Program are unaware of this fact (Thistlethwaite et. al., 2017a). The federal government is encouraging communities and property owners to take protective measures and purchase overland flood insurance to offset the costs of recovery (NRCan and PSC 2017). Once property owners become aware that additional coverage may be necessary to finance recovery, a demand for insurance is stimulated (Seifert et al. 2013).



WHAT IS A 1-IN-100-YEAR FLOOD?

The term 100-year flood does not refer to a flood that happens only once in 100 years. It is an estimate (based on historical data) on the chance of such a flood occurring in any given year. 100-year floods may occur **more than once** in consecutive years.

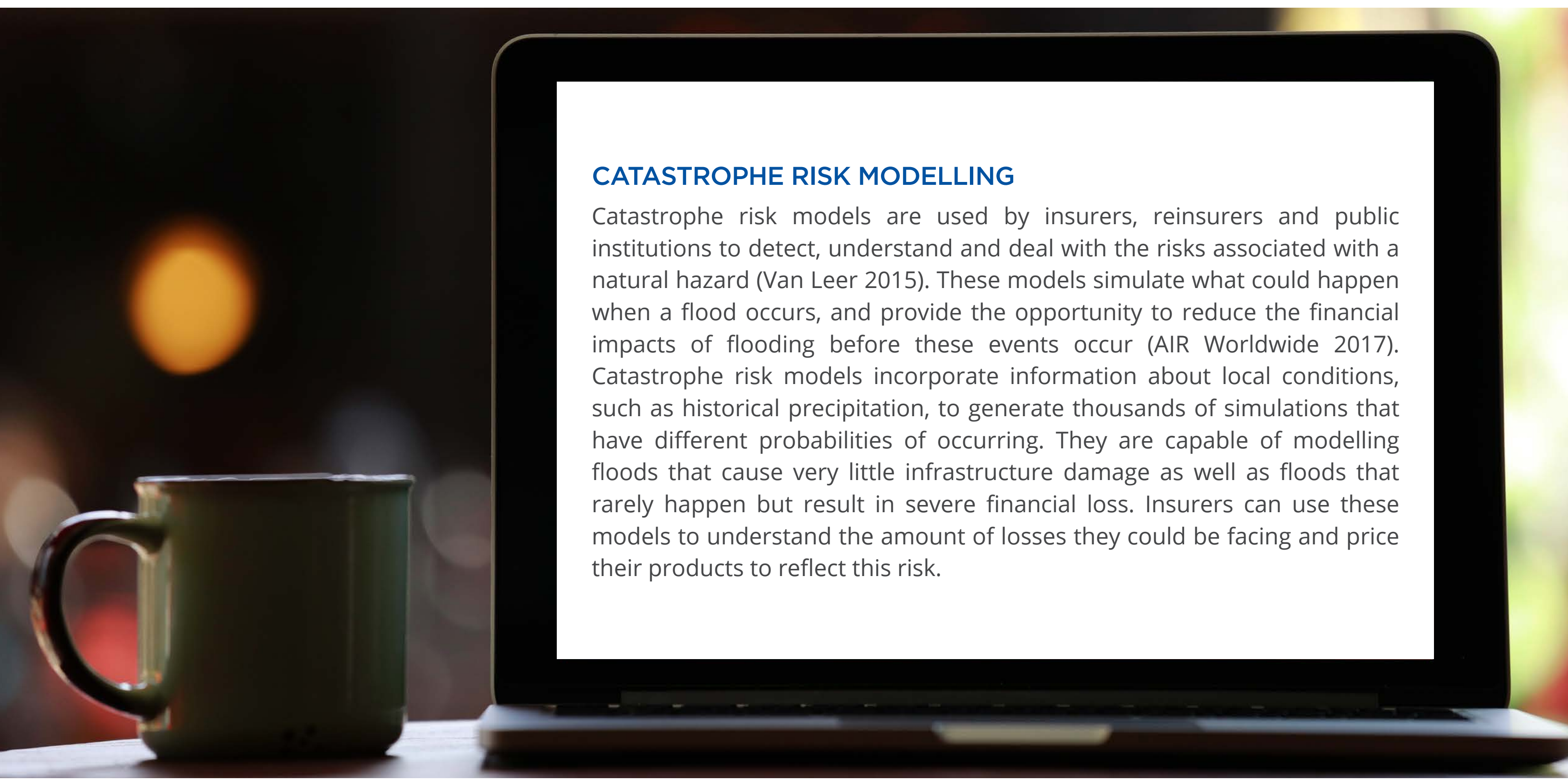
RECURRENCE IN YEARS	PROBABILITY OF OCCURRENCE IN ANY GIVEN YEAR	% CHANCE OF OCCURRENCE IN ANY GIVEN YEAR
500	1 in 500	0.2
100	1 in 100	1
50	1 in 50	2
25	1 in 25	4
10	1 in 10	10
5	1 in 5	20
2	1 in 2	50

This report pertains to a study that was conducted in 2016 and 2017 and focused on riverine flooding, which can occur when extreme rainfall causes rivers to overflow onto surrounding land. Climate change flood risk was assessed in four neighbourhoods in Halifax, Nova Scotia. This municipality was selected because:

- Halifax Regional Municipality (HRM) had recently expressed interest in updating their riverine flood maps (Irish 2016; Berman 2016), which were initially developed between 1984 and 1987 (ECCC 2013).
- Riverine flooding in Halifax had not been researched as much as coastal flooding (Forbes et al. 2009).
- Riverine flooding is now insurable with new residential insurance products, which provides an opportunity for government and the insurance industry to discuss the management of flood-related costs.

A two-part flood risk model was used to identify flood-prone areas and where damages are likely to occur. Location-based hazard and damage information generated by the model were then combined with vulnerable infrastructure like residential properties to map the spatial distribution of flood risk in Halifax. Next, climate change scenarios for changing precipitation patterns were integrated into the model to demonstrate how flood losses are expected to change relative to current flood losses. Finally, the implications of flood risk assessment for municipalities in the era of climate change were examined to inform Canada's evolving flood management policy.

WHAT DID WE DO?



CATASTROPHE RISK MODELLING

Catastrophe risk models are used by insurers, reinsurers and public institutions to detect, understand and deal with the risks associated with a natural hazard (Van Leer 2015). These models simulate what could happen when a flood occurs, and provide the opportunity to reduce the financial impacts of flooding before these events occur (AIR Worldwide 2017). Catastrophe risk models incorporate information about local conditions, such as historical precipitation, to generate thousands of simulations that have different probabilities of occurring. They are capable of modelling floods that cause very little infrastructure damage as well as floods that rarely happen but result in severe financial loss. Insurers can use these models to understand the amount of losses they could be facing and price their products to reflect this risk.

Phase 1: Assessing flood risk under the current climate

Assessing flood risk under the current climate involved: flood hazard mapping, identifying damage-prone areas and determining residential property exposure and vulnerability.

1. The flood risk model incorporated historical precipitation records, topographic data, river flow measurements and other environmental factors to model a 10,000-year deterministic set of major and minor river peak flows (Hunter et al. 2007; Faulkner et al. 2016). The model then generated flood scenarios with different probabilities of yearly occurrence, as well as characteristics like flood depth about these events. The outputs were based on normal depth calculations and used a two-dimensional flood-spreading algorithm (Faulkner et al. 2016, Lamb et al. 2009). This flood hazard information was used to identify areas within the study site that are susceptible to flooding.
2. Flood depth-damage functions were used to identify where floods can cause damages in homes and other structures, because depth directly affects the amount of damage and subsequent repair costs (FEMA 2009). The estimates that were used for this study captured multiple flood scenarios with different intensities to show where flood damages were consistently expected to occur on any given year.
3. The final phase of assessment was quantifying how many residential properties were located inside damage-prone areas and where these properties were concentrated across the study area — i.e., the hot spots. A spatial analysis captured where there were isolated and grouped properties exposed to flooding.

Phase 2: Modelling current and future flood-related losses

During the second phase of the study, potential flood losses were calculated over time. Using available data on the current residential housing stock in Halifax, it was possible to model how flood losses from riverine flooding would change under different climate change scenarios such as extreme rainfall.[1] Flood losses were calculated for flood events of different frequencies and severities such as the 100-year flood. In addition, annual average flood losses were calculated to reflect changes in the costs of flooding over time.

> **AVERAGE ANNUAL LOSS** (AAL) is an output of catastrophe models and is considered an aggregate or "absolute risk" figure because it is calculated by averaging flood losses from multiple simulated flood events (Sly and Ma 2013a; Sly and Ma 2013b). This metric is used by insurers to balance prospective flood losses and profits over time (CAS 2010).

To estimate future flood-related costs, the model was adjusted to reflect future rainfall conditions in the study area, which are expected to become more intense over time. Because the study site is relatively small, it was assumed that climate change impacts all waterways across the site in the same way. The rainfall data used was generated using intensity-duration-frequency (IDF) curves that incorporate future climate change (Sandink et al. 2016b; Western University 2016). The frequency of occurrence of already-modelled floods was adjusted to reflect changes in precipitation based on a 24-hour accumulation time period. These changes were reflected as changes in the frequency rate of floods of various magnitudes.

The researchers were then able to estimate how much flood impacts on residential properties would cost under climatic conditions in the early-, mid- and late-century. Climate change impacts were modelled under two possible scenarios:

→ 2°C increase in global temperatures (Paris Agreement)

→ 4°C increase in global temperatures (business-as-usual)

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1 The loss analysis is reflective of a group of residential properties (detached homes, condos) where about 56% of the population of the study area is estimated to inhabit.

WHAT DID WE FIND?[2]

ASSESSMENT OF PRESENT FLOOD RISK

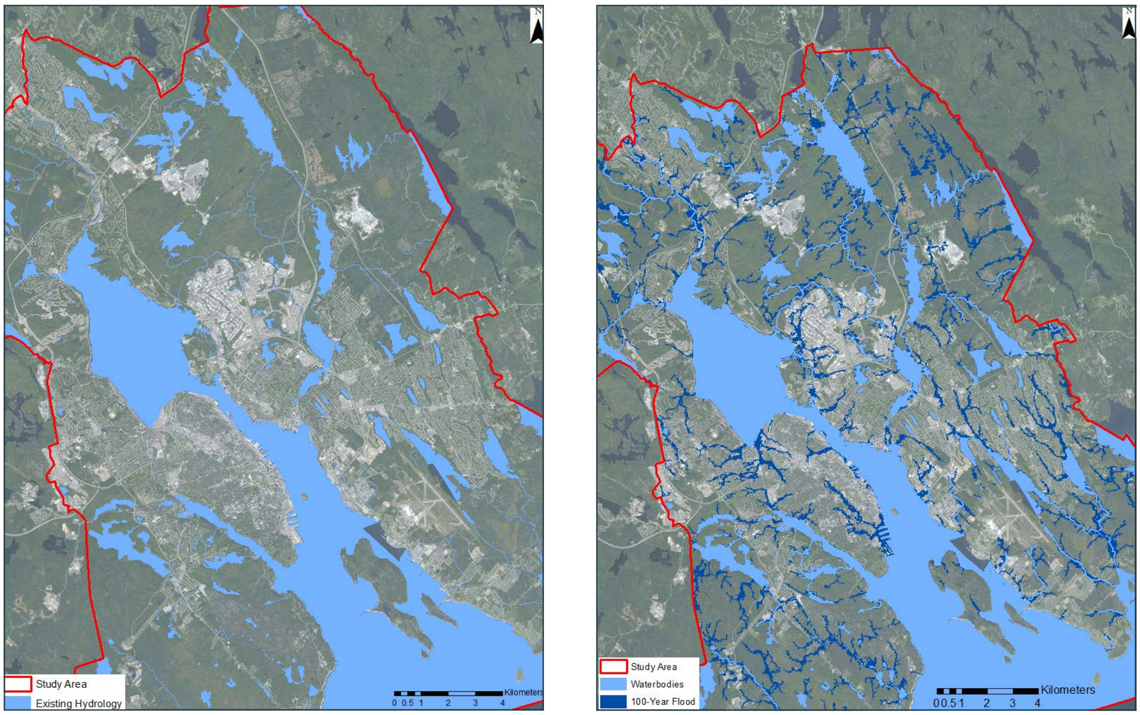


Figure 2. Flood hazards under normal conditions (left) and a 100-year flood zone (right).[3]
***Flood extents are undefended and illustrates a modelled 100-year flood.**

Data sources: Flood data provided by JBA Risk Management, © 2013-2017. This map contains information licensed under the Open Government License – Canada. Base map sources: ESRI, DigitaGlobe, Geoeye, Earthstar Geographics, CNES/ Airbus DS, USDA, USGS, AeroGRID, IGN and the GIS user community 2016.

Residential buildings at risk and high risk of flooding were identified using the flood risk model's damage dataset[4] (Figure 3). There are approximately 96,000 buildings in the study area, of which 66,000 (69%) are residential buildings. About 10% of these residential buildings are located in flood-risk areas. Approximately 1,700 residential buildings (2%) are at high risk of flooding and may experience proportionally more flood damage than other buildings in the study area.[5] Buildings at high risk may experience floodwaters that are faster, deeper and more frequent, and cause proportionally more damage.

2 The flood loss estimates presented do not take into account population growth or additional economic implications that may result from flooding.
3 Areas highlighted on this map have been validated against recorded flood events, which are referenced as flood-prone in HRM's NDMP Risk Assessment Proposal (# P16-338) (HRM 2016).
4 The risk classification is based on the distribution of the damage data and not a specific damage value. Low risk areas are values from zero (i.e., no damage) to the mean damage value; medium risk areas are values from the mean to 1 standard deviation above the mean; high risk includes all areas with values greater than 1 standard deviation above the mean.
5 The damage dataset incorporates frequent low-impact floods and rare high-impact floods up to a 1500-year flood.

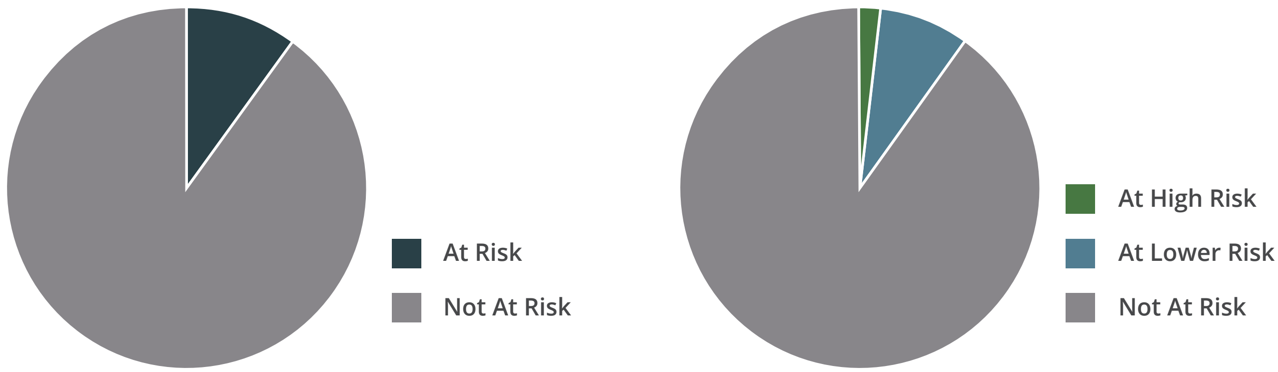


Figure 3. Residential buildings in damage-prone areas of Halifax Regional Municipality

Data sources: Flood data provided by JBA Risk Management, © 2013-2017. Buildings data provided by HRM Open Data Catalogue (2017).

By mapping the location of these at-risk buildings, it is possible to see where there is a high density of residential buildings at risk of flooding across the study site (Figure 4). The highest concentration of buildings at risk follow existing waterbodies and channels, with damage also affecting low-lying areas adjacent to these features. Across the study site, hot spots of high risk buildings are concentrated in Halifax and Dartmouth's downtown cores, as well as in the community of Bedford (Figure 4).

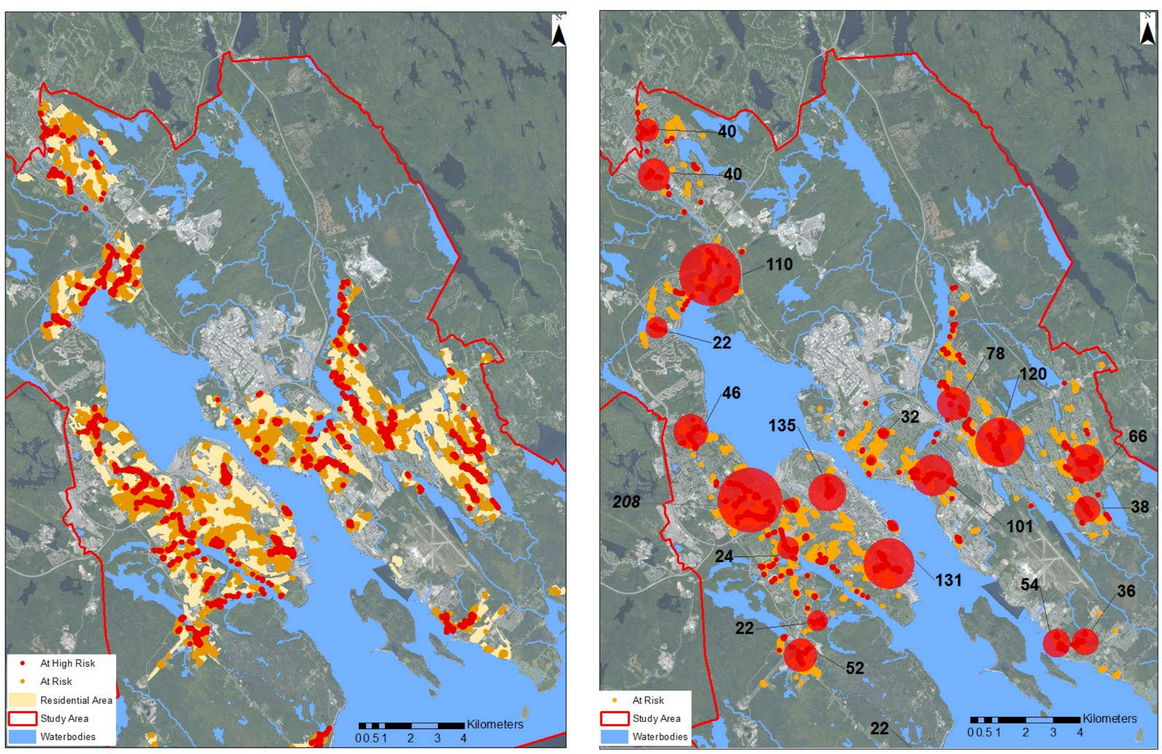


Figure 4. Residential building vulnerability: buildings located within the flood hazard zone (left) and hot spots of residential buildings at high risk of flooding (right).
*** This represents damages associated with only riverine flooding.**

Data sources: Flood data provided by JBA Risk Management, © 2013-2017. Base map sources: ESRI, DigitaGlobe, Geoeye, Earthstar Geographics, CNES/ Airbus DS, USDA, USGS, AeroGRID, IGN and the GIS user community 2016. Buildings data provided by HRM Open Data Catalogue (2017).

ESTIMATION OF CURRENT AND FUTURE FLOOD LOSSES

This study focused on the 100-year flood event to show how losses would change under different climate change emissions scenarios. The results confirm that flood losses are anticipated to increase significantly, which justifies greenhouse gas mitigation and climate change adaptation. The flood risk model estimates that under the current climate, a 100-year flood would cause approximately $7 million in losses to residential properties in the study area (Figure 5). If global temperatures increase by 4°C, flood losses would increase to $67 million by the end of the century. If global temperatures increase by 2°C due to a significant reduction in greenhouse gases, flood losses associated with the 100-year flood would increase to just $10 million in the same period of time.

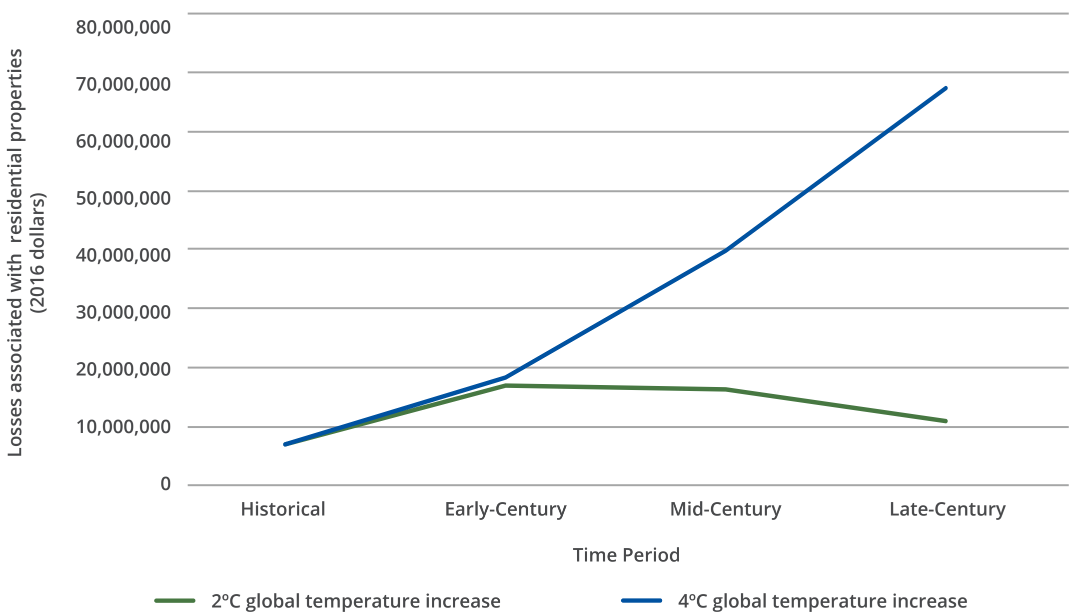


Figure 5. Historical and future scenarios of flood losses resulting from a 100-year flood.
***The flood risk model's results are based on the current build environment in Halifax Regional Municipality.**

Data sources: Guy Carpenter Analytics and Canadian Flood Model. IDF curves retrieved from Western University IDF_CC web tool. Modelled floods are based on 24-hours of precipitation accumulation.

The differences shown in Figure 5 result from changes in the amount of precipitation during a 24-hour period. Historically, a 100-year rainfall event produced 6.3 mm of rain per hour, but this rate changes to 6.49 mm/hour under the 2°C climate change scenario and 7.69 mm/hour under the 4°C climate change scenario (Western University, 2016).

Average annual flood losses (AAL), which represent the total average damage costs that would be expected in any given year, would also change over time (Figure 6). Similar to the 100-year flood, average annual losses increased by 16% under the 2°C scenario by late century or 300% under the 4°C scenario for the same time period. It is important to note that floods that have a high chance of occurring each year, such as 5-year floods, show virtually no change (or little change) in flood losses. Larger floods that are less likely to occur each year, such as 100-year floods, show significant changes in flood losses under future climate scenarios. When aggregating these flood events to calculate AAL, the losses associated with larger and less frequent floods are primarily driving an increase in AAL. This suggests that current flood management is effective at handling frequently-occurring floods and their associated climatic changes. However, flood losses disproportionately increase with lower-probability high impact events because a threshold is surpassed and the existing flood management infrastructure is overwhelmed, putting previously protected areas at risk.

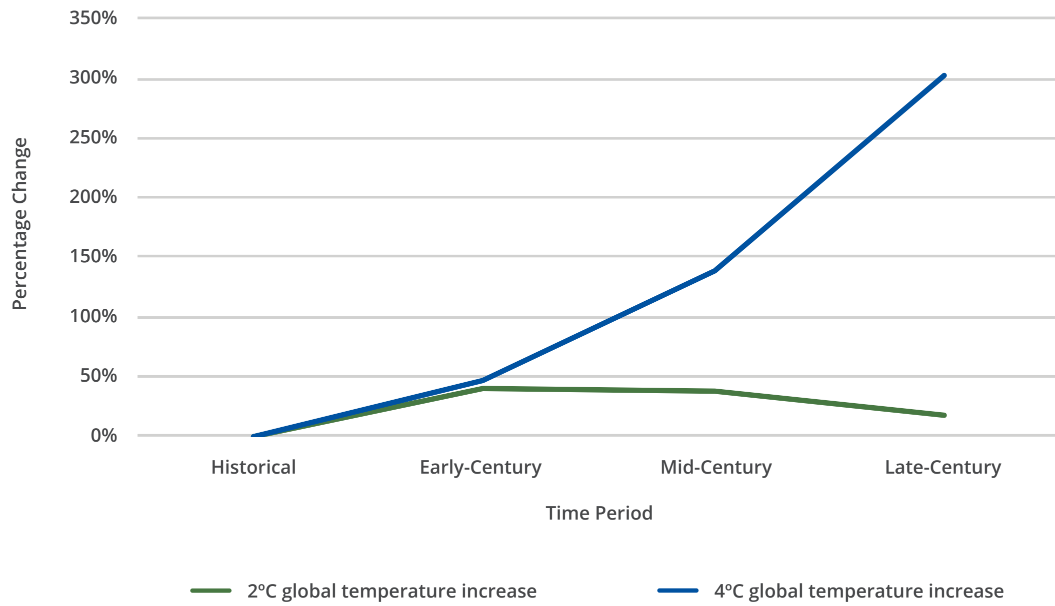


Figure 6. Percentage change in average annual flood losses.

Data sources: Guy Carpenter Analytics and Canadian Flood Model. IDF curves retrieved from Western University IDF_CC web tool.

WHAT DOES THIS MEAN FOR DECISION MAKERS?

1. CLIMATE CHANGE FLOOD RISK ASSESSMENT CAN IMPROVE FLOOD MANAGEMENT IN URBAN AREAS.

Information generated through risk assessments can be used to assess whether the benefits of investments in structural or non-structural flood defenses — such as expanding the size of culverts or permeable surfaces — exceed the costs. Recent policy changes by Natural Resources Canada and Public Safety Canada encourage municipalities to conduct flood risk assessments, but do not require climate change analysis. This study demonstrates the need to include climate change scenarios in all flood risk assessments to clarify cost-benefit determinations.

Climate change flood risk assessment reveals that annual losses from flooding of the existing built environment are anticipated to increase by as much as 50% in the early-21st century, almost 150% by mid-century and 300% by late-century, given a 4°C climate change scenario. Identifying high risk areas provides important information for municipal decisions on future development to reduce liability. This information can also be used to justify mandatory buyout programs such as those being implemented in High River, Alberta or under consideration in Quebec (Thistlethwaite & Henstra, 2017b; Perreaux, 2017; McGillivray, 2017; Bruemmer, 2017).

The National Disaster Mitigation Program funds climate change flood risk assessments. However, while much of the data required to inform the model is publicly available, other inputs (and the models themselves) are often proprietary. For this reason, the federal government should develop standards on how to incorporate climate change risk into municipal assessments. This is particularly important for communities in high risk areas that lack the expertise or resources needed to generate high resolution assessments.

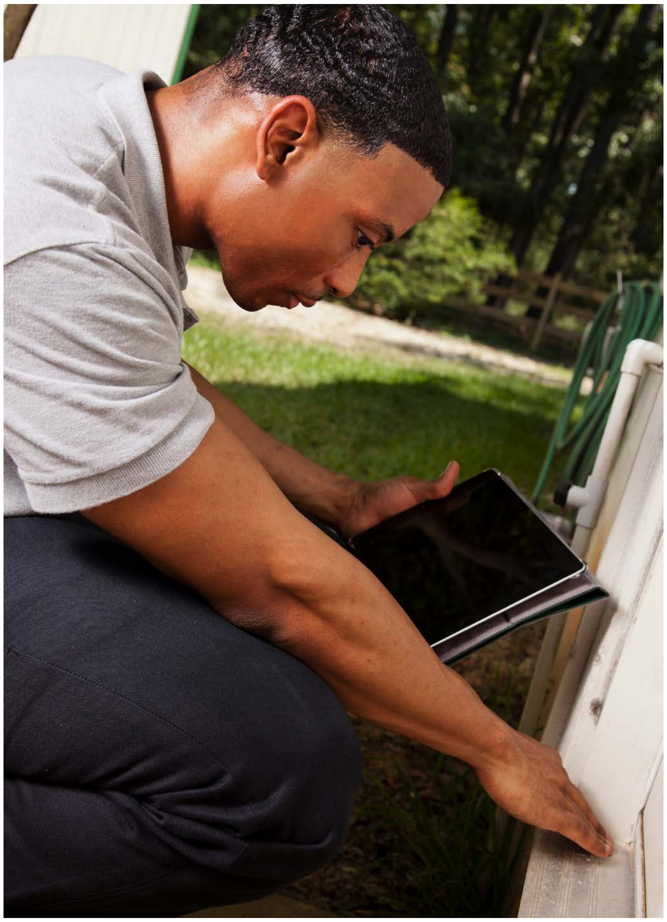
2. CLIMATE CHANGE FLOOD RISK ASSESSMENT PROVIDES MORE COMPELLING INFORMATION FOR PROPERTY OWNERS.

While existing hazard maps capture the depth and extent of potential floods, risk assessment reveals the economic consequences of flooding in these areas. Sharing this information with property owners acts as an incentive to install flood defense mechanisms and/or purchase insurance. This information can also inform discussion/actions in high risk areas, where more specific flood mitigation strategies may be needed, such as raising electrical equipment to a higher level. Information on risk could also be used to stimulate a national discussion among property owners, governments and insurers on accountability for flood risk.

3. MANAGING FLOOD RISK MUST BE A SHARED RESPONSIBILITY.

Climate change scenarios for flood risk confirm that the costs of flooding are anticipated to increase beyond the capacity of governments to finance recovery at the municipal and provincial level. These astronomical costs underscore the need to share risk among all levels of government, insurers and property owners. Although overland flood insurance is increasingly available, it may become unaffordable for homeowners in highly vulnerable locations, and Canada should look to other countries who have adopted policies to offset the costs of coverage. In addition to shared responsibility, an opportunity exists for the federal government to increase funding for risk mitigation, particularly for risk-based land-use and infrastructure improvements in high risk areas.

The costs of inaction on flood risk in a changing climate cannot be ignored. Climate change flood risk assessment can reduce uncertainty and improve risk awareness, spurring the action necessary to protect Canadians from flood risk in the era of climate change.



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