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Climate-Related Flood Risk to Residential Lending Portfolios in Canada

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Abstract

We assess the potential financial risks of current and projected flooding caused by extreme weather events in Canada. We focus on the residential real estate secured lending (RESL) portfolios of Canadian financial institutions (FIs) because RESL portfolios are an important component of FIs' balance sheets and because the assets used to secure such loans are immobile and susceptible to climate-related extreme weather events. We build a loan-level dataset from the residential RESL portfolios of some federally and provincially regulated FIs. We use current and projected flood events under different climate scenarios to apply shocks to these portfolios. We then control for private flood insurance using data from a variety of property and casualty insurers based in Canada.

We find that the direct damages of flooding have modest impacts on the FIs' loss given default on their residential RESL portfolios. This is partly due to rising homeowner equity and the recent rapid increase in house prices across Canada. Nevertheless, some risk channels have emerged. Notably, the combined influence of high household leverage and lending in flood zones can exacerbate the risk that lenders face from extreme weather events. Our analysis also shows that other disaster-related risk channels may increase risk to lenders. These channels include climate change, price adjustment of the salvage value and time to settlement. However, this analysis has several limitations. Specifically, the lack of granular flood data may have led to an underestimation and smoothing of financial risks across households. As a result, the analysis potentially smoothed what could be more acute shocks to specific properties.

Topics: Climate change; Central bank research; Credit risk management; Econometric and statistical methods; Financial institutions; Financial stability
JEL codes: C81, G21, Q54

Résumé

Ce document présente une analyse des risques financiers potentiels résultant d'inondations réelles et projetées causées par des événements météorologiques extrêmes au Canada. Nous concentrons notre attention sur les portefeuilles de prêts garantis par des biens immobiliers résidentiels que détiennent les institutions financières canadiennes, puisque ces portefeuilles constituent une part importante de leur bilan et que les biens fournis en garantie, étant immobiles, sont sujets aux événements météorologiques extrêmes découlant des changements climatiques. L'analyse part d'un ensemble de données qui détaille, à l'échelle des prêts, les portefeuilles de certaines institutions financières sous réglementation fédérale et provinciale. Nous élaborons ensuite différents scénarios climatiques, formés d'inondations réelles et projetées, pour simuler des chocs dans ces portefeuilles. Enfin, nous considérons l'assurance des particuliers contre les inondations, d'après les données de diverses sociétés d'assurances multirisques domiciliées au Canada.

Selon notre constat, les dommages directs des inondations ne se répercutent que modestement sur les pertes en cas de défaut associées aux portefeuilles de prêts garantis par des biens immobiliers résidentiels. Cela est attribuable en partie à l'augmentation de l'avoir propre foncier et à la hausse rapide du prix des logements observée récemment au Canada. Certains canaux de risque se dessinent néanmoins, notamment l'effet combiné d'un fort endettement des ménages et d'un grand volume de prêts dans les zones inondables, qui peut exacerber le risque couru par les prêteurs en cas d'événements météorologiques extrêmes. Notre analyse indique aussi que d'autres canaux impliquant des catastrophes pourraient amplifier le risque qui pèse sur les prêteurs, à savoir les changements climatiques, les ajustements de prix affectant la valeur de récupération, ou encore les délais de règlement. Cette analyse connaît toutefois plusieurs limites, surtout parce que le manque de données granulaires sur les inondations pourrait nous avoir amenés à sous-estimer et à lisser les risques financiers de l'ensemble des ménages. Par conséquent, il est possible que l'analyse ait minoré des chocs qui s'avéreraient en fait plus graves du côté de certains biens immeubles.

Sujets : Changements climatiques; Recherches menées par les banques centrales; Gestion du risque de crédit; Méthodes économétriques et statistiques; Institutions financières; Stabilité financière
JEL codes: C81, G21, Q54

1. Introduction

Extreme weather events can impact the financial system through various channels, including destruction of property and reassessment of the value of a variety of financial assets. This can negatively affect lenders' balance sheets, with potential consequences for the financial system as a whole.[1] Climate change is expected to increase the frequency and severity of extreme weather events, potentially exacerbating these impacts in the future. For these reasons, several central banks and financial authorities have undertaken work to better understand the potential implications of these risks.[2] While several challenges related to data and methodological developments still need to be addressed, a greater understanding of how potential current and future extreme weather events may affect financial system entities helps promote a stable and well-functioning financial system.[3]

One channel through which current and future extreme weather events can influence the financial system is the residential real estate secured lending (RESL) portfolios of financial institutions. The reason for this is that assets used to secure such loans are immobile, repaid over a long period and vulnerable to such events. While Canada experiences many kinds of extreme weather events—including hurricanes, droughts and wildfires—flooding has so far emerged as the most common and costly (Public Safety Canada 2022). A single severe flood event, on its own, could lead to billions of dollars worth of damages to residential properties, and these costs are expected to rise because of climate change.

Against this backdrop, we quantify the financial impacts of current and projected flooding on lenders' RESL portfolios. We do so by building a loan-level dataset using data from federally and provincially regulated financial institutions. We apply shocks to these portfolios using current and projected flood events under different climate scenarios based on information from spatially explicit catastrophe models. Given the important role residential insurance plays in the allocation of disaster-related costs across financial market participants, we control for private flood insurance from a variety of property and casualty (P&C) insurers in Canada in our analysis. This work represents a comprehensive and pan-Canadian analysis of the impact of flood risk to the residential RESL portfolios of Canadian financial institutions using loan-level data.

Evidence suggests that the direct damages from flooding generally appear to have a manageable impact on lenders' residential RESL portfolios. This is partly due to homeowner equity and to the recent and rapid rise in house prices. Homeowner equity can provide a buffer to lenders because losses could be recovered

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[1] While implications of extreme weather events for the macroeconomy may be important (Duprey, Jo and Vallée forthcoming), we have left the integration of macroeconomic shocks associated with flooding to future work.

[2] This work belongs to a growing body of research from central banks aimed at evaluating the financial impacts associated with domestic physical risks. Most similar to the present work are assessments published by De Nederlandsche Bank (Caloia and Jansen 2021), Bank of Finland (Manninen et al. 2021), Bank of Latvia (Strazdins and Sinenko 2023), New York Federal Reserve Bank (Blickle, Hamerling and Morgan 2022).

[3] In addition, a better understanding of transition risk associated with the shift to a low-carbon economy—and potential secondary effects—are also important to the stability and efficiency of the financial system. For recent Bank staff work on climate transition risk, see Bruneau et al. (2023).

if the appreciation of the property was large enough if a flood-related default occurs. Some channels that exacerbate risks to the financial system have nevertheless emerged. Notably, the combined influence of high household debt and lending in flood zones can amplify the risk lenders face from extreme weather events. We find that other disaster-related risk channels—namely, climate change, salvage value price adjustment and time to settlement—may increase risks to lenders.

However, several limitations need to be noted. The most important is related to data limitations, which contribute to a potential underestimation of the flood-related risks to lenders. Notably, the lack of granular data leads us to apply flooding and P&C insurance to properties using average information at the postal code level, potentially smoothing what could be more acute shocks to specific properties. Further, estimates of flood damage exclude potential impacts to the value of land, losses to apartments and condominiums and sea level rise. In addition, we use a simple, deterministic loss-given-default (LGD) formula to estimate the impact of flooding on residential RESL credit risks that may not capture the distinct nature of realized losses for residential RESL portfolios. Finally, we abstract from household dynamics that could influence probability of default. However, mortgage defaults in Canada are exceedingly rare, making it difficult to identify those that are related to floods.

The rest of the paper is organized as follows. Section 2 provides context for flood-related losses to the Canadian residential real estate sector and discusses the flood data we use in our analysis. Section 3 presents the additional datasets used to bridge other gaps in data as well as the methodologies developed to translate current and projected flood events under climate change scenarios into financial impacts. Section 4 presents the results and a sensitivity analysis. Section 5 provides concluding remarks, discusses challenges and limitations to the analysis, and suggests areas for future work.

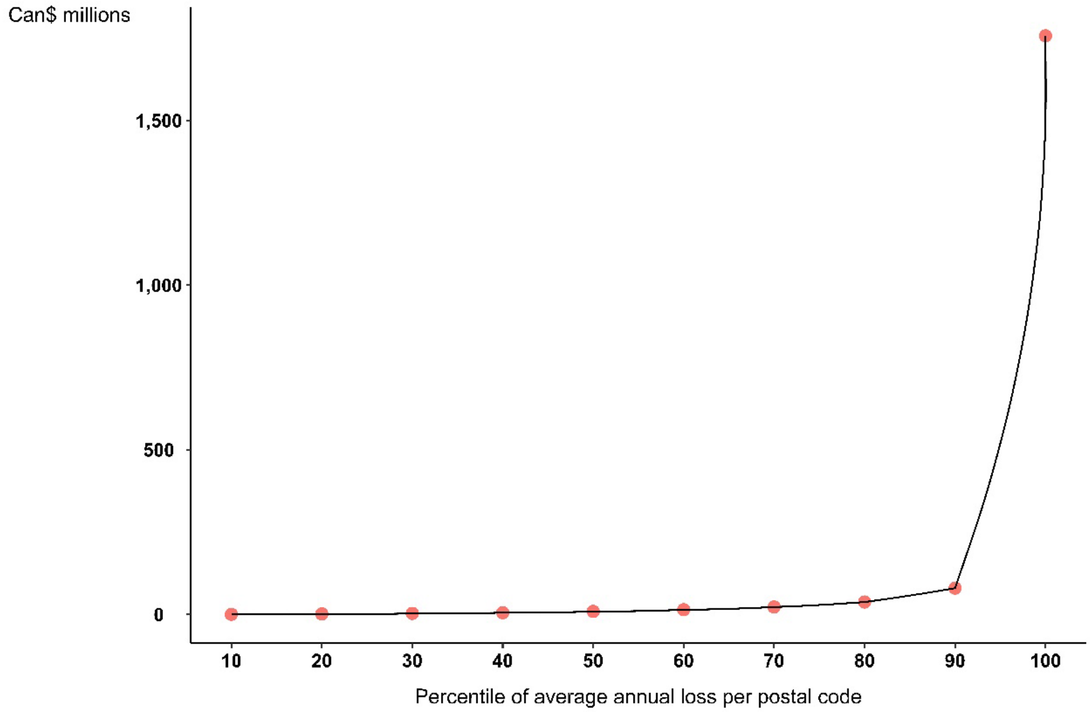
2. Flood-related damage to Canadian residential real estate—State of play and data

To improve our understanding of the financial impacts of extreme weather events to Canadian lenders, we draw on the assessment of flood risk to residential properties in Canada by Public Safety Canada—a leading authority in Canada on modelling and assessing flood-related impacts.

Specifically, Public Safety Canada provided data at the postal code level on average annual loss (AAL). These data include information on the extent of flood-related damage that could be expected, on average, in any given year, and on the occurrence of more severe flood events. Public Safety Canada also provided information on how flood-related damage are expected to evolve under different climate change assumptions. **Box 1** provides additional details on Public Safety Canada's dataset, including recent updates to its exposure data, damage estimation methodologies and approach to modelling of future climate scenarios.

Public Safety Canada estimates the average expected flood-related loss to be $2.97 billion per year when considering both the damages to the structure of residential real estate and the contents within it. Focusing only on the damages to the value of collateral—the residential structures—Public Safety Canada estimates flood-related losses to be $1.93 billion per year, with most of this loss concentrated in a small fraction of properties. Approximately 89% of Canada's total flood-related damages to residential real estate, excluding damages related to contents, is concentrated in 10% of properties (**Chart 1**). Furthermore, 34% of total national damages are concentrated in only 1% of properties in Canada.

Chart 1: Total average annual flood-related loss to residential real estate across Canada ranked by percentile



Note: Numbers reflect damages to the residential structure only and exclude damages to contents. The total average annual loss is $1,930 million.

Sources: Resilience and Economic Integration Division (REID) at Public Safety Canada and their external data partners (DMTI Spatial, Opta Information Intelligence, KatRisk LLC, JBA Risk Management and Fathom) and Bank of Canada calculations

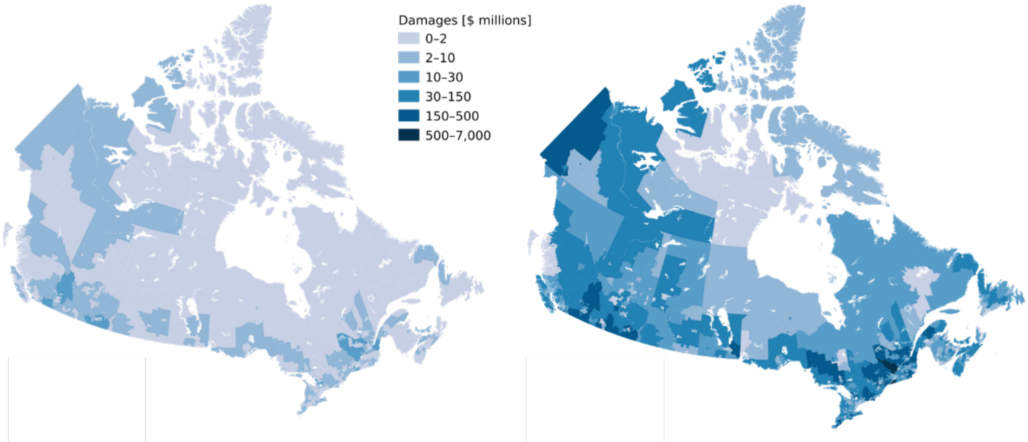
Last observation: 2022Q3

AAL provides an estimate for the average dollar value of flood damage that could be expected to occur in any given year. However, the occurrence of more severe events, such as those with a return period of 100 years, can cause significantly higher damages. **Chart 2** plots the estimated flood-related damages to residential real estate across different flood events, shown as the percentage of property value damaged for a given flood event. Note that these numbers represent the average impact on property across aggregated geographic areas and may hide important variability across properties. For most areas in Canada, properties are exposed to an AAL that represents less than 0.1% of property value on average. Meanwhile, events with a return period of 100 years lead to greater AAL, with damages to properties in many areas exceeding 10% of their property value. These events are uncommon but can cause significant damages in areas of high exposure.

Chart 2: Current estimated flood-related damages to residential real estate, by forward sortation area

(a) Total dollar value of average annual loss

(b) Total dollar value of 1-in-100-year event damages



Note: Numbers reflect damages to the residential structure only. A forward sortation area delineates a specific section of a given geographic area and is represented by the first three digits in the six-digit Canadian postal code.
Sources: Resilience and Economic Integration Division (REID) at Public Safety Canada and their external data partners (DMTI Spatial, Opta Information Intelligence, KatRisk LLC, JBA Risk Management and Fathom) and Bank of Canada calculations

Climate change can further exacerbate the flood-related damages. To assess climate change implications, we use representative concentration pathways (RCPs) which span a large range of future global warming scenarios. RCPs quantify future greenhouse gas concentrations and the radiative forcing—additional energy taken up by the Earth system—due to climate change. The present study examined two RCPs—RCP 4.5 and RCP 8.5—with the latter implying more rapid warming and marked changes in the climate.[4]

Chart 3 shows the estimated climate-induced change in damages relative to current levels by end of the century by forward sortation area (FSA). The national increase in AAL in Canada is estimated to be 6.7% and 11.9% under RCP 4.5 and RCP 8.5 scenarios, respectively. However, this varies significantly across FSAs, with some FSAs expected to experience less than a 1% increase in AAL, while other FSAs are estimated to be exposed to an increase in AAL of greater than 25%. Note that AAL calculations are based on the expected severity and frequency of a distribution of return period flood events.[5] Consequently, AAL mask the variability in the climate-induced change in severity of flood events with different return periods. The severity of an event with a return period of 100 years is expected to increase significantly for most FSAs

[4] More specifically, the RCP 4.5 assumes future emissions that range from low to moderate (a slight increase in carbon dioxide emissions occurs until the middle of the century, then it declines). The RCP 8.5 results in more rapid warming and more pronounced changes in the climate (e.g., river flow, water temperature or precipitation) given the assumption of very high future emissions (by the end of the century, carbon dioxide emissions are three times higher than they are now) (Intergovernmental Panel on Climate Change 2023).

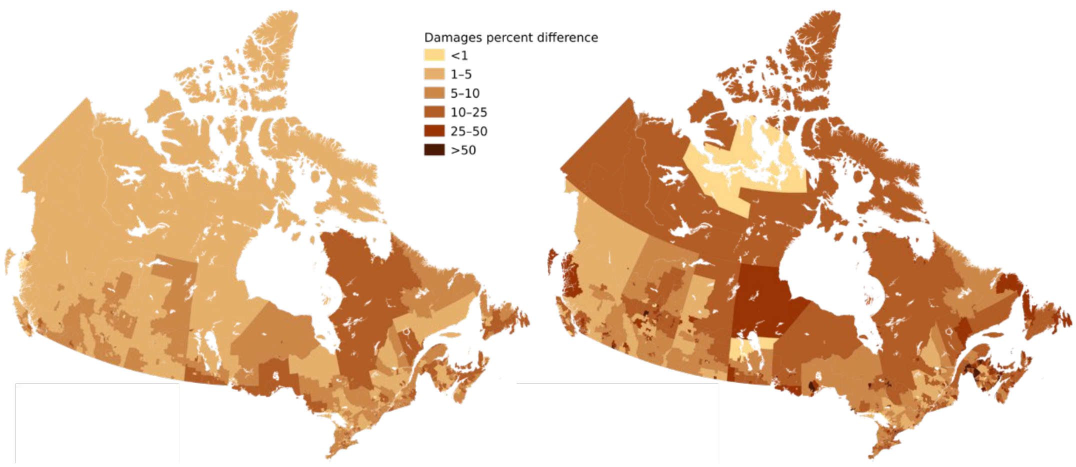
[5] Return periods are a common metric for the occurrence of natural hazards, including floods. They describe how likely a hazard event is to occur at, or above, a given intensity within a time frame defined by a probability. For example, a 1-in-100-year return period means that a flood of a given magnitude has a 1% chance of occurring in any year.

across Canada, with many FSAs expected to see an increase in damages of over 50% from these events by the end of the century. In our analysis, we hold the frequency of recurrence of events constant and simply measure the change in their severity.

Chart 3: Climate-induced percentage change in estimated damages by end of the century relative to current levels, by forward sortation area

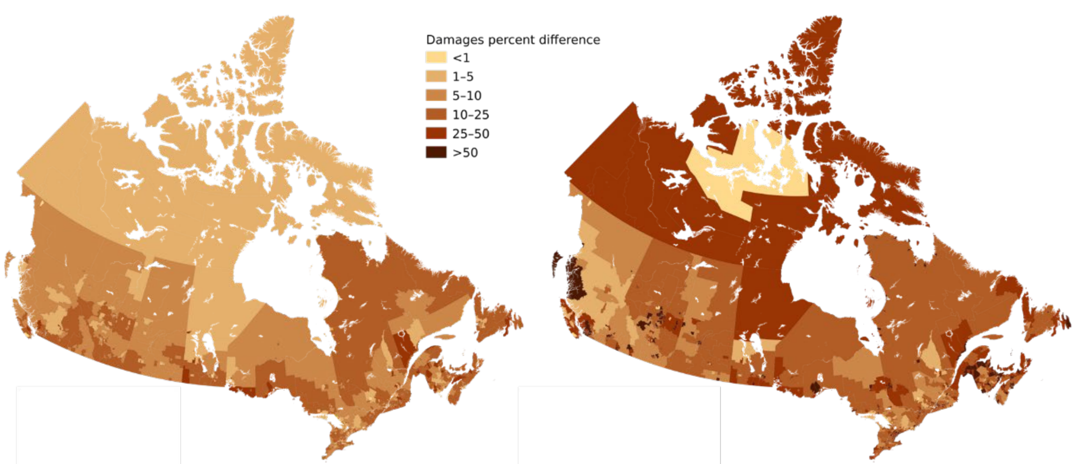
(a) Percent change in average annual loss under RCP 4.5 scenario

(b) Percent change for a 1-in-100-year event under RCP 4.5 scenario



(c) Percent change in average annual loss under RCP 8.5 scenario

(d) Percent change for a 1-in-100-year event under RCP 8.5 scenario



Note: RCP means representative concentration pathways. Damages refers only to structural damages. A forward sortation area delineates a specific part of a given geographic area and is represented by the first three digits in the six-digit Canadian postal code.
Sources: Resilience and Economic Integration Division (REID) at Public Safety Canada and their external data partners (DMTI Spatial, Opta Information Intelligence, KatRisk LLC, JBA Risk Management and Fathom) and Bank of Canada calculations

Box 1: Public Safety Canada flood damage methodology

Estimating flood damage requires an understanding of three key components:

- flood hazard, which includes information on flood extents and depths at certain frequencies (expressed as the annual exceedance probability [AEP])
- flood exposure, which describes the valued assets in the path of the flood—in this case, residential properties
- flood consequence, which, in this case, is a modelled estimate of flood damage in dollars based on relationships between flood depths and building attributes, such as replacement value, presence of a basement and other characteristics

Public Safety Canada estimated the financial flood risk to residential addresses in Canada, expressed as the average annual loss (AAL): a combined dollar-value of expected damage to each address on an average annual basis. The current-day estimate of AAL for all residential addresses in Canada was estimated at Can$2.92 billion for property and content damages.[1] This damage estimate is nearly identical to the AAL calculated under Public Safety Canada's Flood Insurance and Relocation Project (published in the August 2022 *Adapting to rising flood risk: An analysis of insurance solutions for Canada report*).[2]

Estimating flood hazard

Flood hazard was estimated using two Canada flood hazard models:

- one from JBA Risk Management, which included three flood-generating mechanisms (fluvial, pluvial and coastal), flood defences and complete spatial coverage of Canada
- one from KatRisk, which included two flood-generating mechanisms (fluvial and pluvial), spatial coverage of Canada south of 60°N, and climate change scenarios

Both models provided the extent and depth of flooding at multiple return periods, which were used in the calculation of AAL. The AAL, 1-in-100 years and 1-in-500 years return periods were provided to the Bank of Canada. KatRisk models climate change by:

- adjusting local precipitation extremes using the Clausius-Clapeyron equation, which correlates temperature with water holding capacity of the atmosphere
- using representative concentration pathway (RCP) scenarios, which are associated with different potential futures for carbon emissions (from low at 2.6 to high at 8.5). Flood damage was estimated for future climate scenarios RCP4.5 and RCP8.5 for the years 2050 and 2100.

Estimating flood exposure

Public Safety Canada developed a comprehensive exposure dataset from multiple sources, including:

- Lightbox / DMTI's CanMap address points
- Open Street Maps' building location data
- Microsoft building footprints
- Statistics Canada Open Database of Buildings

- Opta Intelligence building attribute data

The above datasets were evaluated by Public Safety Canada and then combined into a single residential address exposure dataset, which was subjected to a rigorous quality control procedure. For condominiums, individual units are often insured by condo corporations. As a result, the replacement value (and subsequently the loss potential) of apartment and condominium unit structure was set to zero, while contents value was set to $50,000 for each unit based on input from industry experts.

Estimating dollar-value of flood damages

Public Safety Canada applied Fathom's depth-damage functions (vulnerability functions) to the flood hazard data. The vulnerability functions represent the empirical relationship between water depth and damage for a variety of residential buildings using a large database of past flood insurance claims. Due to underlying uncertainty about the relationship between flood depth and damage, these probabilistic vulnerability functions were sampled 10 different times for both structure and contents for the fluvial, pluvial and coastal flooding to capture a breadth of possible loss scenarios. Using the various data sources listed above, it was possible to create:

- two unique estimates of AAL expected from flooding per residential address across southern Canada—south of 60º North
- one estimate of AAL in the northern portions of Canada—north of 60º North

These estimates include structure and contents losses but exclude additional living expenses. The mean of the two different damage estimates was used at each location to combine the data from different flood damage models, which is considered more robust than having a single damage calculation. The address level results were then aggregated to the postal code level and provided to the Bank of Canada. This flood damage analysis is considered best practice for quantifying physical climate risk on a large scale and is aligned with the Government of Canada's Sustainable Finance Action Council work on enhancing climate-related financial disclosures.

Data limitations and uncertainty of results from residential financial flood risk estimation

Flood hazard modelling is a complex process with inherent uncertainty because of the quality and resolution of topographic, meteorologic and hydraulic data. When data from two different flood damage models are combined, loss estimates are considered more robust than having a single damage calculation. This flood damage methodology was designed to reduce as much of this uncertainty as possible. In addition to flood model uncertainty, there is uncertainty in the exposure data estimation. Building a national residential dataset is challenging because these datasets are constantly changing and accurate household-level data for every property in Canada is difficult to obtain and verify. As well, in some cases, lower resolution building attribute data is disaggregated to the property level. These data are considered the most accurate depiction of residential addresses available for Canada at the time of this publication.

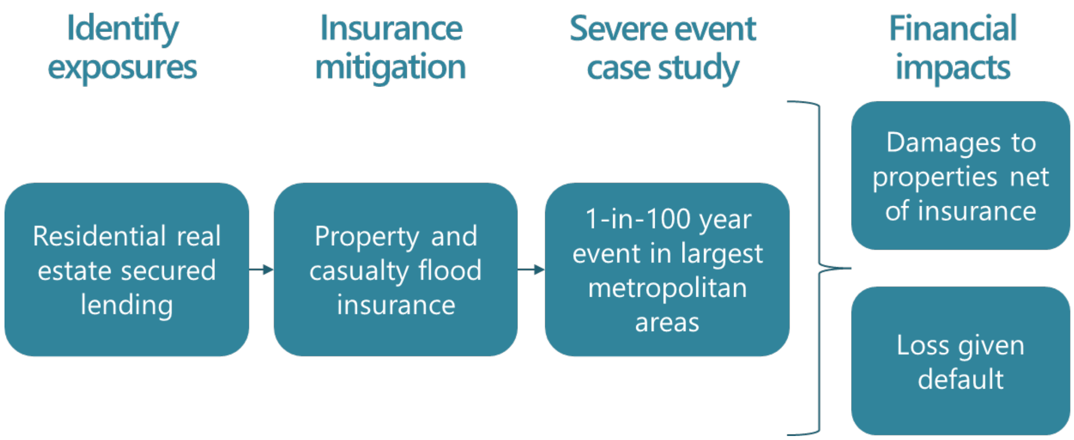
[1] Estimates used to assess financial institutions exposures differ because these only consider structural damage and omit content damage.

[2] In 2020, the Resilience and Economic Integration Division (REID) at Public Safety Canada began an assessment of flood damage to residential addresses as part of the Flood Insurance and Relocation Project. This assessment was used to support subsequent actuarial analysis and policy recommendations for a national flood insurance program in Canada, culminating in the August 2022 report, *Adapting to rising flood risk: An analysis of insurance solutions for Canada*. For any questions regarding this analysis, please contact communications@ps-sp.gc.ca.

3. Methodology for assessing financial risks

Figure 1 presents a high-level overview of the methodology we use to conduct the financial risk assessment.

Figure 1: Overview of financial risk assessment methodological steps



3.1. Residential real estate secured lending and property and casualty insurance

In addition to detailed flood-related datasets, assessing the exposure of lenders' residential RESL portfolios to climate-related flood events requires detailed and granular data on their residential real estate secured lending. Furthermore, understanding how P&C insurance mitigates risks, including for homeowners in the event of a flood, is equally informative. To address these data gaps and challenges, the Bank of Canada and the Office of the Superintendent of Financial Institutions (OSFI) partnered with five provincial regulatory authorities and nine P&C insurers.[6]

3.1.1. Residential real estate secured lending

The residential RESL data included anonymized loan-level information across a total of 63 lenders.[7] This dataset included useful features such as the outstanding balance and credit limits on the anonymized mortgage loans and home equity lines of credit, the postal code of the property used as collateral, and the date and value of the latest property evaluation. No personal information was included in the dataset to

[6] Data were provided by federal and provincial regulators, including the Office of Superintendent of the Financial Institutions, BC Financial Services Authority, the Alberta Credit Union Deposit Guarantee Corporation, the Alberta Ministry of Treasury Board and Finance, the Financial Services Regulatory Authority of Ontario and the Autorité des marchés financiers, and property and casualty insurers, including Aviva Canada, Beneva, Co-operators General Insurance Company, Definity Financial Corporation, Desjardins Groupe d'assurances générales inc., Intact Insurance Company, TD Insurance and The Wawanesa Mutual Insurance Company.

[7] To support this work, financial data from selected financial institutions from each participating regulator were provided. These data were anonymized at the source—all personally identifiable information, such as the name of the borrower, property address, was excluded. While the data included in this analysis are not comprehensive, they nevertheless cover a large fraction of all residential RESL loans in Canada.

retain the anonymity and privacy of data. Since the time frame for the latest property valuation may differ across all the loans, we leveraged data from the Teranet–National Bank House Price Index to update all property values to the third quarter of 2022 so we could use a common time frame.

In Canada, homeowners who borrow against their property will typically hold a mortgage, a home equity line of credit or both. We therefore track all loans securitized against a single property. We combine this residential RESL dataset with Public Safety Canada's flood dataset, which allows us to examine the resiliency of financial institutions' residential RESL portfolios to the occurrence of different flood events.

In total, we include 7.7 million residential properties in our sample. Most borrowers take out loans secured against their properties from one of the six domestic systemically important banks.[8] These financial institutions tend to have less concentration in residential lending than other smaller banks or credit unions. This diversification into other assets and business lines could potentially mitigate the losses associated with acute physical risk events, such as flooding. Conversely, financial institutions that have portfolios concentrated in residential lending could face higher losses from such events. Therefore, including a diverse set of residential real estate lenders in the assessment was crucial to identifying lender's potential exposures and subsequent resiliency resulting for the realization of different flood events (**Table 1**).

Table 1: Overview of exposure data and financial institutions in scope

	Number of lenders	Number of properties (millions)	Average RESL concentration (to total assets)
Domestic systemically important banks	6	6.2	20%
Small and medium-sized banks	18	0.5	57%
Credit unions	39	1.0	56%
Total	63	7.7	53%

Note: Residential real estate secured lending (RESL) are loans like mortgages, home equity lines of credit or other loan products that use the value of residential properties as collateral

Sources: Data from provincially and federally regulated lenders and Bank of Canada calculations

Last observation: 2022Q3

[8] The six domestic systemically important banks are the Bank of Montreal, Bank of Nova Scotia, Canadian Imperial Bank of Commerce, National Bank of Canada, Royal Bank of Canada and Toronto-Dominion Bank.

3.1.2. Property and casualty insurance

In Canada, homeowners can choose to purchase home insurance from private P&C insurers to protect residential buildings, outbuildings and contents and to cover additional living expenses associated with the occurrence of an insurable risk. Also, most lenders require proof of home insurance for a property to obtain a loan.

P&C insurers offer a range of home insurance products, which include different types of policies and vary in the risks they cover. For instance, typical home insurance will cover water damage associated with plumbing leaks but might exclude sewer backup and overland flooding. Homeowners are not required to purchase flood insurance but can elect to purchase an optional flood policy to enhance their base home insurance policy. These policies range in price, type of coverage and insurable value.

While flood insurance has the potential to protect homeowners if a flood occurs, the level and location of such coverage remains unknown to us. To fill this gap, we approached P&C insurers to ask them to voluntarily provide relevant data elements of their flood insurance policies. We obtain point-in-time data from nine Canadian P&C insurers, reflecting home insurance and optional flood policies active during the third quarter of 2022. We calculate that 58% of residential homeowners in Canada elect to have home insurance through one of these insurers and that 38% of homeowners choose to have an additional flood policy.

The data provided by the nine participating P&C insurers reflect information anonymized at the postal code level.[9] Because connecting an insurer's flood coverage with a specific property is not possible in our analysis, we generate a representative insurer. This representative insurer offers policies that vary across postal codes. We calculate the policy coverage and deductible as a weighted average of observed coverage and deductibles across all insurers active in a postal code. The insurer's market share in each postal code determines the weights. **Chart 4** and **Chart 5** provide a snapshot of this representative insurer. The charts show the share of households that take up an additional flood coverage on their property as well as the intensity of that coverage, measured by the flood policy sublimit as a share of total insurable value.

[9] We conduct the analysis at the postal code level to ensure accurate mapping flood risk to residential properties. However, charts present data and results aggregated at the forward sortation area as agreed with data providers.

Chart 4: Share of households with additional flood coverage on top of base home insurance, by forward sortation area

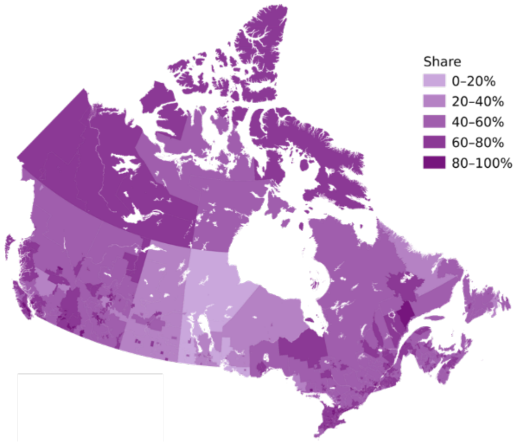
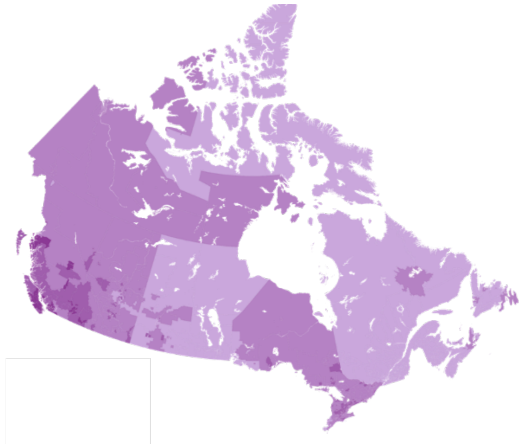


Chart 5: Flood insurance amount as a share of total insurable value, by forward sortation area

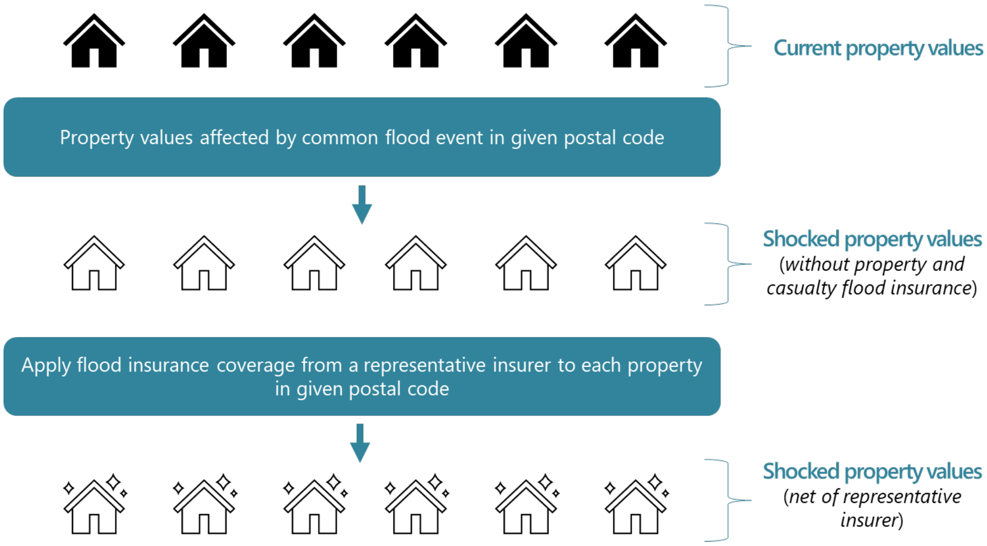


Note: A forward sortation area delineates a specific part in a given geographic area and is represented by the first three digits in the six-digit Canadian postal code.
Sources: Participating property and casualty insurers and Bank of Canada calculations

3.2. Translating flood events into financial impacts

To translate flood events into financial impacts, we consider the unrepaired flood-related damages to residential structures, after controlling for private P&C flood insurance. For lenders, these unrepaired damages translate into losses that we account for in LGD while controlling for both mortgage loan insurance and P&C flood insurance. LGD measures the total loss a lender faces in the event a borrower defaults on a loan. **Figure 2** provides an illustration of how we apply flood damages and the representative insurer to individual properties.

Figure 2: Overview of approach to calculating damages to properties and coverage from property and casualty insurance



3.2.1. Recoverable and unrecoverable damages

After a flood event, property owners choose to make an insurance claim and receive a payment (pay_i) if the damage to their property exceeds their insurance deductible ($deduct_i$). Given that we cannot observe whether a property is covered by P&C insurance, we divide damages (d_i) into a recoverable amount and an unrecoverable amount (**Equation 1** and **Equation 2**), respectively, where d_i^r represents the recoverable portion and d_i^u represents the unrecoverable portion. These two amounts vary across postal codes and are a function of the flood insurance take-up rate. In other words, the observable share of homeowners in a postal code who opt to purchase an additional flood insurance policy ($\sum_{i=1}^{I}(n_i|flood\ insurance\ = 1)$) over the total number of properties ($\sum_{i=1}^{I} n_i$). [10, 11] While we may not be able to adequately capture the property-specific insurance coverage, our method of dividing damages allows us to capture the aggregate role of insurance at the postal code level. We calculate the damages applied to individual property i, along with the insurance condition using **Equation 3**.

$$d_i^r = d_i \times \frac{\sum_{i=1}^{I}(n_i|flood\ insurance = 1)}{\sum_{i=1}^{I} n_i} \tag{1}$$

$$d_i^u = d_i - d_i^r \tag{2}$$

$$d_i^{unrepaired} = \begin{cases} d_i^u + (d_i^r - pay_i + deduct_i), & if\ d_i^u + d_i^r > deduct_i \\ d_i, & else \end{cases} \tag{3}$$

We assume that any damage that exceeds the insurable amount—or is uncovered by insurance—is left unrepaired after the insurance payout. This unrepaired damage ($d_i^{unrepaired}$) adversely affects the value of the property by that same amount.

3.2.2. Loss given default

We adopt a simplified approach to calculate LGD and apply this to all lenders. This is partly because we do not have access to many of the lender-specific LGD methodologies. This approach also enables us to isolate the impacts of flooding on financial outcomes without further confounding the results with various LGD methodologies. However, we acknowledge that our LGD calculations may differ from the estimates obtained from lender-specific methodologies.

To begin, we divide LGD into two components (**Equation 4**): gross loss amount (GLA) and net recoverable amount (NRA). The GLA component (**Equation 5**) captures all the losses the lender faces when holding a defaulted property. This includes the remaining and unpaid balance on the loan (b_i), the accrued interest and time to settlement (r_i and t) and various costs associated with holding the property, such as property

[10] In Canada, certain types of hazards, like flooding, require policy holders to purchase additional coverage to increase their base home insurance policy to insure their property against risks that are not covered.

[11] We calculate the take-up ratio for hazard-specific insurance using all residential properties, excluding non-mortgaged properties, in a postal code. We follow this approach to avoid the selection bias that could occur if we only consider the insurance habits of mortgaged properties.

taxes (tax), maintenance fees ($maint.$) and property insurance ($insure$), which are a function of the property value (v_i), as well as legal costs ($legal$) and any unrepaired damages from flooding ($\mathrm{d}_{\mathrm{i}}^{\mathrm{unrepaired}}$). The NRA component (**Equation 6**) of the LGD includes any amount the lender may recover from the sale of the property, net of the fees. Finally, we assume no losses for properties where the NRA exceeds the GLA; in other words, when the sale of the property net of fees is greater than the associated losses from the default.[12]

$$LGD_i = \begin{cases} GLA_i - NRA_i, & if\ GLA_i > NRA_i \\ 0, & if\ GLA_i \leq NRA_i \end{cases} \quad (4)$$

$$GLA_i = b_i + b_i\left(\left(1 + \frac{r_i}{12}\right)^t - 1\right) + v_i \times \frac{t}{12} \times (tax + m\,rate + insure) + legal + maint. + d_i^{unrepaired} \quad (5)$$

$$NRA_i = v_i \times (1 - depreciation) \times (1 - real\ estate\ commission) - appraisal\ fee \quad (6)$$

We also control for the role of mortgage loan insurance. Unlike P&C insurance, mortgage loan insurance protects lenders from losses if a borrower defaults on their mortgage. In Canada, borrowers are typically required to purchase mortgage loan insurance if the loan-to-value (LTV) ratio is greater than 80% at origination. Mortgage lenders may also purchase mortgage loan insurance for portfolios of mortgages with LTVs at or below 80%. We assume that mortgage loan insurance covers losses from accrued interests and outstanding balances and that it excludes unrepaired damages from the flood events.[13]

Thus, **Equation 7** defines the GLA for properties with mortgage loan insurance:

$$GLA_i^{mortgage\ insured} = d_i^{unrepaired}. \quad (7)$$

In this analysis, impacts from flooding on lenders' residential portfolios are presented as the change in LGD relative to LGD under current average annual loss (**Equation 8**). In other words, we assume that the current average annual loss reflects the current flood risk landscape and is already embedded into existing LGD numbers for each loan. It is important to note that our analysis abstracts from the role of household dynamics, and its influence on the probability of default. Mortgage defaults in Canada are exceedingly rare, making it difficult to identify flood-related defaults.

$$\Delta LGD_i = LGD_i^{shock} - LGD_i^{AAL} \quad (8)$$

Table 2 shows the baseline assumption for parameters found in the GLA and NRA calculations. We note that many of these parameters vary across time, region and borrower and may also change in response to a severe flood event. However, for this exercise, we keep the assumption for parameters constant to better isolate the effects of extreme flooding on the financial system.

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[12] This assumption is consistent with reality because a lender would not incur losses on a loan after a homeowner default if the property value was great enough that it could cover the repayment of the outstanding loan(s) and cover all incidental fees and cost associated with the default.

[13] This assumption is in line with the practice followed by the Canada Mortgage and Housing Corporation (CMHC)—Canada's largest mortgage loan insurance provider CMHC does not cover losses from damages due to natural disasters (CMHC 2016).

Table 2: Summary of parameters and assumed values in calculations of loss given default

Parameter	Variable	Assumed value
Interest rate (%)	r_i	*Observed loan rate*
Time to settlement (months)	t	12
Property tax (%)	tax	2
Insurance rate (%)	$insure$	3
Maintenance rate (%)	$mrate$	1
Fixed maintenance cost ($)	$maint.$	2,000
Legal ($)	$legal$	5,000
Real estate commission (%)	$real\ estate\ commission$	5
Appraisal fee ($)	$appraisal\ fee$	500
Property value depreciation post severe flood (%)	$depreciation$	0

Time to settlement and depreciation of property value after a flood event, in particular, influence the LGD calculations in our analysis, but they prove to be highly uncertain.[14] We explore the sensitivity of the results to alternative parametrization in **section 4.2.3**.

3.3. Severe event case study

We assess the potential financial risks from flooding in Canada using two types of flood events. The first relates to an event that could be expected to occur, on average, in any given year, as presented earlier with AAL as the corresponding measure of damages. AAL allows us to capture the expected damages from a specific flood each year and to estimate the current level of flood risk. This type of event serves as the baseline for the financial risk assessment.

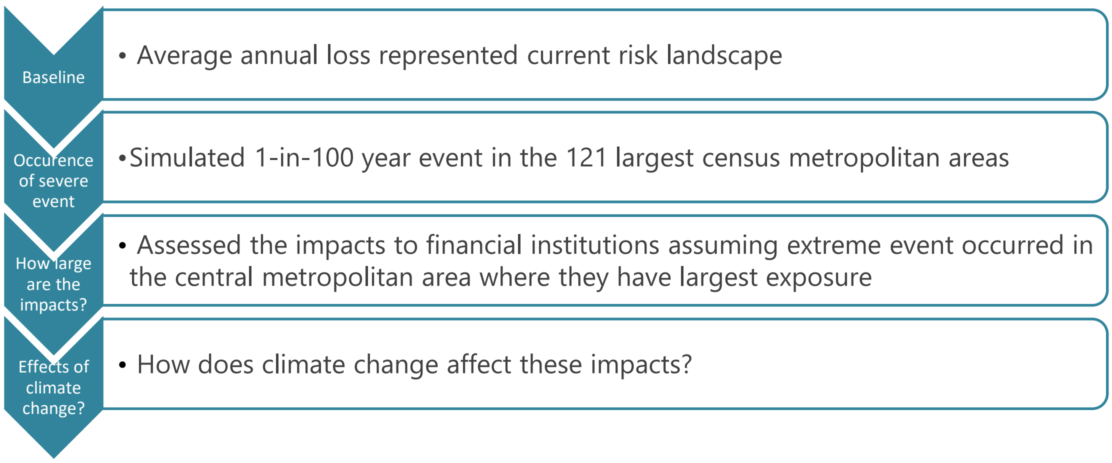
We assess the resilience of lenders to flooding by simulating a severe flood affecting the properties that are used as collateral in their residential lending portfolios. We examine this using a plausible but stressful 1-in-100-year flood event. This type of event occurs annually with a 1% probability, which is equivalent to happening once in every 100 years. However, this does not imply that this type of event can only occur once every 100 years. In fact, as climate change accelerates, an event that was expected to happen once in 100 years could occur more frequently.

Given that weather events tend to be localized, we consider the occurrence of localized severe weather events rather than a nation-wide one. To do so, we simulate city-specific severe events for each lender, looking at catastrophic events taking place across 121 census metropolitan areas in Canada. We identify the city where that lender's borrowers experience the largest damages because this would represent the

[14] For simplicity, we assume a common time-to-settlement period of 12 months. However, in the case of an extreme weather event with several defaults, the average time to settlement could be longer. We also note that the foreclosure process is not uniform across Canada. Some provinces use a judicial foreclosure process, while others primarily use a power of sale—a process where the lender can sell property that is in arrears on behalf of the borrower. The processes vary significantly depending on the province, property and situation of the borrower, which means that the time between a first missed payment and sale of the property can be as short as three to four months or be more than one year.

most potentially stressful event to a lender's portfolio. We then assess the financial impacts on only the affected portion of the lender's residential RESL portfolio using LGD. This allows us to determine lender-specific exposures to a particular flood hazard as well as the lender's resilience to it. Thus, our results show the impacts across all lenders for each census metropolitan area. In section 4.2.2., we consider the additional effect that climate change can have on lenders' LGDs. We do this by bringing forward future climate events to today's portfolios (**Figure 3**).

Figure 3: Outline of case study of an extreme weather event



4. Results

4.1. Lenders' annual expected risk from flooding

Nearly half of the average annual expected flood-related damages to residential real estate in Canada affected properties used as collateral on residential loan products. **Table 3** highlights the scope of average annual expected damages to residential properties under two climate change scenarios, namely RCP 4.5 and 8.5, by the year 2100. The current structural damages expected from flooding to all residential properties in Canada totalled $1.9 billion in any given year.[15] Of these damages, approximately $940 million fall within the scope of our analysis and are expected to affect properties that hold at least one residential loan product.

[15] When damages to residential contents are included, Public Safety Canada estimates losses to equal $2.92 billion (**Box 1**).

Table 3: Description of flood hazard data—average annual loss

	Total damages in Canada (millions)	Total damages to properties in scope (millions)
Current	$1,930	$940
By the year 2100 with ~2˚C warming (RCP 4.5)	$2,060 (+6.7%)	$1,004 (+6.8%)
By the year 2100 with ~4˚C warming (RCP 8.5)	$2,160 (+11.9%)	$1,055 (+12.2%)

Note: RCP means representative concentration pathways "Damages" refers only to structural damages. Numbers in parentheses denote percentage change from current levels.

Sources: Resilience and Economic Integration Division (REID) at Public Safety Canada and their external data partners (DMTI Spatial, Opta Information Intelligence, KatRisk LLC, JBA Risk Management and Fathom), provincially and federally regulated lender data, property and casualty insurers and Bank of Canada calculations

The risk to lenders from flooding depends on several factors. These include the value of residential RESL in their portfolios, the concentration of that RESL in flood zones and the level of borrower equity (**Table 4**).[16] Flood zones are defined as postal codes where AAL damages as a percentage of property values are in the 90th percentile. Lenders with the highest and lowest concentration of their business in residential RESL tend to have the lowest level of lending in flood zones. This suggests that some lenders could be actively managing their risk. However, a portion of lenders with a high level of residential RESL lending continues to offer loans in areas more susceptible to flooding.

That said, almost all financial institutions in our sample had active residential RESL lending in flood zones (**Table 4**). This implies that almost all lenders have some segment of their residential portfolio at risk of a flood. For many lenders, this represents less than 30% of their residential lending portfolios. However, some lenders, which may be more geographically concentrated, have more than 50% of their lending to borrowers with properties in flood zones. This can increase the likelihood of having distressed borrowers, especially if many are in the same flood zone.

[16] We assess borrower equity by using the loan-to-value (LTV) ratio—a common measure for determining the level of indebtedness relative to the collateral value. The LTV ratio of a property is calculated by summing across all mortgage balances, adding 75% of the limit for home equity lines of credit, and dividing by the value of the property.

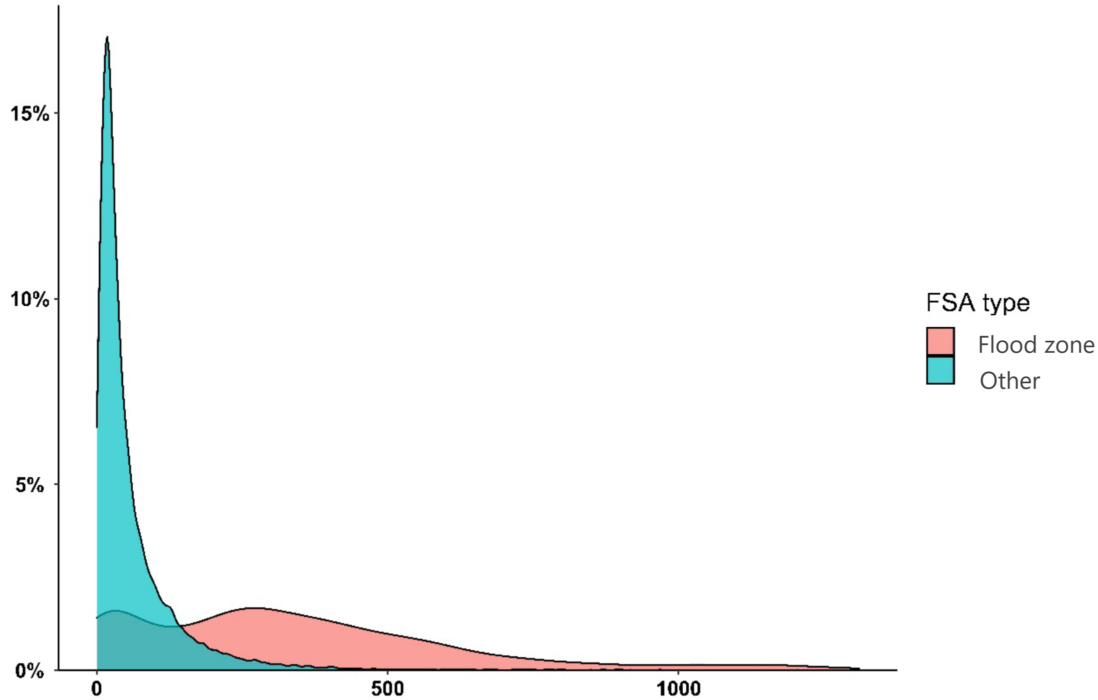
Table 4: Concentration and share of lending in flood zones of lenders

		Lenders	Lending in flood zones (%)		Average loan-to-value ratio
			Average	Maximum	
Concentration of lending in real estate secured lending	≥ 80%	9	4%	8%	39%
	60%–80%	16	8%	62%	38%
	40%–60%	18	13%	65%	38%
	20%–40%	15	15%	97%	31%
	< 20%	5	5%	7%	29%

Sources: Resilience and Economic Integration Division (REID) at Public Safety Canada and their external data partners (DMTI, Opta Information Intelligence, KatRisk LLC, JBA Risk Management and Fathom), provincially and federally regulated lender data and Bank of Canada calculations

Properties located in flood zones are expected to experience, on average, four times more damages than those not located in flood zones. Given the geographical size of Canada, the variations of topology and hydrology can lead to large ranges of potential impacts from flooding. **Chart 6** presents the distributions of AAL damages across residential properties with at least one residential lending product. This chart shows the highly uneven nature of flooding in Canada. It highlights the elevated annual damages that are expected to accumulate, on average, to properties located in flood zones. This sheds light on the risk associated with properties located in flood zones. However, to address privacy and confidentiality concern, we average the flood damage to the postal code level, potentially smoothing what could be more acute shocks to specific properties.

Chart 6: Distribution of damages per property under current average annual loss



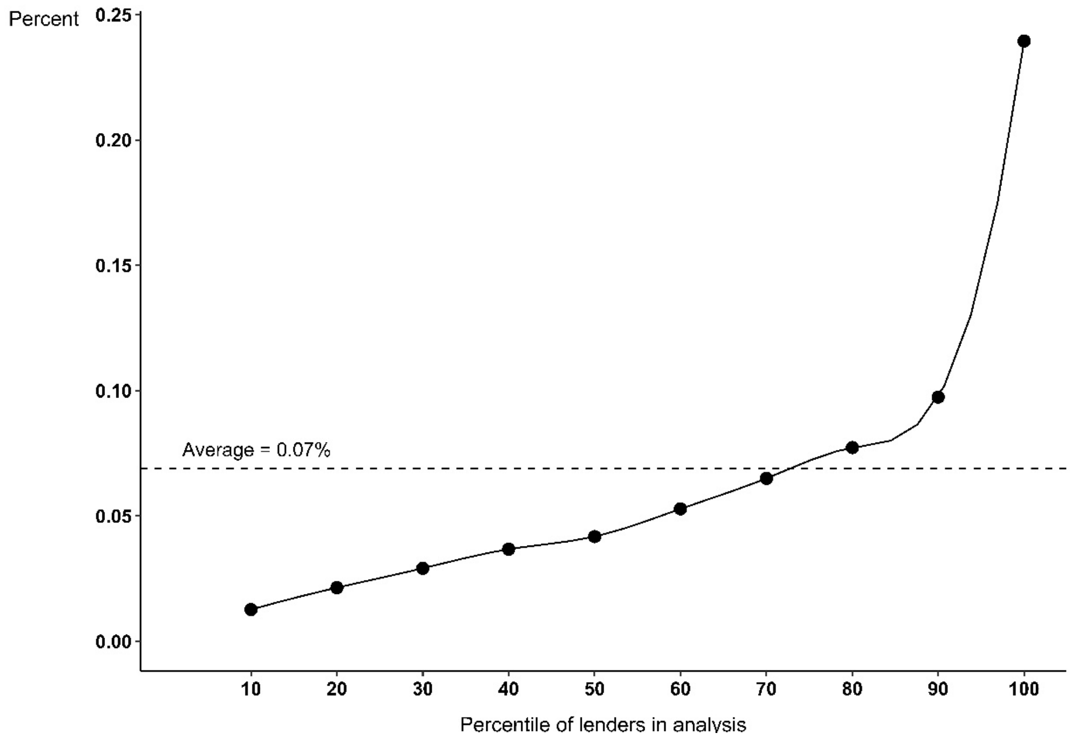
Note: The tail of the flood zone distribution extends beyond what is observed in the chart. “Damages” refers only to structural damage. We calculate the results net of representative property and causality insurer.
Sources: Resilience and Economic Integration Division (REID) at Public Safety Canada and their external data partners (DMTI Spatial, Opta Information Intelligence, KatRisk LLC, JBA Risk Management and Fathom), provincially and federally regulated lender data and Bank of Canada calculations

Overall, the average LTV ratio across all borrowers for most lenders remains relatively low (**Table 4**). An LTV ratio lower than 50% implies that the borrower has 50% equity in their home. This equity is important because it can help borrowers buffer certain shocks, including those from extreme weather events. In addition, a lender’s exposure to losses from a default are lower when borrowers have more equity.

We find that the risk to lenders from AAL seems manageable. On average, the financial impacts lenders face from flood events are small, representing an annual expected loss equal to 0.07% of their outstanding residential RESL balances (**Chart 7**). Even for the top 10% of lenders, the expected impacts represent less than 0.25% of their outstanding balance in any given year. The relatively small levels of flood damages expected in a year appear manageable because many lenders:

- do not rely only on residential RESL
- have less than 30% of residential RESL in flood zones
- have borrowers who, on average, have strong equity positions

Chart 7: Distribution of lenders' average total annual loss as a share of total outstanding balance residential real estate secured lending



Note: Results are calculated net of representative property and causality insurer.

Sources: Resilience and Economic Integration Division (REID) at Public Safety Canada and their external data partners (DMTI Spatial, Opta Information Intelligence, KatRisk LLC, JBA Risk Management and Fathom), provincially and federally regulated lender data, property and causality insurers and Bank of Canada calculations

Lenders nevertheless need to regularly assess and manage their flood-related risks. In this section, we highlight the risks lenders face from expected flooding in a given year. However, managing risk associated with flooding requires lenders to account for potential losses from risks associated with extreme events. In addition, the risk from these events implies that the effects can be highly uneven, affecting properties located in flood zones more profoundly. Hence, lenders who wish to manage their flood risk also need to isolate the impacts using granular data.

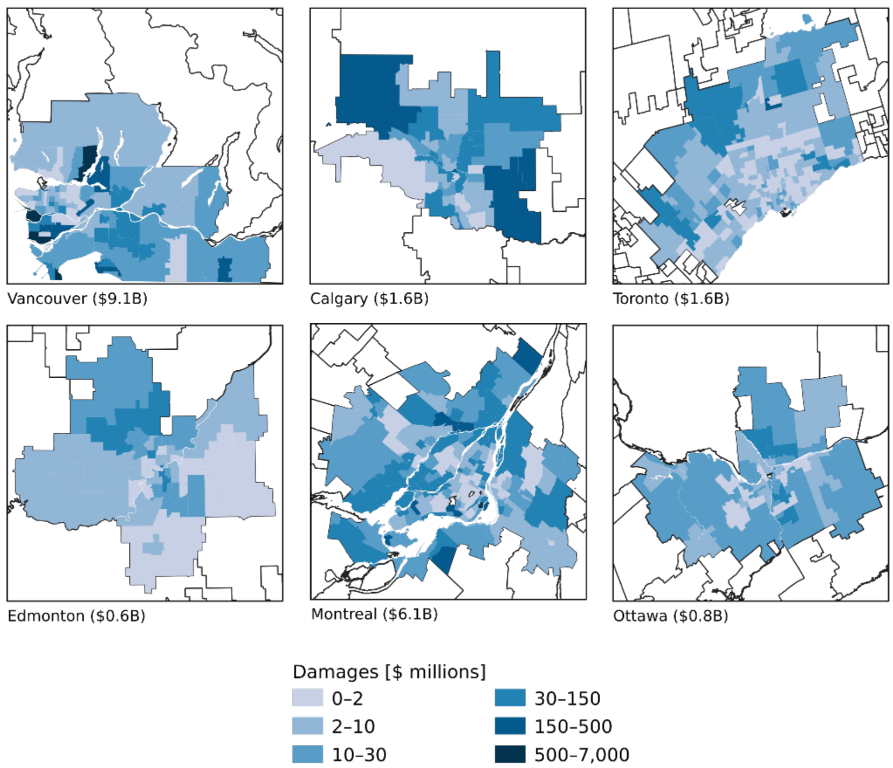
4.2. Case study of a severe event: simulating a 1-in-100-year flood

To better understand the impacts to lenders from extreme floods, we develop lender-specific case studies by simulating a severe flood only to the segment of each lenders' portfolio most at risk.

4.2.1. Current occurrence

A severe, localized flood event can lead to billions of dollars in damages to residential properties. For instance, we estimate that such an event would cause approximately $9.1 billion in residential damage in Vancouver, $6.1 billion in Montréal and $1.6 billion in Calgary (**Figure 4**). For owners of residential property, the magnitude of the damages depends on whether the residence is in a flood zone. On average, the properties we include in the severe case study experienced approximately $4,800 in damages from a 1-in-100-year flood. For those properties in flood zones, this average reached approximately $29,000. In contrast, the expected annual damages calculated from AAL is approximately $230 for the same properties. The difference in magnitude produced by a severe flood highlighted the need to consider several events when conducting climate risk assessments.

Figure 4: Example of simulated 1-in-100-year flood events across six select census metropolitan areas

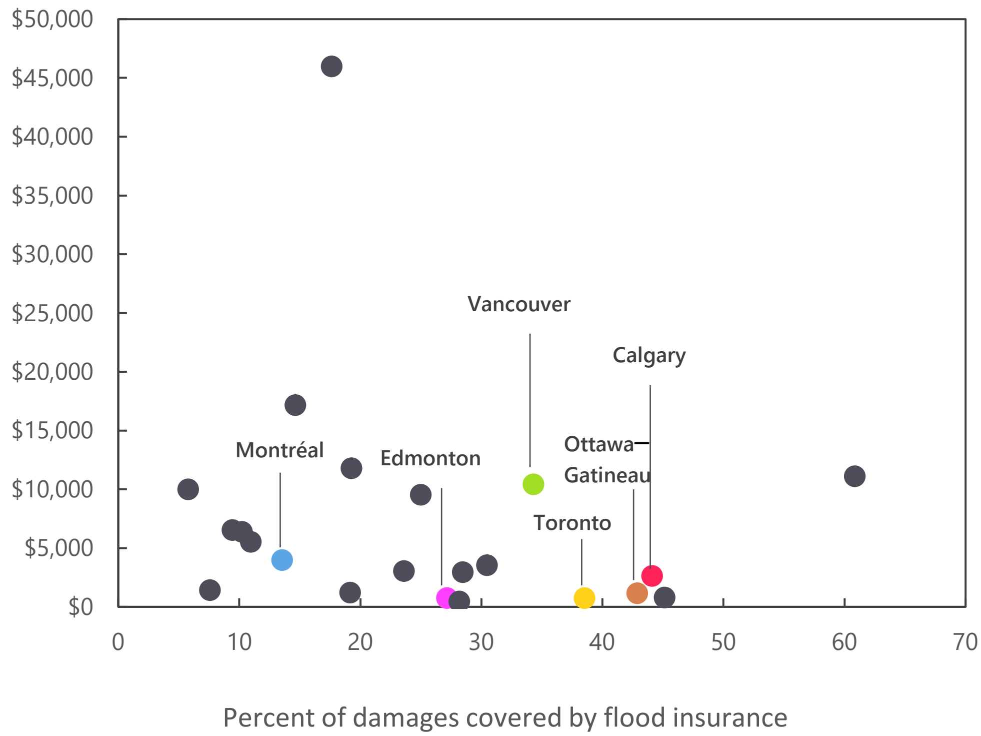


Sources: Resilience and Economic Integration Division (REID) at Public Safety Canada and their external data partners (DMTI Spatial, Opta Information Intelligence, KatRisk LLC, JBA Risk Management and Fathom), provincially and federally regulated lender data and Bank of Canada calculations

The ability of households to cope with a severe flood event also depends on the availability and level of insurance coverage. Flood insurance coverage and take-up varies across Canada. We show that flood insurance in cities affected by a severe flood almost always covered less than 50% of damages on average (**Chart 8**). In addition, this coverage was below 20% of damages in some cities, pointing to potential financial distress for some households should coverage be insufficient or unaffordable. Flood insurance can play an important role in reducing the risk of default that may arise if households face large-scale damages.

Chart 8: Average percentage of property damage covered by insurance by census metropolitan area

For properties selected in the severe case study



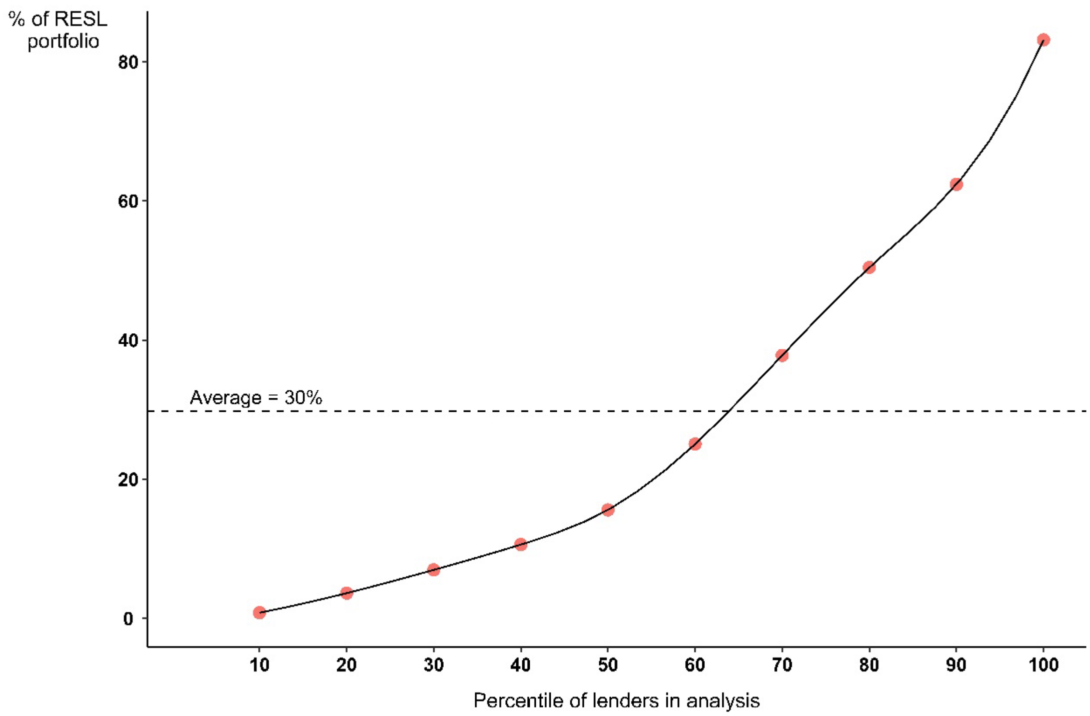
Note: For exposition, we highlight the average insurance coverage for the census metropolitan areas of Calgary, Edmonton, Montréal, Ottawa–Gatineau, Toronto and Vancouver, as identified in Figure 4.

Sources: Resilience and Economic Integration Division (REID) at Public Safety Canada and their external data partners (DMTI Spatial, Opta Information Intelligence, KatRisk LLC, JBA Risk Management and Fathom), provincially and federally regulated lender data, property and causality insurers and Bank of Canada calculations

Last observation: 2022Q3

Overall, we find that many lenders have high exposures to a single severe flood event. For over half of lenders, a single large-scale severe flood affected properties that made up more than one-third of their residential RESL portfolio (**Chart 9**). For some lenders, this exposure was even greater. In fact, for 10% of lenders, 80% of their residential RESL portfolios would be affected by a single event.

Chart 9: Distribution of the proportion of residential real estate secured lending portfolios affected by simulated 1-in-100-year case study



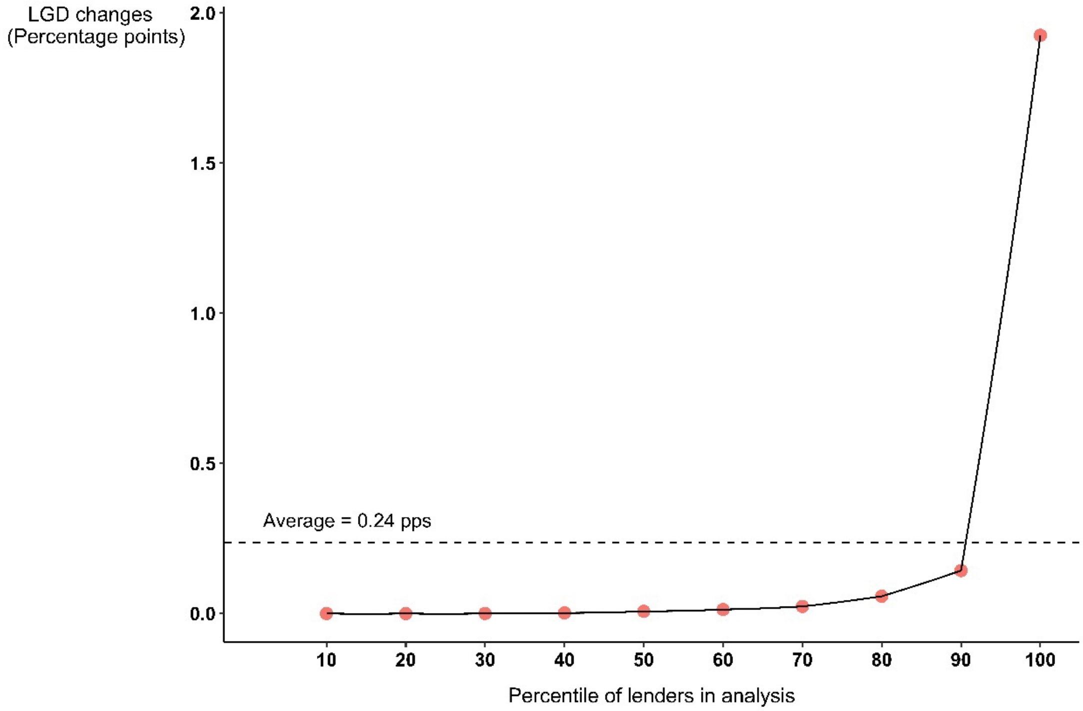
Sources: Resilience and Economic Integration Division (REID) at Public Safety Canada and their external data partners (DMTI Spatial, Opta Information Intelligence, KatRisk LLC, JBA Risk Management and Fathom), provincially and federally regulated lender data and Bank of Canada calculations

Despite lenders' high exposures to a single severe flood, these events produce modest changes to lenders' LGDs. We find that severe floods lead to increases in lenders' LGD relative to the baseline LGD, which we assume is incorporated in the expected annual flood losses as described in **Equation 8**. In fact, the transmission of property damages resulting from a severe flood increased lenders' LGD as a share of their outstanding balance by approximately 0.24 percentage points, on average (**Chart 10**).[17]

[17] For example, a lender with a pre-flood average portfolio LGD of 30% would become 30.24%.

Chart 10: Distribution of change in loss given default across lenders for portion of residential real estate secured lending portfolio affected in the severe case study

Loss given default as a share of outstanding balance for properties affected by 1-in-100-year flood



Note: Losses refers only to those incurred from structural damage. Change in loss given default (LGD) is calculated as the difference between 1-in-100-year LGD and the baseline LGD, which assumes and environment with average annual losses (Equation 8). We calculate results net of the representative property and causality insurer.

Sources: Resilience and Economic Integration Division (REID) at Public Safety Canada and their external data partners (DMTI Spatial, Opta Information Intelligence, KatRisk LLC, JBA Risk Management and Fathom), provincially and federally regulated lender data, property and causality insurers and Bank of Canada calculations

These modest effects on lender LGDs were partly due to homeowner equity and the recent rapid rise of house prices. On the one hand, most borrowers had spent several years paying down their mortgages and building equity in their homes. This helped buffer them from shocks and led to smaller changes in LGD relative to borrowers with current total current LTVs above 80% who have less equity (**Table 5**).[18] On the other hand, the rapid rise in house prices provided a buffer to lenders, who could recover their losses if a default were to occur and the property had appreciated enough.[19]

[18] Total current LTV refers to the current total value of outstanding balances for all loan products secured against a property, divided by the current home value.

[19] National residential house prices rose rapidly from 2020 to early 2022.

Table 5: Average impact on loss given default as a share of outstanding balance from 1-in-100-year severe case study floods

	Change in LGD (pps)	Proportion of balances in severe case study
Total current LTV ratio <= 80%	0.2	94%
Total current LTV ratio > 80%	0.4	6%

Note: LGD means loss given default. PPS means percentage points. Total current loan-to-value (LTV) ratio refers to the total outstanding balances for all loan products secured against a property, divided by the home value. We calculate results net of the representative property and causality insurer.

Sources: Resilience and Economic Integration Division (REID) at Public Safety Canada and their external data partners (DMTI Spatial, Opta Information Intelligence, KatRisk LLC, JBA Risk Management and Fathom), provincially and federally regulated lender data, property and causality insurers and Bank of Canada calculations

However, a segment of residential loans remains more sensitive to severe flood events. Highly indebted households have long represented a key vulnerability to the financial system (Cateau, Roberts and Zhou 2015). These households have less equity to buffer them when a shock occurs. Severe flooding is an example of such a shock. Those borrowers with total current LTVs above 80% induced larger losses to lenders relative to borrowers with total current LTVs below 80% (**Table 5**).

Furthermore, when highly indebted households are in flood zones, losses are magnified. Approximately 13% of properties affected by the simulated severe flood are in flood zones.[20] Damages in these zones induce higher losses for lenders, increasing them by 0.2 percentage points to 2.1 percentage points for properties with loans that have a high LTV ratio (**Table 6**).

Table 6: Impact on loss given default as a share of outstanding balance for 1-in-100-year flood

Percentage point change from baseline (Proportion of balances in severe case study)

	Other	Flood zone
Total current LTV ratio <= 80%	0.05 (81.5%)	0.8 (12.6%)
Total current LTV ratio > 80%	0.2 (5.2%)	2.1 (0.7%)

Note: Total current loan-to-value (LTV) ratio refers to the total outstanding balances for all loan products secured against a property divided by the home value. We calculate results net of the representative property and causality insurer.

Sources: Resilience and Economic Integration Division (REID) at Public Safety Canada and their external data partners (DMTI Spatial, Opta Information Intelligence, KatRisk LLC, JBA Risk Management and Fathom), provincially and federally regulated lender data, property and causality insurers and Bank of Canada calculations

4.2.2. Role of further climate change

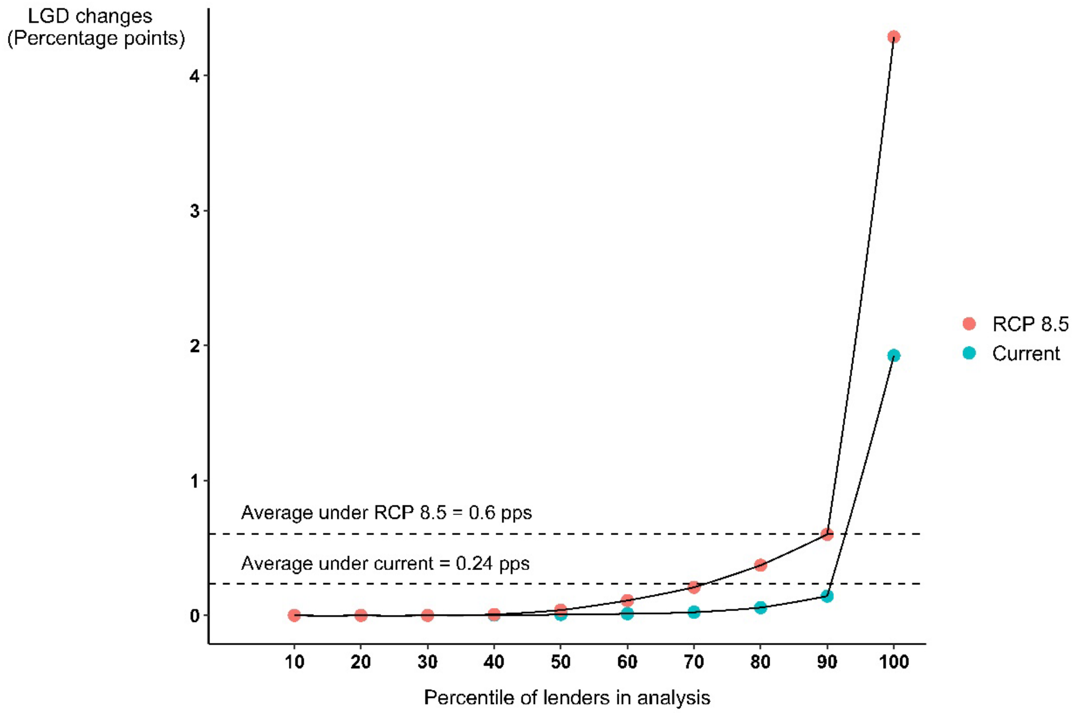
The change in lenders' LGD associated with localized severe flood events increased with climate change. The transmission of property damages resulting from a severe flood under climate change scenario RCP 8.5

[20] Across Canada, 10% of residential properties are in flood zones. However, the simulated severe case study focused on a subset of properties located in areas where lenders would face worse potential losses. Hence, a slightly higher share of properties located specifically in flood zones are affected.

increased lenders' LGD as a share of outstanding balance by approximately 0.6 percentage points on average compared with 0.24 percentage points under current conditions (**Chart 11**). Lenders face higher physical risks in the tail of the distribution. That is, the shift in lenders' LGD from severe events under the climate change scenario is largest for those lenders currently exposed to the damages from severe events.

Chart 11: Distribution of change in loss given default across lenders for portion of residential real estate secured lending portfolios affected in a severe case study, under current and projected flood events under climate change scenario RCP 8.5

Loss given default as a share of outstanding balance for properties affected by 1-in-100-year flood



Note: LGD means loss given default. RCP means representative concentration pathways. "Losses" refers only to those incurred from structural damage. We calculate results net of the representative property and causality insurer.

Sources: Resilience and Economic Integration Division (REID) at Public Safety Canada and their external data partners (DMTI Spatial, Opta Information Intelligence, KatRisk LLC, JBA Risk Management and Fathom), provincially and federally regulated lender data, property and causality insurers and Bank of Canada calculations

As climate change continues to accelerate, more people and assets will become exposed (Intergovernmental Panel on Climate Change 2023). In our analysis, climate change expands flood zones into new areas, increasing the number of FSAs in flood zones by 16%. These new flood zones represent a 27% rise in the number of properties exposed to high levels of damages from floods. These newly exposed properties increase total damages by 7%. In addition, climate change could intensify the severity of floods. The increase in total damages due to intensifying floods faced by properties located in high-risk zones is approximately 33% (**Table 7**).

Table 7: Impact of climate change by end of the century (RCP 8.5) relative to today in flood zones

Increase in flood zone forward sortation areas	+16%
Increase in properties in flood zones	+27%
Increase in damages from properties moving into flood zones	+7%
Increase in damages to properties already in flood zones	+33%

Note: RCP means representative concentration pathways. We calculate results net of the representative property and causality insurer. Sources: Resilience and Economic Integration Division (REID) at Public Safety Canada and their external data partners (DMTI Spatial, Opta Information Intelligence, KatRisk LLC, JBA Risk Management and Fathom), provincially and federally regulated lender data, property and causality insurers and Bank of Canada calculations

4.2.3. Sensitivity of parameters

Other channels can exacerbate financial impacts from floods, particularly for properties with loans that have a high LTV ratio. We focus on two elements related to changes in housing market dynamics:

- a depreciation in house prices
- longer time to settlement associated with mortgage defaults

First, a depreciation in house prices could affect households' equity position and increase lenders' losses. As noted above, households with lower equity positions in their homes tend to transmit larger losses to lenders (**Table 5**), especially if these are in flood zones (**Table 6**). As well, a reduction in the value of the property lowers the portion of lenders losses that are recoverable (**Equation 6**). Assuming a 10% house price depreciation, we find that a severe flood increased LGDs for highly indebted borrowers by 3.8 percentage points, bringing the impacts from LGD from 0.4 to 4.2 percentage points.[21]

Second, longer time to settlement after a default will increase losses for lenders. This is due to higher costs associated with holding the defaulted property, such as property taxes, maintenance costs and accrued interest (**Equation 5**). By increasing time to settlement from 12 months to 18 months, we find that the transmission of damages from a severe flood to LGDs increased by 4.2 percentage points for loans with a high LTV ratio (**Table 8**).

[21] In Canada, little research has been done to identify home price changes after natural disasters, apart from the report by the Intact Centre on Climate Adaptation. Bakos et al. 2022, find decreases of between 1.1% and 17.1% (mean: 8.2%) relative to the control community; this guides our choice of a 10% price depreciation.

Table 8: Average impact on loss given default from a severe flood under different model specifications

	Per balance (pps)	
	Total current LTV ratio <= 80%	Total current LTV ratio > 80%
House price depreciation of 10%	+0.1	+3.8
Increase in time to settlement by 6 months	+0.2	+4.2
Simultaneous 10% house price depreciation and increase in time to settlement by 6 months	+0.5	+13.0

Note: PPS means percentage points. We calculate results net of the representative property and causality insurer. Sources: Resilience and Economic Integration Division (REID) at Public Safety Canada and their external data partners (DMTI Spatial, Opta Information Intelligence, KatRisk LLC, JBA Risk Management and Fathom), provincially and federally regulated lender data, property and causality insurers and Bank of Canada calculations

Taken together, these modest changes in housing markets can amplify losses lenders would face from a severe flood event. This is especially evident for highly indebted households. Under current economic conditions, a severe flood affecting properties with total current LTV ratios above 80% induces a 0.4 percentage point increase in losses for lenders (**Table 5**). However, under a weaker housing market, the transmission of flood losses increases by 13 percentage points (**Table 8**). It is therefore imperative that lenders continue to actively manage their risks from the physical risks of climate change.

5. Conclusion

Our analysis represents an important step toward better understanding the financial impacts of extreme weather events on Canadian lenders' residential RESL portfolios. Physical risks encompass a wide range of events, such as wildfires, hurricanes and droughts, but we focus on flooding due its substantial annual costs. We study this risk using two flood scenarios: AAL events, which highlight potential exposure, and severe 1-in-100-year flood events, which determine the resilience of lenders.

Overall, we find that potential losses from the direct damages of flooding on lenders' residential RESL portfolios appear to generate modest impacts on lenders' LGDs. This is partly due to the recent and rapid acceleration of house prices, which helps bolster the equity position of homeowners. This strong equity position provides an important buffer that reduces the amount of flood-related losses transmitted to lenders. Nevertheless, changes in housing market dynamics, such as a reduction in house prices, could meaningfully increase lenders' financial risk from extreme flooding events.

However, despite the modest LGD impacts, we note that lenders continue to face significant risk. Specifically, we consider the influence of household debt combined with the concentration of lending in flood zones. This combination can exacerbate the risk lenders face from extreme weather events. In fact, we show that borrowers with elevated levels of debt secured against a property transmitted larger losses to lenders, especially if the collateralized properties were in flood zones.

Climate change can also increase flood-related risks to lenders, particularly in the tail of the distribution. One such risk is that the impact from climate change on lenders' LGD from severe events was largest for those lenders currently exposed to damages from severe events. In addition, we show that climate change:

- expands flood zones into new areas
- increases the number of properties exposed to elevated levels of damages from flooding
- increases total damages from flooding

That said, we find several important limitations. First, our analysis abstracts from household dynamics, which could influence the probability of default. Mortgage defaults in Canada are exceedingly rare, making it difficult to identify flood-related defaults.

Second, we focus on acute flooding to domestic residential real estate in isolation and do not consider other events that occur simultaneously—including other risks (e.g., wildfire) or macroeconomic shocks (e.g., rising unemployment)—and that could exacerbate financial stress. While this is the standard approach in assessing flood risk, it can limit the potential flood-related financial impacts to lenders. However, we consider the sensitivity of our results to changes in housing market dynamics, such as increases to time to settlement and house price depreciation. This highlights the importance of considering other risk channels.

Third, we only consider impacts to domestic residential real estate lending. Other forms of collateral important to Canadian deposit-taking financial institutions—including commercial real estate and infrastructure—remain outside the scope of our research. Further, Canadian financial institutions could have important international exposures to flood risk that we do not consider in our analysis. We leave this for future work.

Fourth, we use a static balance sheet approach, focusing on the residential RESL portfolios of Canadian financial institutions for the third quarter of 2022. This is a period of home value appreciation, and the results shed light on the role that home equity plays in shielding lenders from potential losses. We assess the potential impacts from climate change within this current balance sheet approach, assuming the future severity of damages are felt on today's residential RESL portfolios. Consequently, we do not consider other dynamic considerations that are important to assessing the evolution of flood-related impacts. For example, we do not consider how lenders actively manage the risks their balance sheets are exposed to. At the same time, our analysis abstracts from population growth and urban development, which could exacerbate lenders' exposure to risk.

Finally, we do not consider the role of fiscal support that could follow a localized severe flood event.

Our results face a reasonable amount of uncertainty due to data limitations. On the one hand, concerns over privacy and confidentiality influence the level of data granularity available for this analysis. This makes it difficult to link datasets. Due to the anonymization of residential addresses, the precise location of properties and the residential structure type remain unknown. To overcome this, we assume that properties within the same postal code face the same average level of flood damage.[22] While our analysis sheds light on potential extreme risks, we note that averaging the level of flood damage to property at the postal code level potentially smooths what could be more acute shocks to specific properties.

On the other hand, the data are comprehensive, but they are not complete. This could lead to some underestimation of the impacts to the financial system. For example, estimates of flood risk do not consider the effects of sea level rise. In addition, average damage may be underestimated in postal codes with a large concentration of apartment buildings and condominiums. This is mostly due to an inability to accurately estimate flood damage to these structures.

The limitations around the use of granular data due to privacy and confidentiality prevent us from making broader conclusions, including those on P&C flood insurance. The potential smoothing and underestimation of flood damage hides what could be more acute shocks to specific properties. At the same time, the inability to observe property level P&C insurance makes it more difficult to identify areas where coverage was unaffordable or unavailable. For these reasons, we caution against drawing conclusions on the role that P&C insurance plays in mitigating risks to households, lenders and the broader financial system.

Financial institutions should actively manage their exposure to risk from extreme weather. Ultimately, the tail of the flood damage distribution is probably the main source of risk associated with extreme weather events. This tail risk likely poses the greatest concern from extreme weather events to financial institutions and the financial system. Due to privacy and confidentiality concerns around the use of granular data, we apply several simplifying assumptions in our methodology. Most importantly, we assume that postal code average information on flooding and P&C insurance coverage does not reflect property-specific information. Lenders that have access to specific location information of the collateral underlying their loans can better assess the risk associated with their own portfolio.

The averaging out of more acute shocks highlights the importance of Principle 4 in OSFI's Guideline B-15, *Climate Risk Management*, which sets the expectation that federally regulated financial institutions should use climate scenario analysis to assess the impact of climate-related risks on their risk profile, business strategy and business model. Additionally, OSFI plans to conduct a standardized climate scenario exercise (SCSE) in 2024. One objective of the SCSE is to encourage capacity building within financial institutions for them to conduct climate scenario analysis at a granular level, which will lead to a better understanding of the impacts of acute shocks.

[22] We opt to apply these damages as a level rather than a percentage of the property value because the latter would implicitly capture the depreciation in property value.

References

Bakos, K., B. Feltmate, C. Chopik and C. Evans. 2022. Treading Water: Impact of Catastrophic Flooding on Canada's Housing Market. Intact Centre on Climate Adaptation, University of Waterloo.

Blickle, K. S., S. N. Hamerling and D. P. Morgan. 2022. "How Bad Are Weather Disasters for Banks?" Federal Reserve Bank of New York Staff Report No. 990.

Bruneau G., J. Ojea-Ferreiro, A. Plummer, M.-C. Tremblay and A. Witts. 2023. "Understanding the Systemic Implications of Climate Transition Risk: Applying a Framework Using Canadian Financial System Data." Bank of Canada Staff Discussion Paper No. 2023-32.

Caloia, F. and D.-J. Jansen. 2021. "Flood Risk and Financial Stability: Evidence from a Stress Test for the Netherlands." De Nederlandsche Bank Working Paper No. 730.

Canada Mortgage and Housing Corporation (CMHC). 2016. *CMHC Master Loan Insurance Policy*.

Cateau, G., T. Roberts and J. Zhou. 2015. "Indebted Households and Potential Vulnerabilities for the Canadian Financial System: A Microdata Analysis." Bank of Canada *Financial System Review* (December): 49–58.

Duprey, T., S. Jo and G. Vallée. Forthcoming. "Let's Get Physical: Impacts of Climate Change Physical Risks on Local Employment." Bank of Canada Staff Working Paper.

Intergovernmental Panel of Climate Change. 2023. "Climate Change 2023: Synthesis Report Contribution of Working Groups I, II, and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change." Core Writing Team, H. Lee and J. Romero (eds.). IPCC, Geneva, Switzerland, pp. 1-34, doi: 10.59327/IPCC/AR6-9789291691647.001

Manninen, O., N Tiililä, A. Saada and K. Kauko. 2021. "Increased Flood Risks Caused by Climate Change Will Also Affect Banks." Bank of Finland Bulletin—Articles on the Economy.

Public Safety Canada. 2022. *Adapting to Rising Flood Risk: An Analysis of Insurance Solutions for Canada—A Report by Canada's Task Force on Flood Insurance and Relocation*.

Strazdins, J. and S. Sinenko. 2023. "Klimata Riska Stresa Testi: Fokusā Plūdu Risks" [Climate risk stress tests: focus on flood risks]. Latvijas Banka Makro Ekonomika.